ENVIRONMENTAL IMPACT OF BEEF

BY LIFE CYCLE ASSESSMENT (LCA) - 13 DANISH BEEF PRODUCTION SYSTEMS

LISBETH MOGENSEN, JOHN E. HERMANSEN, LAN NGUYEN AND TEODORA PREDA

DCA REPORT NO. 061 · APRIL 2015

AARHUS UNIVERSITY
DCA - DANISH CENTRE FOR FOOD AND AGRICULTURE

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Environmental Impact of Beef

Supplementary information and clarifications (October 2019)

In an effort to ensure that this report complies with Aarhus University's guidelines for transparency and open declaration of external cooperation, the following supplementary information and clarifications have been prepared in collaboration between the researcher (s) and the faculty management at Science and Technology:

This report is a part-delivery from the project 'Assessment of the total environmental impact of veal and beef ', a project financed by the Danish Cattle Levy Fund and headed by the Danish Agriculture and Food Council.

The participants in the project were: Anette Christiansen, Danish Agriculture and Food Council, daily project manager of the project; Julie Lykke Jacobsen and Camilla Willadsen, Danish Agriculture and Food Council, responsible for communication to the industry and popular communication in general; Niels T. Madsen and Ole Pontoppidan from DMRI with responsibility for data collection from the slaughterhouse. Charlotte Thy from Danish Crown, who contributed with the identification of the relevant product types, as well as Lisbeth Mogensen, John E. Hermansen, Lan Nguyen, and Teodora Preda, AU, who were responsible for the implementation of life-cycle assessments and the reporting of these. This report has been prepared by the four AU researchers mentioned.

The report is based on data collected by the DMRI's in the project, a previously completed project on the productivity and emission of greenhouse gases from beef production systems in Denmark and Sweden (Mogensen et al. 2015) supplemented by a further data collection by the authors regarding further Danish production systems.

DMRI's mapping of the resource consumption and product yields of various types of slaughter cattle was documented in Pontoppidan & Madsen (2014): ' ’LCA-slagteridataopgørelse for kvægproduktionstyper '. In this report, reference is made to the slaughterhouse part for data from this.

As can be seen from the report's foreword, the project steering committee has provided input to identify the relevant products and production types as well as the completion of the project.

In addition, the steering committee has had the report for comments, which resulted in changes in relation to the description of the composition of the steering committee and the naming of product groups from different types of cattle. Photos for the cover were selected by AU from Colourbox and DCA’s image database. The location of photos on the cover was adjusted by input from the project group. In addition, a mistake has been made in table 5.5 found by the L&F.

Before the publication of the report, the method for LCA analysis had been published in Mogensen et al., 2015, and subsequently, significant parts of the results of the report have been published in Mogensen, L., Nguyen, TLT, Madsen, NT, Pontoppidan, O., Preda, T., Hermansen, JE. 2016. Environmental impact of beef sourced from different production systems-focus on the slaughtering stage: input and output. J. of cleaner Production. 133, 284-293. The recalculation has given rise to minor discrepancies in individual results, but the method, data basis, summary and conclusions are fundamentally the same.

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Scientific report
The reports contain mainly the final reportings of research projects, scientific reviews, knowledge syntheses, commissioned work for authorities, technical assessments, guidelines, etc.

Forord

Nærværende rapport er udarbejdet som et led i projektet 'Vurdering af kalve- og oksekøds samlede miljøbelastning'. Projektet gennemføres af Landbrug & Fødevarer (L&F) med støtte fra 'Kvægafgiftsfonden'. Formålet med projektet er at kunne levere en fagligt funderet analyse af oksekøds samlede miljøbelastning og perspektivering af belastningens forskellige parametre, så branchen efterfølgende vil være i stand til at nuancere debatten om oksekøds miljøbelastning. Ligeledes er det formålet at få fokus på, hvilke 'hot spots', der findes i oksekødets livscyklus og dermed give slagterier og primærproducenter viden om, hvor der er potentialer for at nedbringe miljøbelastningen.

Som et led i samme projekt gennemførte Danish Meat Research Institute (DMRI) en kortlægning af ressourceforbrug og produktudbytter på slagteriet af forskellige typer slagtekvæg dokumenteret i *Pontoppidan & Madsen (2014): 'LCA-slagteridataopgørelse for kvægproduktionstyper*.' Disse data danner sammen med data fra Interreg projektet*: 'Regional nöt- och lammköttsproduktion – en tillväxtmoter'* (Mogensen et al., 2015) en væsentlig del af det samlede datagrundlag og baggrundsmateriale for nærværende rapport, der vurderer miljøpåvirkningen i den samlede kæde fra primærproduktion til kalve – og oksekødsprodukt, der forlader slagteriet.

Udover forfatterne, der står inde for beregninger og rapportens konklusioner, har projektets styregruppe givet værdifuldt input til identificering af de relevante produkt- og produktionstyper samt gennemførelse af projektet i øvrigt. Styregruppen har bestået af Allan Munch Mortensen, Kødbranchens Fællesråd, Anette Christiansen, L&F, Julie Lykke Jacobsen, L&F og Charlotte Thy, Danish Crown.

Aarhus Universitet, Institut for Agroøkologi
John E. Hermansen

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Executive summary

It is well known, that the production of beef is related to a significant environmental impact, but also that there is a huge variation in the way beef production takes place at the farm, and this impacts considerable on the environmental profile of the meat produced. Comparatively less is known on how this translates into the environmental impact of different beef products as they appear when leaving the slaughterhouse. This aspect is impacted by differences in resource use and differences in exploitation of the carcass from different types of cattle.

In this work we established the life cycle impact of different types of meat and other beef products in relation to how they are marketed and dependent on the production system at the farm. It was the aim to cover the main types of beef production systems in Denmark, but also to show the influence of very different systems including some that are less common. In total we covered beef products from 13 different beef production systems and evaluated the environmental impact expressed per kg of edible product leaving the slaughterhouse (shortened meat) for each system as summarized in Table A

Table A. Environmental impact of different types of beef products, per kg meat.

Trade mark/sub-classes/production system	GWP, Kg CO_2-eq.[2]	Primary energy, MJ	Acidification, g SO_2-eq.	Eutrophication, kg NO_3-eq.	Biodiversity damage, PDF-index	System Id[3]
Veal (8-12 months at slaughter)						
Danish calf[1]	10.4	36.0	148	0.8	7.2	1
Calf, Limousine (free range)	32.0	37.0	430	2.3	-5.2	10
Young cattle (12-24 months at slaughter)						
Young bull, dairy based[1]	10.5	38.5	142	0.8	8.1	2
Young bull, Limousine	31.0	37.2	420	2.3	-4.4	11
Heifer, Limousine	30.8	30.1	398	2.1	-10.3	12
Young bull, Highland	41.9	27.4	498	3.3	-50.6	7
Heifer, Highland	45.8	28.6	540	3.1	-77.0	8
Beef (> 24 months at slaughter)						
Steers, dairy based[1]	19.4	28.6	243	1.5	1.7	3
Steers, organic, dairy based[1]	18.8	26.3	235	1.3	-1.2	4
Dairy cow[1]	11.1	30.2	118	0.7	4.6	5
Dairy cow, organic[1]	11.5	29.0	99	0.6	1.4	6
Beef cow, Limousine	11.3	9.9	143	0.8	-4.3	13
Beef cow, Highland	12.9	7.5	155	0.8	-19.9	9

1) Dairy based systems are based on Danish Holstein
2) GWP exclusive contribution from soil carbon changes (soil C) and indirect land use change (iLUC)
3) These numbers for identifying each production system are also used in the report by Pontoppidan and Madsen, 2014.

It appears from Table A that there are significant differences in environmental impact for the different types of meat but also that the different impact categories rank differently.

Veal from the dairy system has a lower environmental impact than veal from a beef system across all impact categories, except biodiversity damage. Thus, global warming impact (GWP), acidification and eutrophication amounts about 1/3 in veal from the dairy system. On the other hand the beef system veal in fact has a negative biodiversity damage index, which means that this system actually contributes to improved biodiversity.

Young cattle meat shows the same picture though with a larger difference in GWP in disadvantage for the beef systems but also a larger difference in biodiversity impact in advantage to the beef systems. Across veal and young cattle meat, the use of primary energy per kg meat is almost the same. Meat from Highland cattle shows a higher GWP and a better impact on biodiversity than the limousine, which is related to the fact, that these animals are assumed to graze natural grassland. The methodology to estimate greenhouse gas emission in this system is not fully developed so the numbers on GWP should only be considered indicative.

Beef from adult cattle includes beef from steers and beef from culled cows. No major difference appears between the organic and conventional steer products. Among the different types of cows, only small difference is seen in GWP, acidification and eutrophication. Meat from beef cows require a lower expenditure of primary energy and also impact positively on biodiversity compared to meat from dairy cows.

Looking across all types of meat only small differences exist in GWP within the dairy based systems, except that the GWP of meat form steers are considerable higher than from the other types.

In table A impacts related to changes in soil carbon or to indirect land use changes were not taken into account, since it is generally agreed that these impact should be reported separately due to a lack of agreed methodology. However the impact can be very different for different types of beef systems, and therefore the importance for the GWP has been estimated as well. Grassland based systems sequester carbon and thus reduces the GWP compared to systems based on arable crops. Emissions related to indirect land use changes (*i*LUC) are related to the occupation of land which can be cultivated. While the magnitude of soil carbon changes are not that different among methodologies, the magnitude related to indirect land use changes are greatly impacted by the rationale and methods used. Here we used a conservative estimate.

In Figure A is shown the importance of including soil carbon sequestration and indirect land use in the assessment of different types of beef. In general the GWP of the dairy based calf and cow meat are increased by 11-19 % when including these impacts, while for the beef based systems these two impacts are to a certain degree counter balanced. Thus, the differences between meats from different systems tend to diminish.

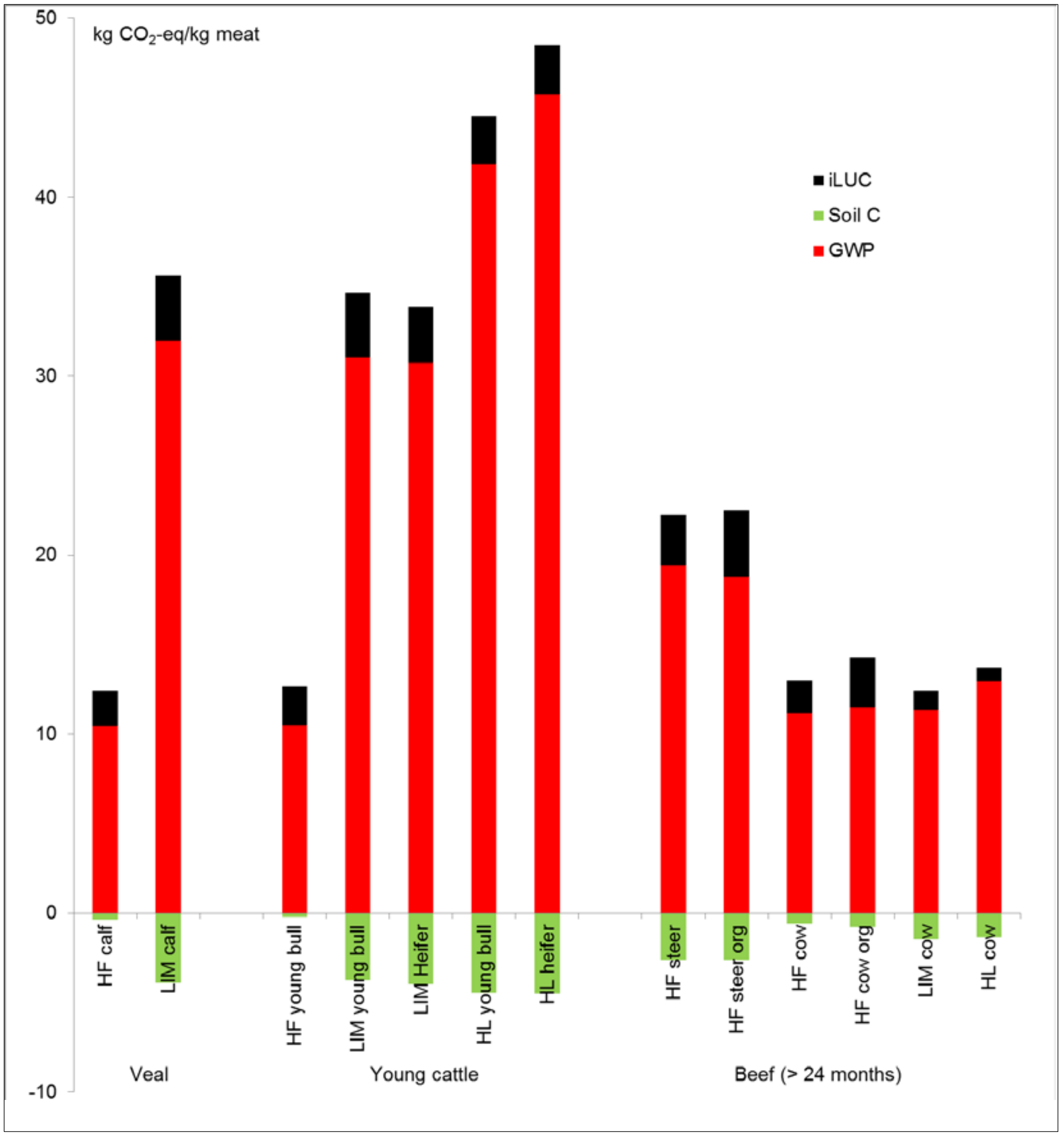

Figure A Global warming potential (GWP) without taking into account soil C and indirect land use change (red column), contribution from soil carbon changes (green column) and indirect land use change (iLUC; black column) for the 13 beef products.

By far the largest environmental impact of the meat is related to the production at the farm. The GWP related to energy use for slaughtering amounts to 30-40 kg CO_{eq} per animal. This energy use is basically offset by the energy recovery from the by-products from the slaughtering process like rumen content, blood tallow. There are only small contributions to acidification and eutrophication. Looking at primary energy, the slaughtering process of steers and cows actually results in a negative net consumption.

Since almost all the environmental impact is related to the farming stage, the degree to which the living cattle are translated into edible products is major determinant for the environmental foot print of the product. While the share of edible products from dairy breeds and Highland cattle is between 45 and 50% of live weight, highest for bull calves, the share of edible products form Limousine is between 53 and 57%, also highest for bull calves. As part of the project it was estimated which by-products that at the moment are used for something else than human consumption, but has a potential for use for human consumption at a global marked in the future. It was estimated that there was a potential for a 12-15% point higher utilization. E.g. for the Danish Holstein calf the present utilization is 49.5% of LW that results in edible products. Whereas with and optimized utilization this could be increased to 62.7% of LW. This would reduce the GWP of the meat by 17 -23%. Thus, this is an important development possibility.

When analyzing the environmental impact related to products from production systems which have more than one output, like beef from dairy systems or when looking at different types of meat from beef cattle production, it is necessary to distribute the total environmental impact from the production system between the various products. For the systems considered here there is no well accepted blue print. In this work we developed a new method which to our mind is closest to the recommendations of ISO 14044 compared to other available methods. For distributing the environmental burden between milk and meat in a dairy system, a sensitivity analysis showed that our method gives estimates of burden related to meat in-between the two mostly used other methods. The method we here propose also allows splitting the burden between different products from a beef production system.

In conclusion, the major environmental burden is related to the farm level stage and innovations to reduce impact should be given high attention. The slaughtering process itself is very energy- and resource efficient. The main innovation to reduce environmental impact of the meat produced will be to ensure a higher utilization of the animal into new edible products not conventionally produced. Also, for beef products there is a significant tradeoff between impact on GWP and impact on biodiversity. The importance of this needs more attention.

1. Introduction

1.1. Aim of the study

Meat is an important part of the human diet and at the same time one of the foods carrying a high environmental foot print, and thus there is considerable interest from industry, NGO's and authorities to relate to that. Beef is in particular perceived as having a high environmental foot print, but at the same time there are huge differences in the way different beef products are produced at the farm, and it is well known that this to a high degree impact on the environmental profile. While a number of studies have been carried out at the farm level and translated into environmental impact of the carcasses produced, comparatively less is known on resource use and exploitation of the carcass at the slaughterhouse from different types of cattle.

The process from live cattle to meat produced is schematically shown below.

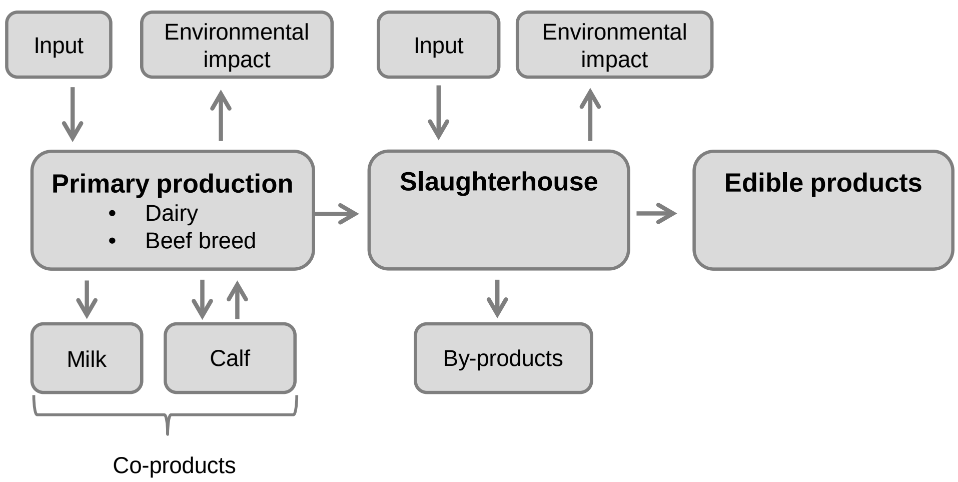

Figure 1. Life cycle of beef.

Since only about half the weight of the living cattle is present in the carcass, and differing between types of cattle, the translation of the impact related to the live animal and the products produced is not straight forward. The actual mass balances and methodologies used in environmental assessment thus influence the environmental profile of the marketed products. Furthermore most work concentrate on the global warming impact and to lesser extent on other impact categories.

Beef is produced in many different ways. A main distinguishing is between meat from dairy cattle and meat from specialized beef breed systems. While the dairy cattle breeds are mainly for milk production less importance have been put on the quality of the carcass for beef production. Contrary in the specialized beef production systems the quality of the carcass has been given attention, but huge differences exist in types of cattle breeds optimized for carcass quality and cattle breeds that are robust and can rely on relatively poor feeding. Another important distinguishing is that the cattle are slaughtered at different ages. All these aspects impacts on the quality of the beef produced and on the remuneration to farmers.

On this background the Danish Agricultural and Food council decided to support an analysis of the environmental impact of the major types of beef products produced in Denmark in order to gain more insight in differences between systems and in the hot spots in the chain, which the industry could relate to. Thus, the aim of the present work was to establish the life cycle impact of different types of beef products from the farm level and to the products is leaving the slaughterhouse. In total we analyze beef products from 13 beef production systems and evaluated the environmental impact expressed per kg of edible product leaving the slaughterhouse for each system. The systems were defined based on statistical data of incoming animals to Danish slaughterhouses to ensure we covered the major types of beef products, but in addition we added some organic systems and systems based on robust low input animals like Highland cattle in order to investigate a wider range of systems. In table 1 is give an overview of the systems and the magnitude of their production in Denmark.

Table 1. Types of beef products and beef systems considered, and their magnitude of production in Denmark in 2012 (after Pontoppidan and Madsen, 2014).

Trade mark/sub-classes/production system	**Age at slaughter, months**	**Live weight at slaughter, kg**	**Number slaughtered animals, 2012**	**System id [2)]**
Veal (8-12 months at slaughter)				
Danish calf[1)]	8.9	391	89877	1
Calf, Limousine (free range)	10.5	491	1733	10
Young cattle (12-24 months at slaughter)				
Young bull, dairy based[1)]	13.5	458	26651	2
Young bull, Limousine	14.4	533	3253	11
Heifer, Limousine	20.2	504	2762	12
Young bull, Highland	17.9	432	82	7
Heifer, Highland	23.7	354	94	8
Beef (> 24 months at slaughter)				
Steers, dairy based[1)]	26.3	611	1716	3
Steers, organic, dairy based[1)]	26.5	600	837	4
Dairy cow[1)]	65.2	653	86140	5
Dairy cow, organic[1)]	68.4	655	9205	6
Beef cow, Limousine	95.4	687	2197	13
Beef cow, Highland	91.4	436	119	9

1) Dairy based systems are based on Danish Holstein
2) These numbers for identifying each production system are also used in the report by Pontoppidan and Madsen, 2014.

1.2. Functional Unit (FU)

In present literature, life cycle assessments typically have calculated the environmental impact of beef as impact per kg carcass, and in some cases per kg of boneless meat. However the empirical basis to translate the findings based on carcass to products available for human consumption is very weak in literature. In this project we get solid estimations of the proportion of a live animal that ends up in edible products. Therefore, in the present study, the functional unit is 'kg products used for human nutrition', i.e. the sum of meat products and edible by-products that are used in human nutrition.

2. Material and methods

The basis for these analyses is two important sources of background information. The system description and input-output at the farm is to a wide extend sourced from the Interreg project*: 'Regional nöt- och lammköttsproduktion – en tillväxtmoter*' (Mogensen et al., 2015). However, for the present work these systems were expanded with input-output relationships for organic systems and also the input-output relations for the previously described systems were adapted to the live weight which is used in this work as presented in table 1. The resource use and the utilization of the animal as well as the by-product flows at the slaughterhouse for the 13 types of beef has been described in detail by Pontoppidan and Madsen (2014).

2.1. Life cycle assessment (LCA)

The environmental impact of beef production was calculated in a life cycle perspective (LCA). This means that the environmental impact of the whole chain until the edible products leaves the slaughterhouse was included. This includes both the emissions that occur on the farm and at the slaughterhouse. But also impacts from producing inputs like feed, bedding, minerals and purchased calves in male production are included.

2.2. Impact categories

This LCA includes the following impact categories: carbon footprint (CO_{2eq}) or global warming potential (GWP), land occupation (m^2) and its impact on biodiversity per kg beef product. The main focus is on these three environmental impact categories, but in addition the impact categories; consumption of fossil energy, eutrophication and acidification were also included.

- Global warming potential is an indicator of climate changes. Some of the biggest human contributors to global warming are the combustion of fossil fuels like oil, coal and natural gas. For agricultural production the main contribution come from the greenhouse gasses methane and nitrous oxide. Global warming potential are presented in CO_2-equivalents.
- Land use: Area of land used in the production of a product presented in square meters per year (m^2 per year).
- Biodiversity loss as compared to natural forest. This is based on land use, i.e. how many vascular plant species that are present in for example a field grown with cereals compared to the natural forest, where a decline in number of species is the biodiversity loss. Presented as loss (%) in plant species in relation to natural forest.
- Fossil Energy is a limited resource and the impacts presented as MJ.
- Eutrophication also called nutrient enrichment causes algal bloom in inlets and springs causing oxygen depletion and death of fish. Emissions of nitrogen and phosphorous to the aquatic environ-

ment, especially fertilizers from agriculture contribute to eutrophication. Also oxides of nitrogen from combustion processes are of significance. Eutrophication potentials are here presented in NO_3-equivalents

- Acidification is caused by acids and compounds which can be converted into acids that contribute to death of fish and vegetation, damage on buildings etc. The most significant man made sources of acidification are combustion processes in electricity and heating production, and transport, but in relation to beef production also ammonia emissions (NH_3) are important. Acidification potentials are presented in SO_2-equivalents.

2.3. Allocation

In a production like milk or beef cattle production, which produces more than one product, it is necessary to distribute the total environmental impact from the production system between the various products. So far, the studies in the literature regarding LCAs have not agreed on one specific method for this allocation. Different methods have been used which influences the environmental impact of the individual product, while the total load of the system obviously will not be changed.

The following ISO 14044 standards provides guidelines for which allocation method should be selected in order of priority:

Step 1. If possible, avoid allocation by

a) dividing the process into two or more sub processes and collect data related to those sub processes

b) expand the system to include the additional functions related to the co-products – system expansion

Step 2. If the allocation cannot be avoided, the input / output should be distributed between the different products / functions in a manner that reflects the underlying physical connection between them.

Step 3. If the physical relationships cannot be estimated, the input /output must be distributed in other ways, for example relative to the economic value of the products (economic allocation).

We find that as regards the production taking place at the farm to produce one animal, it is not possible to split into sub-processes and collect specific data for milk, live weight gain, calf, and manure produced, respectively. However, for manure we use system expansion – accounting for the saved mineral fertilizer which the manure replaces (EU, 2013). For the other on-farm products/co-products we find that it is not possible to avoid allocation, and we use step 2 above.

IDF has proposed a method where in principle the environmental impact is allocated according to the amount of theoretical inputs (especially feed) used in production. In a livestock system, however, a large part of the feed use is caused by requirements for animal maintenance, which by this method are distributed according to the same principle.

In this project we use an adaptation of this method based on the mindset that a production system typically is established primarily to produce one main product, but that besides, there is a production of co-products. The resource consumption for the main product is compensated in the environmental assessment for the resource consumption estimated to be related to the co-products. This method is a development of ISO 14044 step 2, based on an underlying physical relationship, here feed consumption for the various products. The logic is that the main product 'pay' all environmental costs, including maintenance requirements (and emissions related hereto) for the animals, with a correction for 'marginal cost' for production of co-products.

For dairy, milk is the main product, while the co-products; cow live weight gain (= the amount of live weight from cull cows sent to slaughter) and a newborn calf pay only the theoretical feed requirement need for their production corrected for a typical feed efficiency. For beef systems, the calf weaned at 6 months is the main product and must pay the full environmental bill, except for the theoretical resource needs to cow's growth. This co-product is represented by live weight of culled cows sent to slaughter.

The rationale behind the above allocation is that at the farm level, it is in fact possible to influence e.g. the live weight gain of the culled cow by using more feed resources on that, and that the allocation takes this into account by acknowledging and accounting for the changes in feed requirements following a greater or lesser output of co-products marginally.

As regards the slaughter process we use system expansion for by-products or offal used for either feed stuffs or energy recovery, thus counteracting the saved environmental impact by feed or energy that otherwise would have to be produced elsewhere. Regarding hide we preliminary use economic allocation since we were not aware of a reasonable way to make system expansion.

2.4. Carbon footprint

2.4.1. Carbon footprint from primary production

Figure 2 shows the contributions to green-house gas (GHG) emissions from production of beef in a dairy system. In this work we, calculation wise, separated the herd from the land. This means all feed was considered imported to the herd and all manure was applied outside the herd. Input to the herd is then feed, straw for bedding, minerals and calves (only in systems with bull calf fattening). For each of these inputs, an independent LCA for example carbon footprint (CF) per kg straw or per kg barley etc. was calculated. From the herd there is an emission of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). Methane comes both from enteric fermentation and from manure handling. Nitrous oxide originates from the manure in the barn and the storage of manure. Finally, there is an indirect nitrous oxide emission through the evaporation of ammonia (NH_3). All emissions from manure are allocated to the livestock system. But the livestock system then gets credit for the saved production of commercial fertilizer equivalents to the plant-available value of manure. How these individual GHG contributions are estimated is shown below.

Methane from enteric fermentation in the rumen

Methane emissions were estimated using the equations derived from Nordic feed experiments (Nielsen et al., 2013):

Young cattle (heifers, bulls, steers):

- Methane (MJ / d) = (-0.046 * concentrate share + 7.1379) / 100 * GE
  where concentrate share is proportion of concentrated feed in the feed ration expressed as % of dry matter; GE is gross energy in MJ /d, is estimated in NorFor.
  In the daily gross energy intake was not included intake of fresh milk, as it will not give rise to methane

Cows:

- Methane (MJ / d) = 1.39 * DMI -0091 * FA
  where DMI is dry matter intake (kg / d); FA are fatty acids (g / kg DM).

The equation above was also assumed also to be valid for suckler cows, although it was developed for dairy cows.

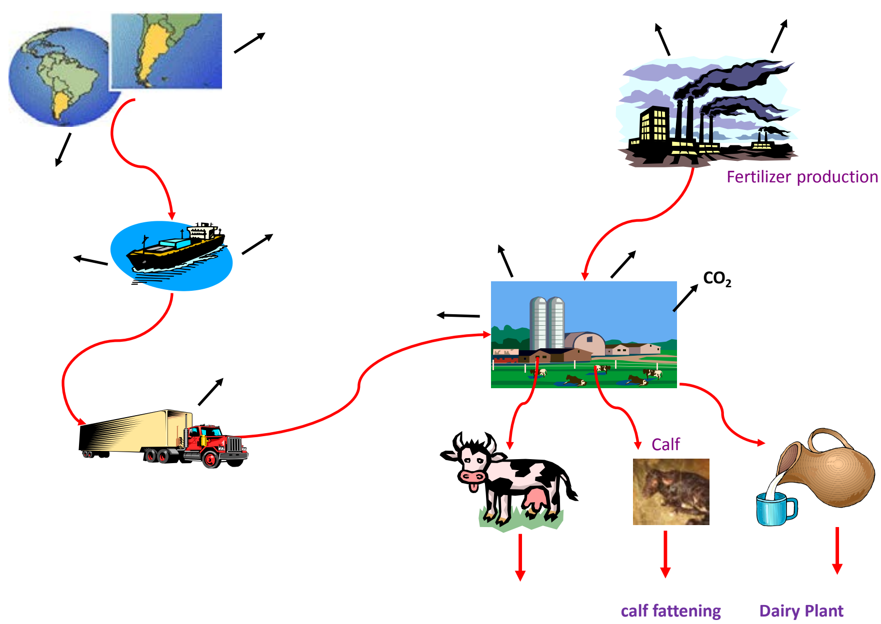

Figure 2. LCA of a dairy system.

Methane from manure

The formation of methane associated with storage of manure occurs in conditions without oxygen why the largest emission occurs from liquid manure systems. The amount of methane formed also depends on the amount of organic matter from the undigested feed and from litter, as well as on the temperature in the storage (IPCC, 2006).

Organic matter in manure (from feed + bedding) is calculated from the feed intake and applied amount of litter:

- Feed organic matter = kg dry matter intake * (1- dig. organic matter/ 100) * (1-ash% / 100)
- Bedding organic matter = kg litter * (DM% / 100) * (1-ash% / 100)

The formation of methane is expressed as:

- Kg CH_4 = (Feed organic matter + Bedding organic matter) * 0.67 * B_o * MCF
  where 0.67 is the conversion from m^3 to kg. B_o is methane formation potential, ICCP (2006) set B_o to 0.24 for dairy cows and 0.18 for young stock. Here however, we used 0.18 for all animal groups. MCF is the methane emission factor. Here is used the Danish values, from Mikkelsen et al. (2006) 10% for slurry and deep litter (Nielsen et al., 2013) and 1% by grazing.

Nitrous oxide emissions from stables and storage

Nitrous oxide emissions from stables and storage and the indirect emissions from ammonia emissions are calculated using the factors in appendix 1. The direct N_2O emissions and indirect N_2O emissions via NH_3 and NO_3- were calculated from flow of nitrogen (N). N excreted ex animal was calculated as the difference between N in feed and N in live weight gain and produced milk. N in feed was based on standard protein contents. The emission factors used for calculating N_2O emissions follow the guidelines from IPCC (2006). Emission factors for calculating NH_3 emission were based on the Danish national norms (Mikkelsen et al, 2005 and 2006; Gyldenkærne and Albertsen, 2008).

GWP related to feed

When calculating GWP of the various beef systems, a common value for each feed items was used in all systems according to appendix 2. GWP for the individual feed items was calculated based on the yield and the fertilizer used as given in Plant Directorate standards. A major part of the GHG emissions of animal feed derives from emissions of nitrous oxide (N_2O) from application of fertilizer, manure and crop residues that are left in the field. In addition there is an indirect nitrous oxide from leaching and ammonia, and there is a contribution from production of input factors such as diesel, electricity and fertilizer. Also there is a contribution coming from transport of feed. In general it was assumed that concentrate feeds was transported whereas roughage was not. It matters how far the feed is transported, and even more how (by lorry or ship for example) the feed is transported.

In Table 2 is shown some examples of CF of feeds, the contribution from growing, processing and transport as well as from changes in soil C (respiration or sequestration) and indirect land use change (iLUC). Further details can be seen in appendix 2, including contribution from other impact categories.

Table 2. GWP of feeds from growing, C sequestration and indirect land use change (iLUC), g CO_2/kg DM.

Feed	Barley	Rape seed cake	Grass clover Silage	Grass clover grazed	Perma-nent Grazed	Maize silage
Contribution to GWP						
- Growing	467	365	403	433	211	216
- Processing	11	28	0	0	0	0
- Transport	18	75	0	0	0	0
Total CF$_{\text{before soil C and LUC}}$	496	468	403	433	211	216
Contribution to GWP From soil C changes [1)]	109	-12	-42	-188	-81	38
From iLUC	328	182	173	202	0	128

1) A positive number means the carbon release and a negative number means that C is sequestrated

In table 3 is given examples of the other environmental impact categories for different feedstuffs.

Table 3. Environmental impact of different feeds; acidification, eutrophication, use of fossil energyand effect on biodiversity, per kg dry matter.

Feed	Barley	Rape seed cake	Grass clover silage	Grass clover grazed	Perma-nent grazed	Maize silage
Acidification, g SO_2-eq.	4.7	3.5	3.42	3.8	2.5	2.3
Eutrophication, g NO_3-eq.	69	56	61	30	8	19
Fossil Energy use, MJ	3.9	3.5	2.3	2.2	1.1	1.6
BD loss, PDF index	1.3	0.7	-0.07	-0.8	-1.5	0.5

GWP of a calf from the dairy system sold for fattening

In the 4 systems with fattening of bull calves from the dairy system there is a contribution to GWP from input of a calf. This GWP contribution from production of a new born calf of 40 kg arise from allocation of the feed requirement from the dairy cow's production as described in section 3.1 ‘Allocation in the conventional dairy system’ and in appendix 3.

Manure as a co-product

The livestock system ‘pays’ all environmental costs related to emissions from handling manure in the barn and during storage. The livestock system also ‘pays’ if the emissions from spreading the manure exceed emissions from spreading the same amount of artificial fertilizer. However, on the other hand the livestock system gets credit for the fact that the produced manure is a nutrient source that can substitute some use of artificial fertilizer. Saved production of fertilizers was estimated to 4.4 kg CO_2 equivalents per kg plant available N, 2.7 kg CO_2 equivalents per kg P and 0.8 kg CO_2 equivalents per kg K (appendix 1).

GHG contribution from soil carbon changes

Farming practices that sequester carbon (C) in the soil can reduce greenhouse gas emission while at the same time increasing soil fertility. Carbon is sequestrated in the soil when we add different biomasses, but the binding will not last forever. The amount of carbon staying in the soil is determined by the balance between input of organic carbon entering and how much is degraded. Carbon sequestration in soil is stimulated primarily by incorporation of crop residues, input of animal manure (especially deep litter), growing grass and use of cover crops.

In this project the contribution from carbon changes in soil was calculated using the method described by Pedersen et al. (2013), where the type of crop grown affects whether C is sequestrated or released. According to this methodology, the annual input of C is the sum of above-ground and below ground crop residues. In addition there may be some input from manure. These inputs of C to each crop are shown in Appendix 2, Tables 2.1 and 2.2 respectively for conventional and organic crops. The calculation also takes into account whether the individual crop is annual or perennial and the degree of tillage. According to Petersen et al (2013), one can assume that 10% of this C input will still be found in the soil in a 100 year perspective. The calculated carbon changes in soil is subsequently scaled to a scale with 'barley with all straw incorporated and no use of animal manure' as zero. Appendix table 2.3 shows, for example for conventional crops that 'natural grass' is in carbon balance, i.e. either release or sequestration of carbon. Carbon is sequestrated in the other grass crops, rapeseed cake and maize cob, while for other crops a release of carbon occurs.

GHG contribution from indirect Land Use Change (iLUC)

The forests play an important role in the global carbon cycle as the forest binds 80% of the carbon bound in terrestrial ecosystems. The biggest threat to forests and their carbon stock is changes in land use and deforestation, especially in the tropics. Changes in land use and deforestation contributes with about 18% of the global greenhouse gas emissions (Stern et al., 2006), but the figure is very uncertain. By far the largest contribution comes from deforestation, and according to FAO (2007), 58% of this deforestation is driven by agricultural production. Audsley et al (2009) assumed that all land use bring pressure on the world's limited resources - land - , and hence all cultivated crops are responsible for a part of deforestation takes place somewhere in the world - the so-called indirect land use change effect (iLUC). The argument is that the global food system is connected and therefore LUC counted as an indirect effect.

Audsley et al (2009) suggest an average iLUC emission factor of 1.43 tones CO_2/ha of agricultural land or 143 g CO_2/m^2 used for this crop production. An exception is permanent pastures and natural areas, which we assume do not contribute to iLUC, since these areas do not have an alternative use like cultivation of another crop. In this work we use the approach by Audsley knowing that this is a very conservative estimate compared to other estimates based on a marginal approach. In general it is recommended (e.g. by Roundtable for Sustainable Consumption) that impact related to land use change or indirect land use change should be reported separately in the accounting, and therefore we do that also.

2.4.2. GWP related to the slaughtering process

During the slaughtering process, the living animal entering the slaughter house is transformed into the main product; i.e. products for human nutrition (which include meat without bones, other edible products and bones used for human nutrition, in total from 45.1 to 57.2% of the live weight of the 13 different types of beef ends as human products). Besides that, by-products (which include bones, blood, rumen contents, etc., in totals from 38 to 47.2% of live weight) and hides (ranges from 4.8 to 7.7% of live weight) are produced (Pontoppidan and Madsen, 2014).

Input for the slaughtering process

The slaughtering process requires input of electricity, natural gas and water. Values from Danish slaughter houses were described (Pontoppidan and Madsen (2014) and they are related either to the weight of the animal or to one slaughtered animal. The consumption of electricity in the slaughter house (for cooling and for other operations) varies for the different beef production systems (from 32 to 47 kWh/animal) because it is influenced by both the weight of the animal and by the number of slaughtered animals. The water and the natural gas are not used directly in the slaughtering process and therefore their values are assumed the same per animal slaughtered for all systems: 29kWh/ animal natural gas for heating the buildings and for hot water production and 686 l water/ animal for handling the slaughtering and cleaning.

Wastewater treatment and SRM products

The emissions to municipal wastewater treatment plant consisted in 3.6 kg BI_5 (degradable organic matter in waste water) and 0.6 kg N per 1.65 t live weight cattle slaughtered (LCAfood.dk). The impacts due to incineration of the SRM by-products were based on the assumptions by Nguyen et al. (2011).

Handling of by-products from slaughtering process

The applied method was based on the ISO hierarchy step 1b using system expansion; i.e. taking into consideration the benefits from the use of the by-products from the slaughtering process in different processes as this use will substitute the use of other products. For all systems, a significant amount of by-products

(13.7-21.5% of total LW) goes into biogas production. Also, small amounts of by-products are used for animal feed (2.1-3.7% of LW) and for the production of medicines or other very specific purposes (0.1-0.2% of the LW). A part of the by-products (4.6-9.9% of LW) is SRM (specific risk materials) and it is assumed to be incinerated. At the same time, the manure that is produced during the transport of animals from farms or/and in stables at slaughter house is collected and it is delivered to farms to be used directly as substitute for fertilizer or transformed into biogas, and the leftovers from bio gasification are delivered to farms to be used as fertilizer. Finally, during the slaughtering process 1.1-2.2% of the animal LW is lost as drip loss (Pontoppidan and Madsen, 2014).

a) *By-products for biogas*

   The benefits from biogas production from by-products were estimated according to Nguyen et al (2011). We assumed that the production of energy from biogas will avoid coal-based electricity and oil-based heat. At the same time, the emissions of N_2O and CH_4 are reduced by 50%, respectively 90% when the application of manure is substituted with residual compounds from biogas production.

b) *Manure for biogas*

   The same judgment also applies in the case of production of biogas from manure. It is assumed that 1 t of manure used for biogas production substitutes 70.5 kWh electricity (from coal) and 91 kWh heat (from oil) (Nguyen et al., 2011). The N, P, K fertilizer values of the degassed manure (after biogas production) were based on Nguyen et al. (2011) and the N, P, K content in manure was from Normtal (2013). The inputs and the emissions from the biogas plant were calculated according to Nguyen et al (2010), while the Volatile Solid content of manure was considered to be 98% of the dry matter content of manure (LCAfoood.dk).

c) *By-products for animal feed*

   Regarding the production of animal feed from by-products, we assumed that 1 kg by-product replaces the production of 1 kg barley and we calculated the avoided emissions according to Nguyen et al (2011). The emissions from production of animal feed were estimated according to Nguyen et al (2011).

d) *By-products for medicines*

   In the case of production of medicines from cattle by-products, we use a LCA process for the synthetic production that is avoided. The amount of medicine produced per kg by-product was assumed to correspond to the protein content of the by-product (same N content as in meat was assumed).

e) *Manure for fertilizer use*

   The manure that is delivered to farms is used as fertilizer for the crops and therefore avoids the production of mineral fertilizers (CF of fertilizer is given in appendix 1). The fertilizer values of manure were estimated according to Nguyen et al (2011), the N, P, K content in cattle manure was from Normtal 2013 and the emissions due to manure application were based on the methodology used by Mogensen et al, 2014.

Economic allocation between hides and beef products for human consumption

In order to divide the overall environmental impact after taking into account system expansion used for by-products, we used economic allocation. Therefore, the remaining environmental impact was allocated between the amount of hides and the amount of beef products for human consumption in relation to their share of total value on market based on a fixed ratio from literature. The price index used was 1:7 for hides:food products (JRC, 2014).

2.5. Biodiversity

In this project the effect on biodiversity (BD) from producing different types of beef products was estimated according to Knudsen et al. (2015). By this method the number of vascular plants is used as a proxy for biodiversity due to the relation between number of plant species and other organisms in the agricultural land scape. Thus, the number of plant species typically present at the different types of land used for the production of beef is the basic indicator, and the impact is expressed as the potential reduction in biodiversity compared to the biodiversity that would have been present under natural conditions. Under Danish conditions as well as in many other cases this would be a natural forest. This allows that a biodiversity loss caused by land use can be calculated.

In the beef production systems examined here the cattle occupy land for cereal, oilseed and soy bean growing, land for production of silage, and different types of grazed land. The main differences in biodiversity from land use is whether the land is with annual crops or perennial crops, organically or conventionally managed, or different quality of the grass land.

In Table 4 are given characterization factors for impacts of land use on BD (Knudsen et al., 2015). In conventional annual crops, number of plant species per area unit was found to be 11 plants compared to 25 species in natural forest. That means that 14 species or 58% of the species in relation to forest has disappeared. Thereby, the potential disappeared fraction (PDF) was 0.58. Contrary, in permanent and nature pastures, BD is increased compared with natural forest, as there was 35% more species, PDF is -0.35.

Table 4. Biodiversity loss compared with natural or semi natural forest presented as PDF (Knudsen et al., 2015).

Crop	**System**	**Number of plant species** 3)	**PDF (potential disappeared fraction)**
Annual crops, not grass	Conventional	11	0.58
	Organic	16	0.35
Natural forest in EU		25	0
Grass clover in rotation	Conventional 1)	27	- 0.06
	Organic 1)	30	- 0.18
Permanent pasture	2)	34	- 0.35
Nature pasture	2)	34	- 0.35

1) Modified from Knudsen et al. (2015) as the average number of plant species from 'grassland fertilized' and 'grassland non-fertilizer' for organic and conventional respectively
2) As an estimate was used number of plant species from 'grass-land non-fertilizer – organic' from Knudsen et al. (2015)
3) Sample units of 10*10 m

2.6. The 13 beef production system – primary production

In this project we defined 13 types of beef production system resulting in 13 types of live cattle delivered for slaughtering. These 13 types represent the types of beef produced in Denmark today. Two main categories of beef exist: beef from beef cattle breeds and beef from dairy production. In Denmark, beef cattle breeds represent 15% of both the 207,000 cows slaughtered and the 266,000 bull calves slaughtered in 2011 (Kviesgaard, 2012). As beef breed farming systems are very diverse; both an extensive and an intensive system were defined. When looking at slaughter data for male calves of dairy breeds, three main systems could be identified. It was decided not to include in the present study beef from surplus dairy heifers slaughtered.

2.6.1. Beef from the dairy production

2.6.1.1. Beef from bull-fattening systems based on dairy calves (system 1-4)

The first four beef types are based on male calves from dairy production. System 1 and 2, Danish calves and young bulls are intensive indoor systems where the bulls are slaughtered at respectively 8.9 and 13.5 months. In system 3 and 4, a conventional and an organic steer system, the bull calves are castrated. These systems are more extensive than system 1 and 2 and are based on grazing during summer and the feeding of roughage in the winter. For the sake of the quality of meat, a finishing stage was included prior to slaughter. Feed consumption and productivity of the system 1 to 4 shown in Table 5 and in further details in appendix 4.

System 1, bull calves slaughtered at 8.9 months

This system is a contract production with specific stipulations for age at slaughter (8 to 10 months), EUROP conformation (>3.0), and carcass weight (180–240 kg). Furthermore, the calf must be housed in deep-bedded stalls until aged 6 months. From 6 months calves are housed in cubicle stalls with rubber mattresses and slatted floor, which is typical for modern cattle housing in Denmark. The feed ration consists mainly of a concentrate mixture and 10% of DM from roughage (barley straw). Total feed use is 1470 kg DM per produced animal and daily gain is 1295 g from birth and until slaughter at 391 kg LW.

System 2, bull calves slaughtered at 13.5 months

Production of so-called 'young bulls' does not stipulate a specific age or size at slaughter. Typically, the age at slaughter is between 11 and 14 months with a carcass weight of 210-250 kg (Spleth and Flagstad, 2012). This is an indoor fattening system involving housing of the calf in deep-bedded stalls until 200 kg LW and then on slatted floors until slaughter (Vestergaard and Fisker, 2008). The feed ration consists of a pelleted concentrate mixture available *ad libitum* leading to 9% of DMI originating from roughage (straw and grass-clover silage also available *ad libitum*), although variation in feed ration composition exists among p herds.) Total feed use is estimated to1903 kg DM per produced animal and daily gain of 1114 from birth and until slaughter at 458 kg LW.

System 3, conventional steers slaughtered at 26.3 months

The system is extensive and based on grazing and roughage (Nielsen, 2003). Grazing occurs for 160 days of the year on grass-clover pastures on high-yielding arable land to obtain a daily gain of 730 g. Housing during winter takes place in deep bedded stalls, and with a restricted feeding of concentrates attempts are pursued to reach a rather low daily gain (640 g). A final 63 days of fattening with a more cereal-based ration before slaughtering are used to obtain a satisfactory meat quality (Nielsen, 2003).

System 4, organic steers slaughtered at 26.5 months

The system is very similar to system 3 regarding feed ration and gain, except that the feed is organically grown, and the organic steers 8 days are older and 11 kg LW lighter at slaughtering.

Table 5. Input and output in the 4 bull-fattening systems based on dairy calves, per produced animal.

System Id.	**1**	**2**	**3**	**4**
Animal group	**Bull calf**	**Young Bull**	**Steer Conv.**	**Steer Org.**
Age at slaughter, months	**8.9**	**13.5**	**26.3**	**26.5**
Days in the fattening system	271	421	799	806
Feed intake, kg DM				
Maize silage	0	0	0	0
Grass clover silage	11	11	1840	1804
Straw	136	166	241	232
Barley	0	0	392	385
Rape seed cake	0	0	93	90
Grazing, rotation	0	0	1572	1540
Grazing, semi-natural pasture	0	0	0	
Milk powder	23	23	22	22
Concentrate mixture	1280	1695	8	8
Fresh milk[4)]	20	20	20	20
Total kg DM	**1469**	**1903**	**4189**	**4102**
Total Scandinavian Feed Unit (SFU)	**1526**	**1979**	**3893**	**3816**
Minerals, kg [1)]	13	16	37	37
Straw for bedding, kg [2)]	472	307	1269	1239
Input of a dairy calf				
Live weight, kg	40	40	40	40
Energy for manure handling in stable, kwh [4)]	12	24	23	23
Energy for feeding, diesel, l	1.3	1.7	2.1	2.1
Output				
Live weight, kg per animal	391	458	611	600
Carcass, %	51.4	51.7	50.5	50.5
Carcass, kg	201	237	309	303
Type of collected manure at stable				
Litter:slurry (% of N) [3)]	50 : 50	25 : 75	75 : 25	75:25

1) 50 g mineral/feeding day based on standard feeding of heifers and young bulls in Denmark (Håndbog for kvæg, 2013)
2) Amount of straw for litter; 0.65 kg straw per kg DM feed at stable based on Danish data for cows (Håndbog for Kvæg, 2013).
3) Distribution between housing at litter and slurry based system Based on number for dairy cows (Mortensen, 2011) energy for slurry handling in stable is 0.813 kwh/kg N in slurry
4) 152 kg fresh milk or 36 SFU

2.6.1.2. Beef from culled dairy cows (system 5 and 6)

The input-output relations in relation to the production of the dairy cows were based on standard figures from Aarhus University (Normtal, 2013). A conventional cow has a milk production of 9300 kg milk/cow/year and a feed consumption of 6958 SFU/cow/year. An organic dairy cow has a milk production of 8900 kg milk/cow/year and a feed consumption of 6484 SFU/cow/year. Quantities and types of feed used as well as turnover of animals were based on figures from Budget Calculates (Knowledge Centre, Danish Agricultural Advisory Service, 2014). In both systems 0.42 cows per cow-year were slaughtered and replaced with heifers reared in the herd. Thus, the herd includes 0.45 replacement heifer per cow-year calving at 26 months of age. This is equivalent to 0.98 'heifer-year'(365 feeding days) in the herd per cow. A total of 1.06 live born calves were weaned per cow per year, of which 0.53 bull calves and a surplus of 0.08 heifer calves per cow-year were sold.

Feed consumption and productivity of the system 5 and 6 is shown in Table 6 per milk producing unit (MPU) which is defined as 1 cow with replacement heifer production. Further details about the feeding are given in Appendix 4.

Table 6. Annual input and output of system 5 and 6 presented per Milk Producing Unit (MPU), i.e. one dairy cow with 0.98 heifers for replacement.

Systems	**5. Conv. dairy cow**	**6. Org. dairy cow**
Feed Intake, kg DM/MPU/year		
Barley	935	1642
Rape seed cake	1051	0
Soybean meal	352	302
Conc, small calves	49	0
Concentrate mixture	494	0
Milk	22	35
Grazing, rotation	555	1803
Grass silage	2552	3444
Maize silage	2699	941
Whole crop silage	0	204
Straw	0	188
Total kg DM	**8709**	**8560**
Total SFU/animal/year	**8783**	**8309**
Minerals, kg/year	60	60
Straw bedding, kg 1)	226	226
Energy for milking and manure handling in stable, kwh 2)	690	690
Output		
Calf for sale, No/year	0.61	0.61
Milk production kg/year	9300	8900
No of cows slaughtered/year	0.42	0.42
Live weight, kg per cow	653	655
Carcass, %	45.3	45.3
Carcass, kg/cow	**295**	**296**

1) Amount of straw for deep litter; 0,65 kg straw per kg DM feed at stable based on Danish data for cows (Håndbog for Kvæg, 2013)
2) Based on numbers for dairy (Mortensen, 2011) energy for light is (149 kwh/cow/year),for pumping water and slurry (109 kwh/cow/year) for milking and cooling (433 kwh/cow/year)

2.6.2 Beef from beef cattle breeds

Two different beef breed production systems were included in this study, one system based on extensive grazing by a robust breed (Highland cattle) and one system representing a high quality beef system (Limousine) and with two different options for slaughter age of the bull calf, either at 10.5 or 14.4 months of age. The systems consist of suckler cows with corresponding heifers for replacement and weaning of calves at 6 months of age, where after the calves enter a separate fattening unit. The suckler cow with replacement heifers and calves until weaning was defined as a Meat Producing Unit (MPU). Across these beef breed production systems a total of 7 different beef breed cattle were produced as described in Table 1.

The environmental impact of for example a bull calf or a heifer calf slaughtered includes a contribution from the cow-calf system and a contribution from the fattening period (e.g. from 6 to 18 months for the extensive bull calf). It is therefore necessary to make a distribution of the cow-calf system's overall environmental impact between the suckler cow and the produced 6 months calves. This is elaborated in section 3.1.

In Table 7 are given production data for different beef breed systems presented per MPU for the cow-calf system and for the fattening period of bull calves and heifers, respectively, for one year's production. The amount of carcass produced per year is a function of the weight of the animal at slaughter and the proportion of animals that can be slaughtered each year. This information is detailed in Table 7 and is necessary in order to obtain coherent data on the entire production from a beef system. In order to estimate the resource use for the production of one animal in its entire period of life before slaughter, data can be derived from appendix 4, where further details about feeding of the different animals are given.

System with highland cattle (System 7, 8, 9)

This system is based on data for Scottish Highland cattle, the most typical breed used in extensive beef breed farming systems in Denmark. Grazing is at maximum level with 180 days on extensive pastures (permanent and natural grasslands) with a relatively low production per ha. During winter the animals are housed on deep bedding in open barns and fed restricted to stimulate gain during the following summer periods. The expected daily gain is a result of type of animal, and this feeding strategy focuses on the use of grazing. Calving occurs during spring and each cow weans 0.9 calves per year, of which 0.2 heifer calves per year is used for replacement and surplus heifers are slaughtered at 24 months. In this extensive system, age at first calving is 36 months and age for slaughtering of bull calves is 18 months.

Limousine system (system 10, 11, 12, 13)

The most typical breed used in intensive beef breed farming systems in Denmark is Limousine. The cows and calves are on grass for 150 days of the year on higher-yielding pastures than for extensive systems, i.e. permanent pastures but also grass-clover on arable land. During winter all animals are housed in deep-bedded stalls and fed maximum proportions of roughage, although bull calves are fed more intensively with mainly concentrated feed. Calving takes place in spring and 1.0 calf 6 month of age is weaned per cow per year. Of this, 0.25 heifers are used for replacement calving at 30 months of age whereas the remaining heifers slaughtered at 20 months of age. The bull calves are slaughtered either as calves at 10.5 months (system 10) or as young bulls at 14.4 months of age (system 11).

Table 7. Input and output of the beef breed systems per year.

Type of breed	**Highland Cattle**			**Limousine**			
System id. **Animal group**	9 Cow with calves[4)]	8 Heifer, 6-24 m	7 Bull, 6-18 m	13 Cow with calves[4)]	12 Heifer, 6-20 m	11 Bull, 6-14,4 m	10 Bull, 6-10,5 m
Feed use, kg DM	**Per MPU**	**Per animal-year [1)]**		**Per MPU**	**Per animal-year [1)]**		
Grass clover silage	1309	618	700	1710	1000	1018	1481
Straw	569	315	403	480	131	0	0
Barley	49	39	215	369	248	1131	1772
Rape seed cake	0	0	77	63	58	249	400
Grazing, rotation	0	0	0	624	309		
Grazing, permanent	1158	201	1364	1733	726	0	0
Grazing, nature	849	609	0	0	0	0	0
Cow milk	92	0	0	153	0	0	0
Total kg DM [3)]	4026	1782	2760	5132	2472	2417	3658
Total SFU[3)]	3277	1380	2241	4532	2218	2505	3805
Minerals, kg	45	12	12	48	18	18	18
Straw, kg [2)]	1223	632	857	1662	934	1427	1571
Energy[5)]	0	0	0	0	0	0	0
Output							
No slaughtered/year	0.2	0.25	0.45	0.25	0.25	0.5	0.5
Live weight, kg per animal at slaughter	436	354	432	687	504	533	491
Carcass, %	48.0	50.5	51.9	55.0	57.9	59.7	60.7
Carcass, kg/year	41	11	101	95	73	159	149

1) One animal in one year is 365 feeding days.
2) Amount of straw for deep litter; 0,65 kg straw per kg DM feed at stable based on Danish data for cows (13 kg straw/day at 20 kg DM feed) (Håndbog for Kvæg, 2013)
3) Including fresh milk
4) Cow with calves and replacement heifers
5) Energy for manure handling in stable

3. Results

3.1. Environmental impact from primary production

Dairy based systems

The environmental impact from beef produced in the 6 dairy production systems (system 1-6) is presented in table 8 and 9. In table 8 the impact is presented per production system, which for system 1 to 4 is one bull calf fattened. For the dairy cow systems the production system include one dairy cow for one year (365 feeding days), production of 0.42 replacement heifer per year and 1.06 new-born calf per year. In table 9, the impact from one produced animal ready to slaughter has been divided by amount of edible products produced for each animal and presented per kg edible product, shortened 'per kg meat'.

In table 8 the detailed contributors to GWP from different types of input, e.g. feed and emissions are given. Further, the possible impact of soil carbon sequestration and ilUC is illustrated as is the land occupation as well as the biodiversity impact related hereto. It should be mentioned that land use occupation includes both on-farm and off-farm land use, since - as explained earlier - we modelled the herd independent from the feed production. Impact on acidification and eutrophication as well as use of fossil energy is given by its aggregated impact.

Overall there are small differences between the organic and conventional dairy cow systems as well as between the organic and conventional steer systems, except that land use requirement are largest in the organic systems, while the loss of biodiversity is less. In fact, in the steer systems the organic system is connected to a minor improvement in biodiversity whereas the conventional system is related to a minor loss of biodiversity.

For the dairy cow systems it is also shown how large proportion of the impact that is related to the production of beef from the systems as detailed in the following section.

Table 8. Environmental impact from primary production of cattle from the dairy production systems.

System	5	6	1	2	3	4
	Dairy cow/year	Dairy cow/year, Org.	Bull 8.9 months	Bull 13.5 months	Steer	Steer Org.
GWP						
GHG from total system, kg CO_2eq	1)	1)	2)	2)	2)	2)
Input						
Feed	3369	2977	1063	1288	2017	1771
Energy use	504	501	12	22	22	22
Straw	20	20	27	18	74	72
Minerals	24	24	5	6	15	15
Calf	0	0	165	165	165	169
Output						
Fertilizer value of manure	-640	-623	-82	-120	-325	-319
Emissions						
CH_4, enteric [3)]	4823	4974	405	523	2296	2248
CH_4, manure	496	442	194	176	485	474
N_2O, stable and storage	587	458	156	161	441	432
Indirect N_2O	153	131	39	40	125	122
Application manure>fertilizer	397	526	64	78	434	426
GWP before soil C and iLUC **per system**	9733	9430	2051	2358	5749	5433
Soil Carbon sequestration	-513	-664	-77	-51	-775	-765
iLUC	1605	2307	391	498	841	1081
LAND USE						
In rotation, ha	1.12	1.61	0.274	0.349	0.588	0.756
-Hereof grass in rotation, ha	0.39	0.85	0.008	0.008	0.452	0.567
Permanent grass, ha	0	0	0	0	0	0
Nature, ha	0	0	0	0	0	-0
Total area per system, ha	1.12	1.61	0.280	0.355	0.595	0.771
BIODIVERSITY						
PDF, per m^2	0.36	0.07	0.56	0.57	0.09	-0.05
PDF-index [4)]	4000	1130	1538	1973	518	-359
Acidification,						
Total system, kg SO_2-eq.	103	81	29	32	72	68
Eutrophication,						
Total system, kg NO_3-eq.	624	470	150	175	433	361
Energy, MJ						
Total system, MJ	27047	24360	7095	8734	8582	7727
Allocation to beef, %	14.4	15.2	100	100	100	100
FU						
Kg 'edible product' per animal	294	292	193	222	290	284
No slaughtered per year	0.42	0.42	1	1	1	1
Kg 'edible product' per year	124	123	193	222	290	284

1) The system include 1 cow and heifer for replacement during 365 feeding days
2) The system is the production of one animal
3) The higher enteric methane emission in the organic dairy system compared with the conventional one (system 6 versus 5) was mainly caused by a lower content of FA in the feed ration (19 vs. 31 g/kg DM), where high FA has a positive effect on CH_4, but also due to a higher level of roughage (1.03 vs. 0.98 kg DM/SFU), which also has a negative effect on CH_4. Based on feed ration from practical farms Kristensen (2014) found a lower difference in fatty acids between conventional and organic rations (29,3 vs 25,8) – but only including winter rations, whereas grass has a low fat content.
4) Average PDF per m^2 * total number of

Allocation in the conventional dairy system exemplified of system 5

As explained earlier the main product, the milk pays all the environmental costs, but are compensated for the impact of the theoretical needs of feed to produce the two co-products, the calf and the replacement cow sent to slaughtering. This is illustrated in Figure 3 and explained below.

For the co-product: 'a calf' the share is found by the following calculation:

Feed required for embryo production: 1.06 calf * 130 SFU/calf with 87% feed utilization -> 158 SFU per year, which is 1.8% of the 8783 SFU used in this system per year. 1.8% of 9733 kg CO_2/(1.06 calves/cow/year) = 165 kg CO_2 / calf.

For the co-product: 'cow for slaughtering' the calculation is as follows:

274 kg LW sent for slaughter per year (feed use: 4 SFU/kg gain, 87% utilization -> 1260 SFU (14.4% of total feed use in the system) = 1396 kg CO_2 (11.3 kg CO_2/kg edible products)

Thus the GWP related to milk production is (9733 -165- 1396) kg CO_2eq corresponding to 0.88 per kg milk.

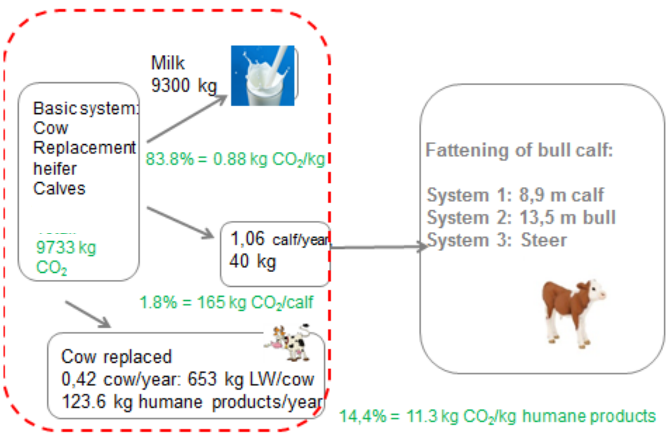

Figure 3. Allocation in the conventional dairy system (system 5).

In Table 9 is given the environmental impact per kg of meat from the different types of dairy production systems taking into account the allocation described above and the amount of edible products that ultimately are available from the different types of animals. No major difference is seen in GWP between meat from calves and cows, whereas the meat from steers has almost double GWP as well as double acidification and eutrophication impact per kg meat compared to meat from cows and calves. Regarding biodiversity the bull calf rearing is connected to the largest burden per kg meat due to the high reliance on concentrated feed from annual crops. No major differences are seen in use of fossil energy.

Table 9. Environmental impact from primary production of cattle from dairy cattle production systems, per kg meat.

System	5	6	1	2	3	4
	Dairy Cow Conv.	**Dairy Cow Org.**	**Bull 8.9 m Conv.**	**Bull 13.5 m Conv.**	**Steer Conv.**	**Steer Org.**
GWP, kg CO_2						
GWP before soil C and LUC	11.3	11.7	10.6	10.6	19.8	19.2
Soil Carbon sequestration	-0.6	-0.8	-0.4	-0.2	-2.7	-2.7
iLUC	1.9	2.9	2.0	2.3	2.9	3.8
LAND USE, m^2						
Area in rotation	13.1	20.0	14.2	15.7	20.3	26.7
-Hereof grass in rotation	4.5	10.5	0.4	0.4	15.6	20.0
Permanent grass	0	0	0	0	0	0
Nature	0	0	0	0	0	0
Total area	13.1	20.0	14.2	15.7	20.3	26.7
BIODIVERSITY						
PDF, per m^2	0.36	0.07	0.56	0.56	0.09	-0.05
PDF-index 3)	4.7	1.4	8.0	8.9	1.8	-1.3
Acidification,						
Total system, g SO_2-eq.	119	100	150	144	248	240
Eutrophication,						
Total system, g NO_3-eq.	724	582	776	789	1493	1273
Energy, MJ						
Total system, MJ	31.4	30.2	36.7	39.4	29.6	27.3

1) One cow (0.42 cow sent to slaughtering per system per year)
2) The system is production of one animal
3) PDF-index = average PDF/m^2*total land use (m^2)

Specialized beef systems

The environmental impact from primary production for beef produced in the specialized beef breed systems resulting in 7 types of cattle delivered for slaughter (system 7-13) are presented in table 10, 11, and 12.

Table 10 shows the contributors to the environmental impact for the cow-calf system and for the fattening periods of bulls and heifers, respectively, not taking into account the allocation between outputs of the cow-calf system as regards the calf, which is transferred to the fattening unit. The major contribution to GWP from feed and methane emission is related to the cow-calf system and this also holds for the other impact categories. Thus, the allocation between the cow-calf system and the fattening units are really important for a valid assessment.

In the first place we show in Table 11 the environmental impact per kg of meat averaged within the three total beef production systems; the two types of breed used in the production and for the Limousine cattle with the options of early or late slaughtering of the bull calves. This is not impacted by the allocation issue and it represents the average production of meat of animals of all ages within the beef breed systems considered. Thus, there is a biological relation between how much meat that originates from the cow, the heifers and the bulls, and this is taking into account in this assessment. In this table the environmental impact is expressed per kg edible products that ultimately are available from the different systems.

It appears that there are almost no differences in impact whether the bull calf is slaughtered at 10 or 14 months of age within the intensive system. Contrary, the GWP of meat from the extensive system is much higher than from the intensive system. It should be mentioned that regarding the extensive system there is a methodological complexity in estimating the GWP related to the feed coming from the nature area, since this is basically the only possible use of that resource. Thus, this evaluation should be considered with caution.

As mentioned earlier in order to assess the environmental impact of the different meat products from the two beef breed systems there is a need to allocate the burden between the production of the 6 month calf and the fattening period. This is elaborated in the following.

Table 10. Environmental impact from primary production of cattle from the beef breed production systems.

Breed	**Highland cattle**			**Limousine**			
System id	**9**	**8**	**7**	**13**	**12**	**11**	**10**
	Cow-calf (365 days)	**Heifer, 6-24 m**	**Bull, 6-18 m**	**Cow-calf**	**Heifer, 6-20 m**	**Bull, 6-14.4 m**	**Bull, 6-10.5 m**
No of animals in the system	1 MPU[1)]	0.375	0.45	1 MPU[2)]	0.292	0.35	0.188
GWP							
GHG from total system, kg CO_2							
Input							
Feed	1065	187	332	1.566	248	388	316
Energy use	5	1	2	7	1	2	2
Straw	71	14	22	146	24	48	39
Minerals	18	2	2	19	2	3	1
Calf	0	0	0	0	0	0	0
Output							
Fertilizer value of manure	-296	-44	-86	-374	-50	-36	-29
Emissions							
CH4, enteric [3)]	2141	388	687	2719	397	325	260
CH4, manure	478	92	151	614	95	177	144
N_2O, stable and storage	338	62	113	512	85	148	120
Indirect N_2O	102	18	33	148	24	36	29
Application manure>fertilizer	461	68	133	573	74	42	34
$GWP_{\text{before soil C and iLUC}}$ per system	4383	787	1389	5.930	900	1.133	917
Soil C	-454	-71	-157	-764	-118	-110	-88
iLUC	259	48	98	569	97	210	172
LAND USE							
In rotation, ha	0.181	0.034	0.069	0.398	0.068	0.147	0.120
-Hereof grass in rotation, ha	0.158	0.028	0.038	0.295	0.048	0.043	0.034
Permanent grass, ha	0.499	0.032	0.265	0.747	0.091	0	0
Nature, ha	1.464	0.394	0	0	0	0	0
Total area per system, ha	2.144	0.460	0.333	1.145	0.159	0.147	0.120
BIODIVERSITY							
PDF, per m^2	-0.32	-0.32	-0.23	-0.19	-0.15	0.39	0.40
PDF-index [3)]	-6832	-1473	-771	-2194	-231	577	478
Acidification,							
Total system, kg SO_2-eq,	51.9	9.3	16.8	74.5	12.03	19.1	15.5
Eutrophication,							
Total system, kg NO_3-eq, [4)]	284	48	93	407	64	102	83
Energy, MJ							
Total system, MJ	2569	536	1081	5233	999	2480	2026
Allocation to beef, %	12.2	100	100	17.5	100	100	100
FU							
Kg 'edible product' per animal	204	172	210	360	276	305	283
No slaughtered per year	0.2	0.25	0.45	0.25	0.25	0.5	0.5
Kg 'edible product' per year	41	43	95	90	69	153	141

1) The system include 1 Cow + 0.9 calves 0-6 m produced/year + 0.2 replacement heifer produced per year
2) The system include 1 Cow + 1.0 calves 0-6 m produced/year + 0.25 replacement heifer produced per year
3) PDF-index = average PDF/m^2*total land use (m^2)
4) Effect of soil C and N changes on leaching was taken into account

Table 11. Environmental impact from primary production from the total beef breed production systems including both cow-calf and fattening of bull calves and heifers, the results are presented both per system and per kg meat.

	Highland cattle ***(system 7, 8, 9)***	**Limousine** ***(system 11, 12, 13)***	**Limousine** ***(system 10, 12, 13)***
FU			
kg 'edible product' per year	178.5	311.5	300.1
GWP			
GWP, total kg CO_2 per system	6559	7963	7747
$GWP_{\text{before soil C and i LUC}}$, kg CO_2/kg meat	36.7	25.6	25.8
Soil C, total kg CO_2 per system	-682	-992	-970
Soil C, kg CO_2/kg meat	-3.8	-3.2	-3.2
iLUC, total kg CO2 per system	405	876	838
iLUC, kg CO_2/kg meat	2.3	2.8	2.8
LAND USE			
Arable land, ha	0.28	0.61	0.59
Arable land, m^2/kg meat	15.9	19.7	19.5
Arable grass, ha	0.22	0.39	0.38
Arable grass, m^2/kg meat	12.55	12.39	12.56
Permanent grass, ha	0.80	0.84	0.84
Permanent, m^2/kg meat	44.6	26.9	27.9
Nature, ha	1.86	0	0
Nature, m^2/kg meat	104.1	0	0
Total area per system, ha	2.94	1.45	1.42
Total area, m^2/kg meat	164.5	46.6	47.5
BIODIVERSITY			
PDF-index [1)]	-9076	-1848	-1947
PDF-index/kg meat	-50.8	-5.9	-6.5
Acidification,			
Total system, kg SO_2-eq.	78	106	102
kg SO_2-eq./kg meat	0.437	0.339	0.340
Eutrophication,			
Total system, kg NO_3-eq.	425	573	554
kg NO_3-eq./kg meat	2.40	1.84	1.85
Energy, MJ			
Total system, MJ	4186	8712	8258
MJ/kg meat	23.5	28.0	27.5

1) PDF-index = average PDF/m^2*total land use (m^2)

Allocation between suckler cow and weaned calves

The reasoning is that the main product from the cow-calf system is the calves weaned at 6 months. These calves pays the main environmental impact of the cow-calf system except the theoretical feed requirements (including feed efficiency) to produce the co-product, which is the meat from the cows that are culled when they are too old to continue production or have other problems.

For example considering the cow-calf system with Highland cattle (system 9), per year 0.2 cow (87 kg live weight (LW) are sent to slaughter. The theoretical feed requirements are 4 SFU / kg LW gain and assuming 87% feed utilization -> 400 SFU. This represents 12.2% of total feeds (3277 SFU) per year for the basic system and hence 12.2% of 4383 kg CO_2 from basic system = 536 kg CO_2 is to be covered by the culled cow. Translated into meat this amounts to 13.1 kg CO_2 / kg meat for consumption.

The remaining emissions (87.8%) are allocated to the 0.7 calf produced per year for further fattening. This is 0.25 heifer calf weighing 129 kg and 0.45 bull calf weighing 158 kg LW, when they are leaving the cow-calf system at 6 months of age. In total this is 103 kg LW calf/year). Thus, the calf leaving the cow/calf system carries a burden of 37.4 kg CO_2/kg LW.

This is illustrated in Figure 4.

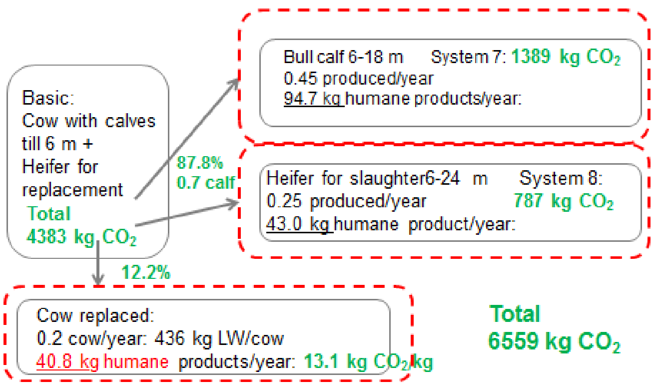

Figure 4. Allocation in the Highland cattle (system 9).

Environmental impact per kg produced meat

In table 12 is given the contribution from the primary production to the environmental impact expressed per kg of meat ready for consumption following the allocation given above. While the meat from the culled cows has a GWP of 11-13 kg CO_2-eq per kg and at the same level as meat from a culled dairy cow, the meat from the calf and the young beef cattle are 3 and 4 times higher. This also holds for the other impact categories.

At a first glance it is surprising that the GWP of meat from the bull calf slaughtered at 10 months of age is slightly higher than the meat from the young bull slaughtered at 14 months of age since the latter uses more feed per kg gain. The reason is that GWP related to the 6 months calf is even higher, 37.4 kg CO_2/kg LW or 65.4 kg CO_2/kg 'meat' and this effect is then more diluted when the calf grows older.

Table 12. Environmental impact from primary production of meat from beef breed production systems, per kg meat.

Breed	**Highland cattle**			**Limousine**			
System id	**9**	**8**	**7**	**13**	**12**	**11**	**10**
Type	**Cow**	**Heifer, 0-24 m**	**Bull, 0-18 m**	**Cow**	**Heifer, 0-20 m**	**Bull, 0-14.4 m**	**Bull, 0-10.5 m**
GWP, kg CO_2/kg meat product							
Total GWP$_{\text{before soil C and iLUC}}$	13.1	46.4	42.7	11.5	31.1	31.4	32.3
Soil C	-1.4	-4.6	-4.6	-1.5	-4.0	-3.8	-4.0.
iLUC	0.8	2.8	2.7	1.1	3.1	3.7	3.7
LAND USE, m^2							
Area in rotation	5.4	19.5	18.8	7.7	21.9	25.7	25.9
-Hereof grass in rotation	4.8	16.7	14.2	5.7	15.9	14.8	15.3
Permanent grass	14.9	39.5	59.9	14.4	36.0	30.2	32.6
Nature	43.8	185.5	93.7	0.0	0.0	0.0	0.0
Total area	64.1	244.4	172.4	22.1	57.9	56.0	58.4
BIODIVERSITY							
PDF, per m^2	-0.32	-0.32	-0.30	-0.20	-0.18	-0.08	-0.09
PDF-index 3)	-20.5	-84.3	-49.0	-4.4	-12.2	-4.1	-5.3
Acidification,							
Total system, g SO_2-eq.	157	547	509	144	402	426	435
Eutrophication,							
Total system, g NO_3-eq.	848	3192	3346	786	2167	2315	2360
Energy, MJ							
Total system, MJ	7.7	28.9	27.9	10.1	30.4	37.4	37.1

2) The system is production of one animal
3) PDF-index = average PDF/m^2*total land use (m^2)

3.2. Environmental impact from the slaughtering process

In Table 13 and 14 is presented input and output from the slaughtering process for the 13 types of cattle slaughtered expressed per animal slaughtered. Input includes the energy and water use in the slaughter house. Output includes how much (and type of) edible products one slaughtered animal gives rise to as well as how much of different by-products that are produced. It is also indicated what the by-products are used for and thus what type of avoided emissions that can be accounted for in the assessment. For GWP, the contribution from energy use in the slaughter house and from avoided production caused by use of by-products was given separately, whereas for the other impact categories, the total amount per slaughtered animal is given.

Regarding the dairy based systems (Table 13) there are only small differences in resource use per animal. From the cows app 45% of the live weight are used for edible products of which the edible products not from the carcass like heart, tail, tripe, meat from head, tongue, blood and thymus constitutes one fourth.

For the calves and young bulls almost half of the live weight is translated into edible product of which 80% is meat. The utilization of the steers is in-between.

While rumen content and blood is the largest fraction for cows, bones and tallow is the major part of the steer by-products. Both fractions are in this assessment used for energy recovery (modeled as biogas production) but these by products are very different in nature and maybe the bones and tallow on some occasions could be used for higher value products, thus substituting more resources.

Hides account for 6-8% of the live weight, being largest for calves and young bulls.

The GWP related to energy use for slaughtering and transport of cattle to the slaughterhouse amounts to 40-50 kg CO_2-eq, hereof on average 10 kg CO_2-eq is related to transportation from farm to slaughterhouse. When accounting for the GWP related to avoided production, the 'net-costs' for the slaughtering process is around 10 kg CO_2-eq slightly higher for young animals than for cows. Thus the GWP related to energy spend at the slaughterhouse is basically offset by the GWP of the avoided production due to produced by-products.

There are only small contributions to acidification and eutrophication. Looking at primary energy, the slaughtering process of steers and cows actually results in a negative net consumption.

Regarding the specialized beef systems (Table 14) there is a clear difference in share of edible products from the Highland and the Limousine cattle, where the young limousine cattle shows a share of 57% of edible product against 49% in the young cattle from Highland. Also between bulls and cows of Limousine there is a significant difference in utilization for human consumption, whereas this difference is less for Highland cattle.

Tabel 13. The slaughtering process; input, output, and contribution to carbon footprint and other impact categories from beef from the dairy systems, for one animal slaughtered.

System id	**1**	**2**	**3**	**4**	**5**	**6**
	Bull 8.9 m Conv.	**Bull 13.5 m Conv.**	**Steer Conv.**	**Steer Org.**	**Conv. dairy cow**	**Org. dairy cow**
Input						
Live weight (LW), kg	391	458	611	600	653	655
Electricity, kwh	34	37	42	42	41	41
Natural gas, kwh	29	29	29	29	29	29
Water, l	686	686	686	686	686	686
Output						
Edible products, kg:						
Meat without bones [1)]	154.3	175.9	227.7	222.1	218.0	214.8
Other edible products (not from carcass)	34.6	40.4	55.2	54.6	71.4	72.7
Bones for food production	4.4	5.4	7.0	6.9	5.0	5.0
Total human products, kg	193.4	221.7	290.0	283.5	294.4	292.3
By-products, kg:						
For animal feed production	10.1	11.8	16.2	16.0	24.1	24.5
For biogas (content of rumen, blood)	59.6	69.6	95.2	94.1	132.7	134.9
Bones, tallow, not-SRM for destruction[4)]	71.3	78.2	104.9	102.7	87.9	87.5
SRM for destruction [5)]	17.8	31.6	43.4	42.7	64.2	64.7
Shrinkage	8.2	9.7	13.3	13.1	9.3	9.4
Other use fx for medicine	0.2	0.2	0.3	0.3	0.3	0.3
Total by-product, kg	167.2	201.1	273.2	269.0	318.6	321.4
Hides, kg	30.2	35.2	48.2	47.6	40.2	40.9
Edible products in % of LW	49.5	48.4	47.4	47.2	45.1	44.6
GWP, kg CO_2-eq.						
Slaughtering process [2)]	37.1	40.3	47.0	46.5	47.4	47.5
Avoided production[3)]						
For animal feed production	-4.1	-4.8	-6.5	-6.5	-9.7	-9.9
For biogas	-17.2	-19.4	-26.3	-25.9	-29.0	-29.2
For destruction	0	0	0.1	0.1	0.1	0.1
For other use f.x. medicine	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
Use of manure	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
Wastewater treatment	0	0	0	0	0	0
Net GWP from slaughtering/transport	**14.9**	**15.1**	**13.2**	**13.2**	**7.7**	**7.3**
Acidification,						
Total system, kg SO_2-eq.	0.2	0.2	0.3	0.3	0.3	0.3
Eutrophication,						
Total system, kg NO_3-eq.	0.2	0.3	0.3	0.3	0.2	0.2
Energy, MJ						
Total system, MJ	21	5	-95	-90	-171	-178
Allocation (economic)						
Hides, %	2.2	2.2	2.3	2.3	1.9	1.9
Edible products.%	97.8	97.8	97.7	97.7	98.1	98.1

1) Though, for meat product sold with bones for example osso buco these are included
2) Including use of heat and electricity, tap water, and 100 km transport to slaughterhouse
3) Calculated by system expansion
4) This was assumed to be used for biogas production
5) SRM (special risk material) was assumed to be incinerated

Table 14. The slaughtering process; input, output, and contribution to carbon footprint and other impact categories from beef breed systems, for one animal slaughtered.

System id	**7**	**8**	**9**	**10**	**11**	**12**	**13**
	Highland Cattle			**Limousine**			
	Bull	**Heifer**	**Cow**	**Bull 10.5 m**	**Bull 14.4 m**	**Heifer**	**Cow**
Input							
Live weight (LW), kg	432	354	436	491	533	504	687
Electricity, kwh	36	33	35	41	43	41	47
Natural gas, kwh	29	29	29	29	29	29	29
Water, l	686	686	686	686	686	686	686
Output							
Edible products, kg:							
Meat without bones [1]	167.7	132.7	155.2	242.2	260.2	228.2	293.7
Other edible products (not from the carcass)	37.6	34.8	45.2	35.5	39.1	42.5	61.6
Bones for food production	5.1	4.1	3.5	5.0	5.4	5.5	5.0
Total human products, kg	210.4	171.6	203.9	282.5	304.7	276.2	360.2
By-products, kg:							
For animal feed production	11.0	11.7	15.3	10.4	11.4	14.3	20.8
For biogas (content of rumen, blood)	64.7	64.6	83.8	61.1	67.4	78.9	114.4
Bones, tallow, not-SRM for destruction[4]	74.1	59.0	59.8	78.9	75.0	77.4	85.1
SRM for destruction [5]	29.4	22.4	42.0	18.2	30.6	27.4	62.8
Shrinkage	9.0	4.6	5.9	8.5	9.4	5.5	8.0
Other use fx for medicine	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Total by-product, kg	188.3	162.5	206.9	177.3	193.9	203.8	291.6
Hides, kg	32.8	19.6	25.5	30.9	34.1	24.0	34.7
Edible products in % of LW	48.7	48.5	46.8	57.5	57.2	54.8	52.5
GWP, kg CO_2-eq.							
Slaughtering process [3]	39.1	35.3	38.5	43.8	45.8	43.9	51.9
Avoided production[4]							
For animal feed production	-4.4	-4.7	-6.2	-4.2	-4.6	-5.8	-8.4
For biogas	-18.2	-16.3	-18.9	-18.4	-18.7	-20.6	-26.2
For destruction	0	0	0.1	0	0	0	0.1
For other use f.x. medicine	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2
Use of manure	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
Wastewater treatment	0	0	0	0	0	0	0
Net GWP from slaughtering/transport	**15.5**	**13.3**	**12.5**	**20.2**	**21.5**	**16.6**	**16.3**
Acidification,							
Total system, kg SO_2-eq.	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Eutrophication,							
Total system, kg NO_3-eq.	0.3	0.2	0.2	0.3	0.3	0.2	0.3
Energy, MJ							
Total system, MJ	22	20	-7	88	109	25	-19
Allocation between (economic)							
Hides, %	2.2	1.6	1.7	1.5	1.6	1.2	1.3
Edible products,%	97.8	98.4	98.3	98.5	98.4	98.8	98.7

1) Though, for meat product sold with bones for example osso buco these are included: 2) Including use of heat and electricity, tap water, and 100 km transport to slaughterhouse: 3) Calculated by system expansion: 4) This was assumed to be used for biogas production.

3.3. Environmental impact of beef – contribution from the whole chain

In the following figures, the environmental impact per kg edible product (shortened meat) from the different types of cattle is presented by impact category as a total and with the contribution from each step in the chain. The detailed information behind the figures is presented in table 5.1 to 5.6 in appendix 5. It appears across impact categories that by far the largest contribution is related to the production at the farm. Only for fossil energy there is a noticeable impact from the slaughtering process, which, however, is by and large offset by the utilization of by-products.

For GWP (Figure 5) the total impact of meat from dairy based calves and young bulls and from cows of all types are almost the same, 10- 12 kg CO_{2eq} per kg meat. Meat from steers has almost the double GWP, meat from calves and young cattle of specialized beef system almost three times that value, and meat from the slow growing robust Highland cattle almost 4 times that value. It should be noticed here that estimating the environmental impact related to Highland cattle that to a high degree utilises nature area is a matter of debate conceptually, since grazing the nature area allows to make use of resources which otherwise probably would not be utilized, and our method does not take that into account.

Figures 6 and 7 shows the total land use and the need for arable land respectively per kg of meat produced. The balance between arable land and grassland on the one hand and whether the land is managed organically or not on the other hand is important for the impact on biodiversity. Also, the requirement for different types of land is important for assessing a possible influence of soil carbon sequestration and indirect land use change.

The impact related to biodiversity is shown in figure 8. A positive value means a loss of biodiversity related to the request for meat while a negative value means that the beef production in fact has a positive contribution to biodiversity. Most types of meat have only small impact on biodiversity. Within veal the dairy based calf is related to a small loss of biodiversity whereas the limousine calf is related to a gain of biodiversity. Similar effects are seen within meat from young cattle. However, meat from young animals of Highland Cattle shows a significant gain in biodiversity due to grazing on large areas.

Use of non-renewable energy is shown in Figure 9. For fossil energy there is a noticeable impact from the slaughtering process, which however was offset by avoided energy production due to utilization of by-products. Compared with the other impact categories, the energy use only differ to a small degree between the different types of meat. One exception was meat from cows from the beef breed systems where energy use was 3-4 times smaller than for other systems.

Effect of beef production on eutrophication (EP) and acidification (AP) is shown in Figure 10 and 11. For both EP and AP, the total impact of meat from dairy based calves and young bulls and from cows of all types are almost the same; 0.6 – 0.8 kg NO_3-eq and 99-148 g SO_2-eq per kg meat. Meat from steers has almost the double EP and AP, meat from calves and young cattle of specialized beef system almost three times that value, and meat from Highland cattle almost 4 times that value. It should be noticed here that estimating the environmental impact related to Highland cattle, which to a high degree utilises nature area, is a matter of debate both conceptually, and methodically regarding estimating eutrophication from nature area.

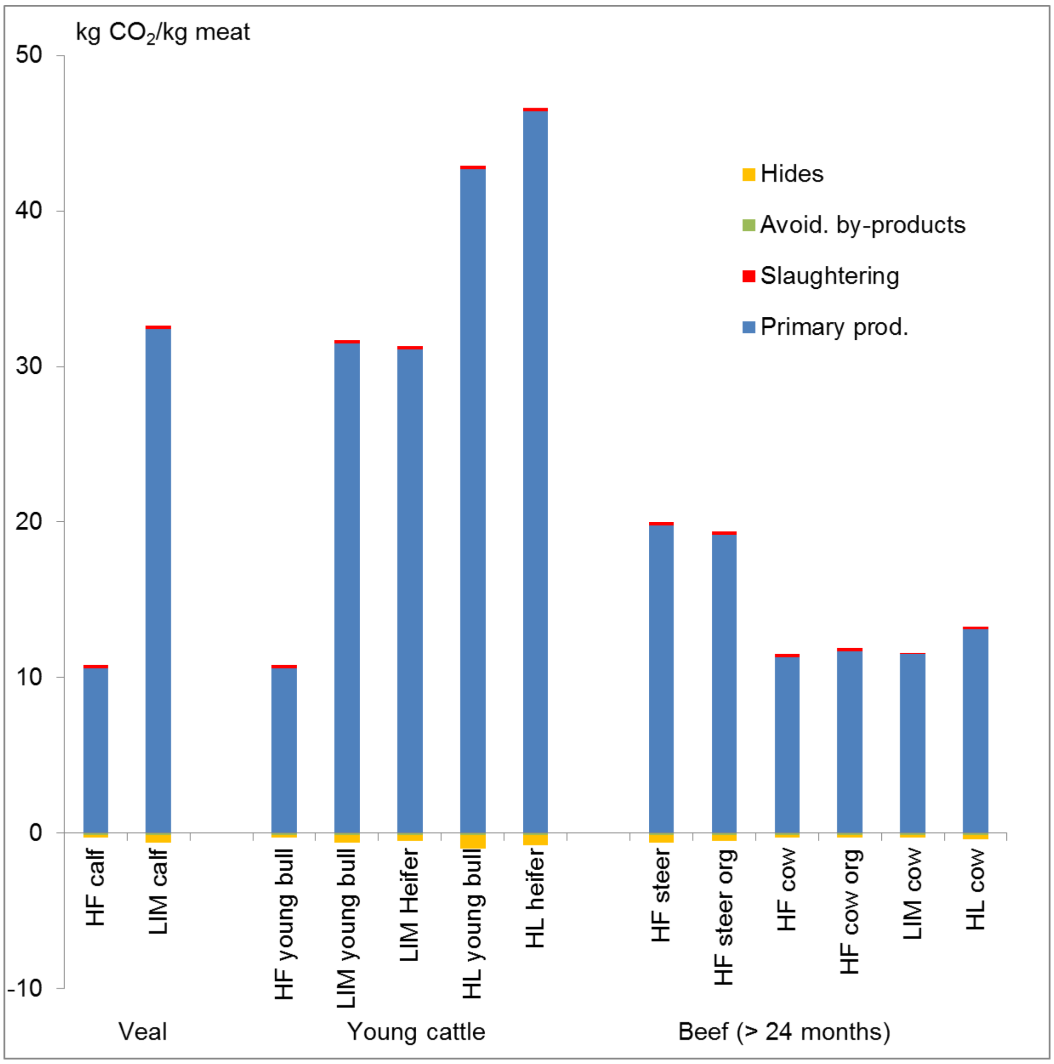

Figure 5. Global warming potential (GWP) (without contribution from soil C and LUC), kg CO_2-eq. per kg meat. The abbreviations used in the figure is HF = Holstein Friesian, LIM = Limousine, and HL = Highland cattle.

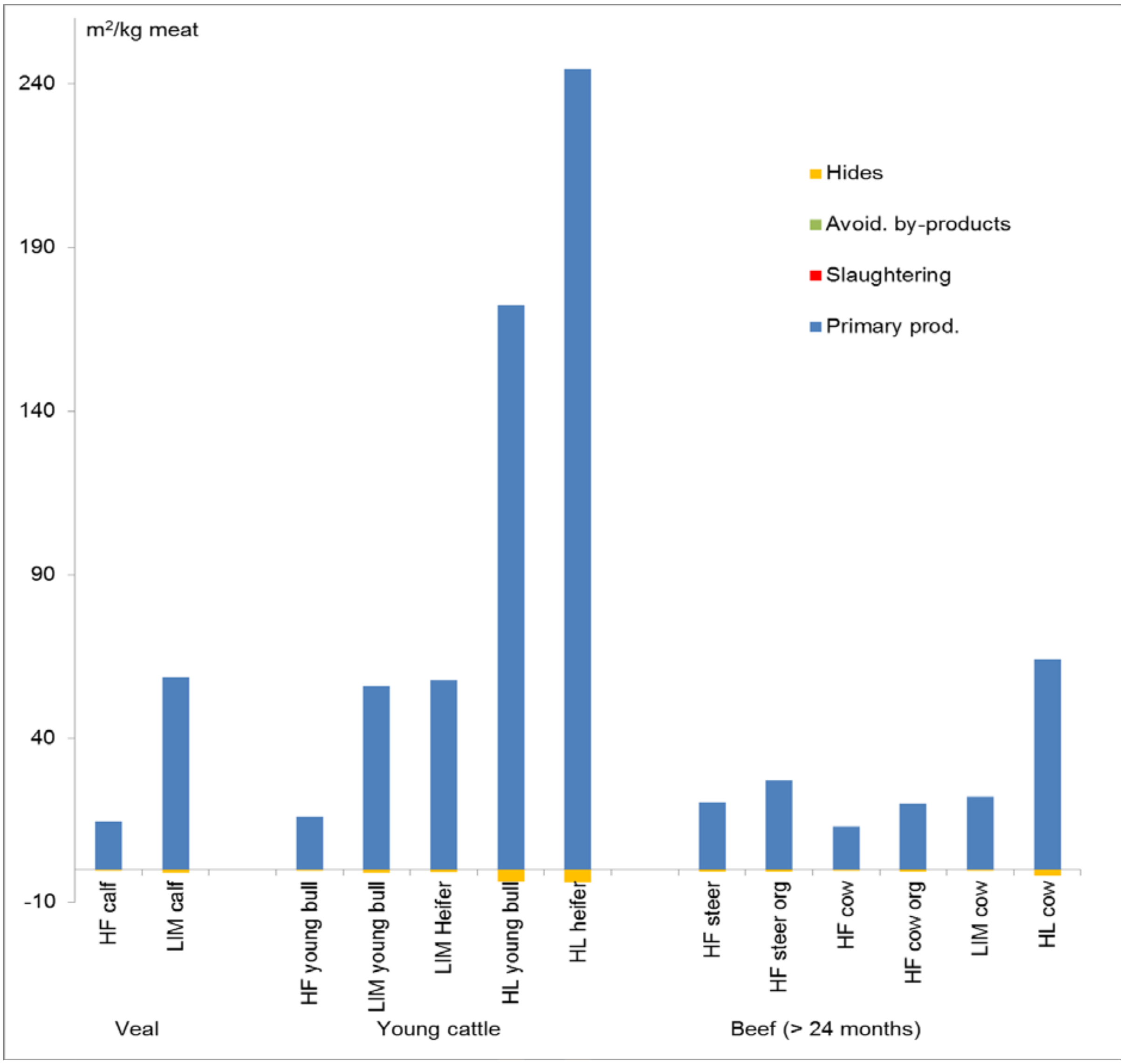

Figure 6. Land use in term of total area, m² per kg meat.

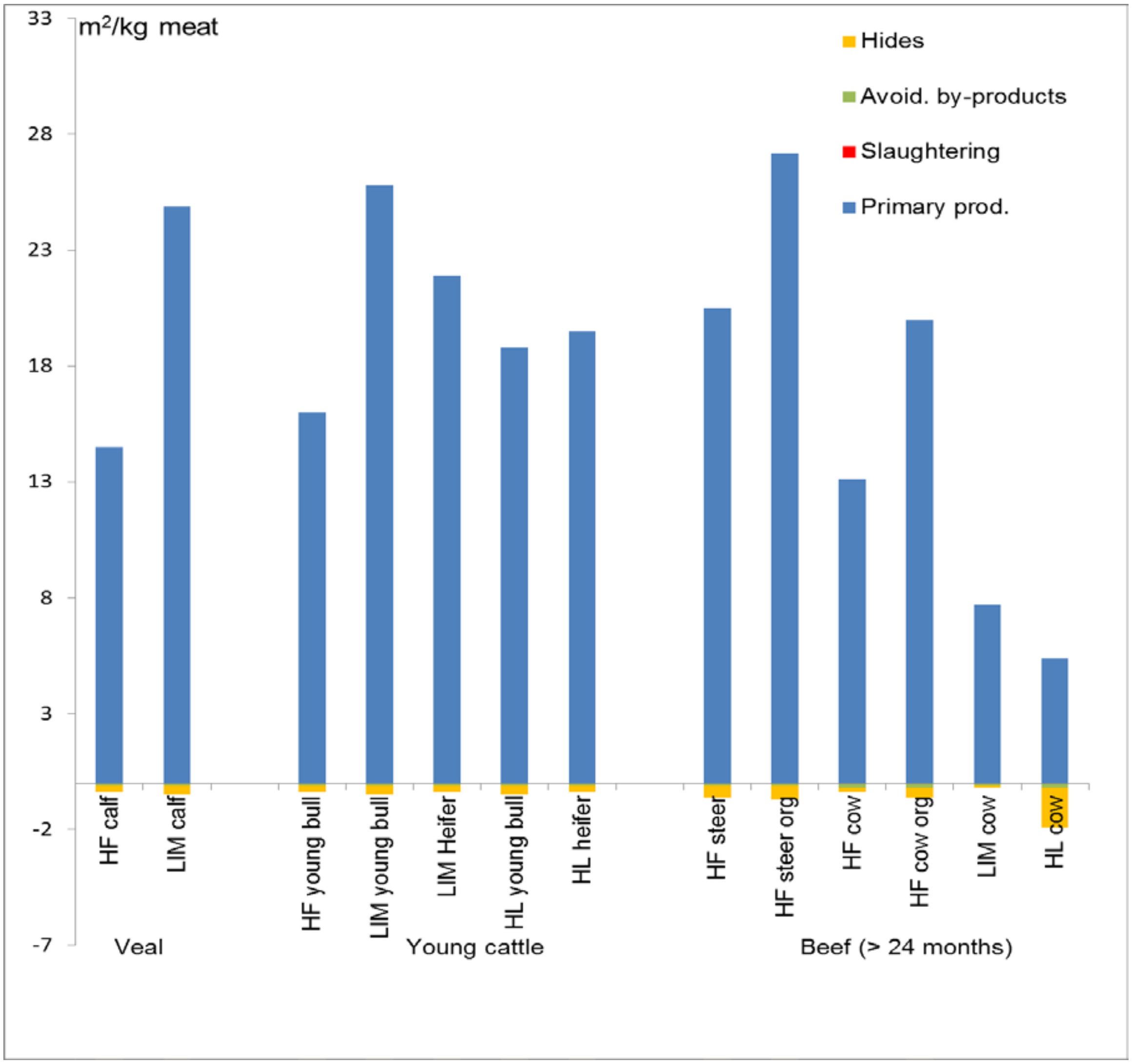

Figure 7. Land use in term of arable land, m^2 per kg meat.

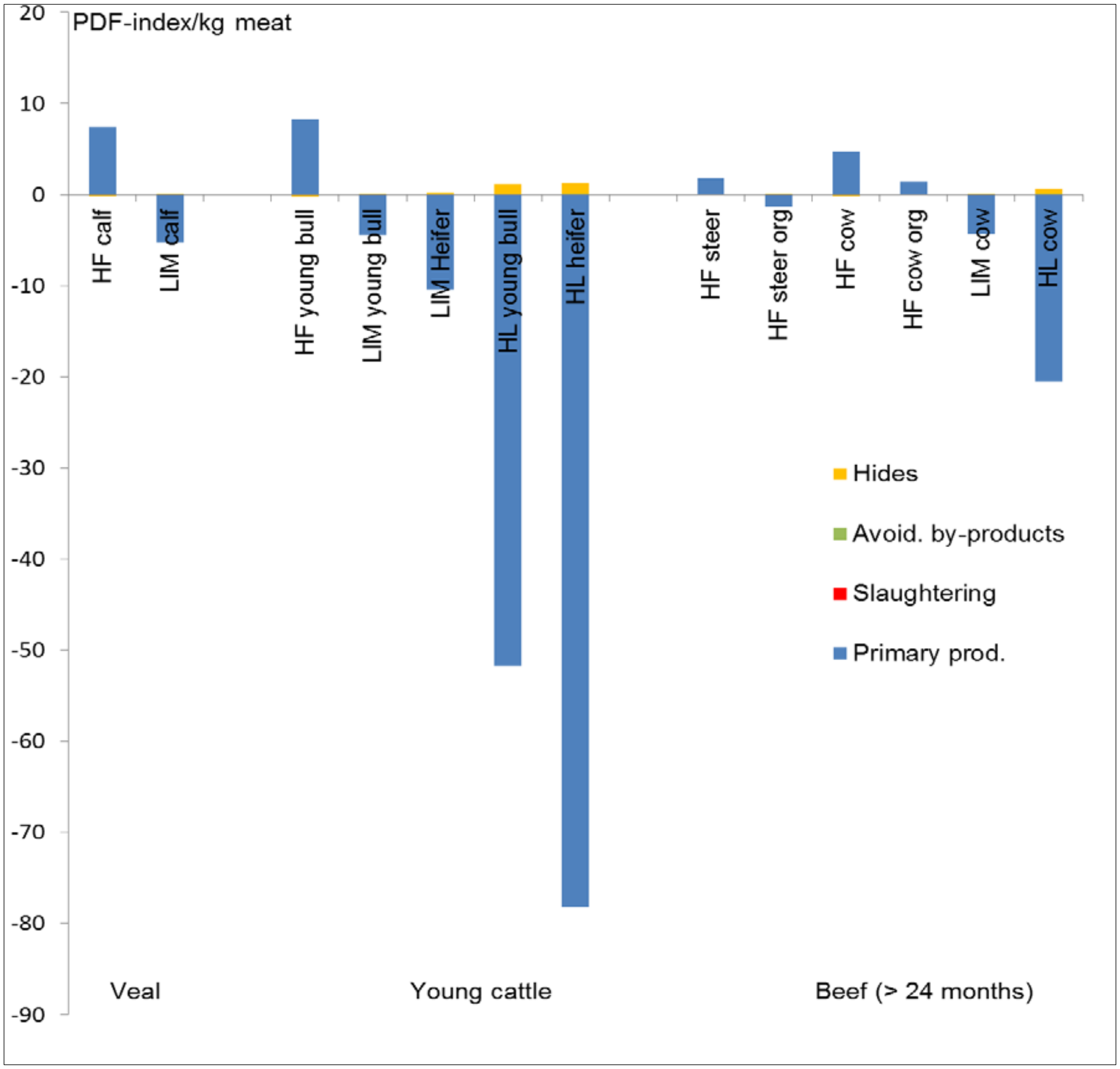

Figure 8. Biodiversity (BD) loss in term of PDF-index per kg meat.
*PDF-index = average PDF/m²*total land use (m²). A positive number means BD loss*

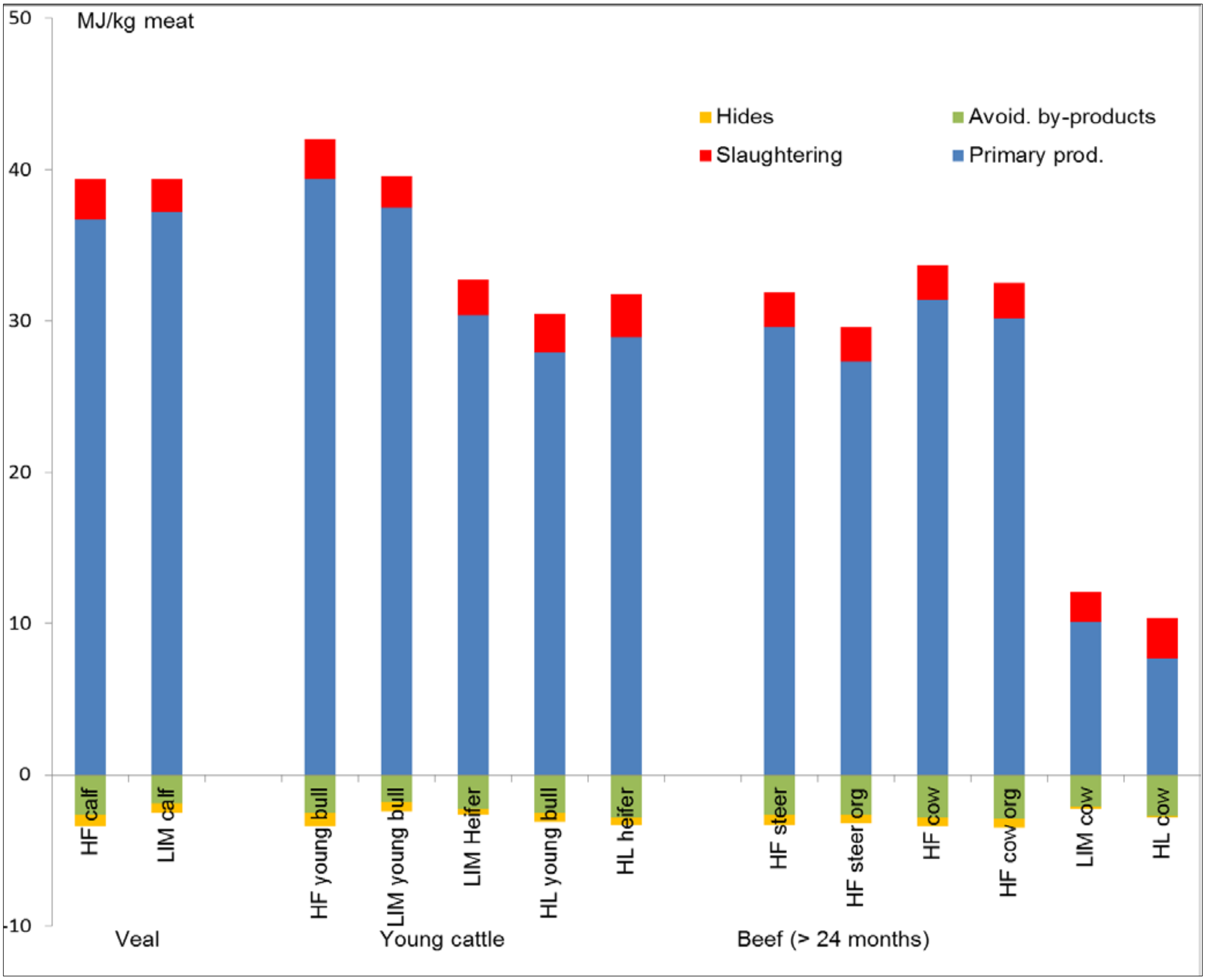

Figure 9. Use of non-renewable energy, MJ primary energy per kg meat.

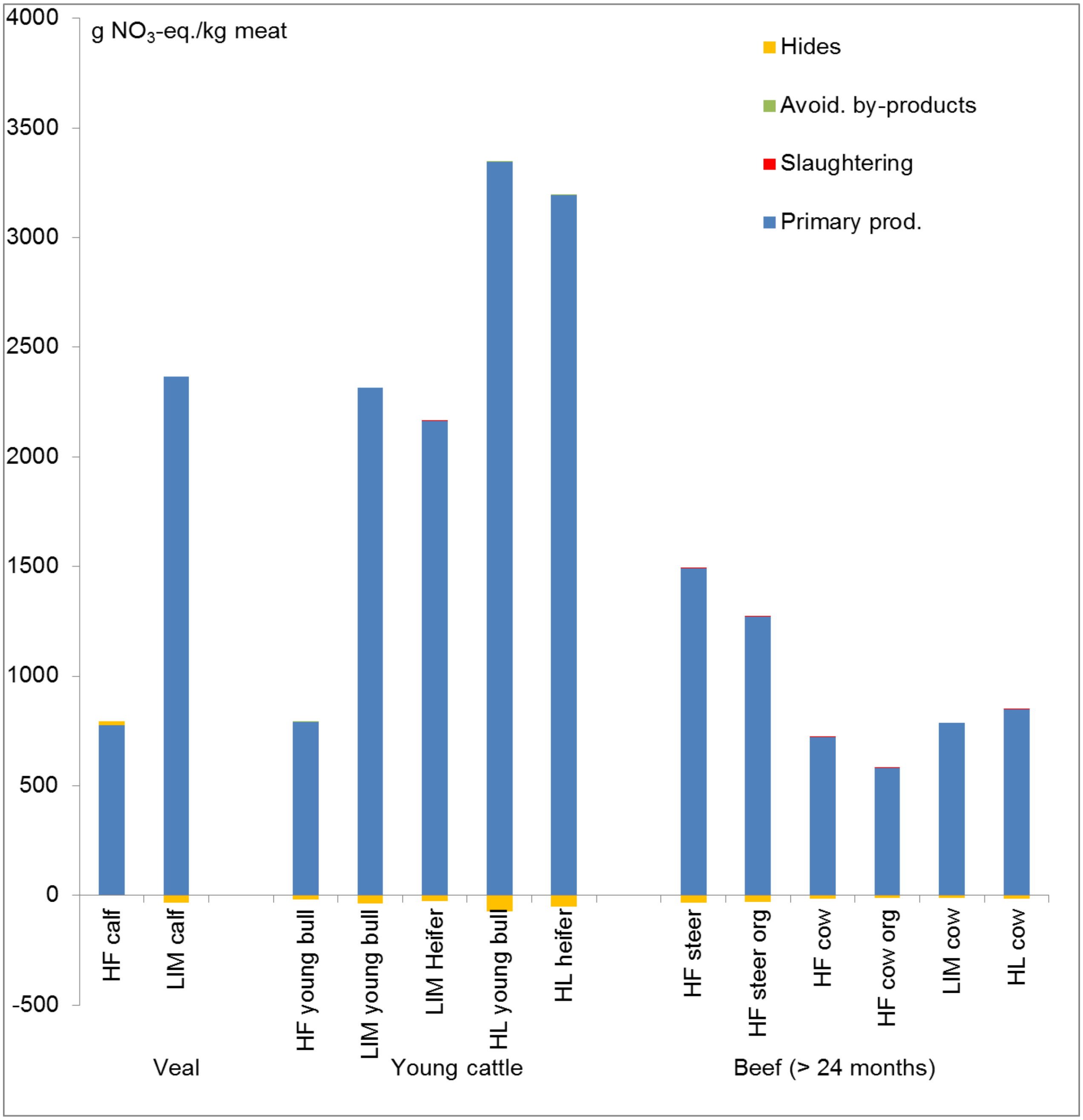

Figure 10. Eutrophication from beef, g NO_3-eq. per kg meat.

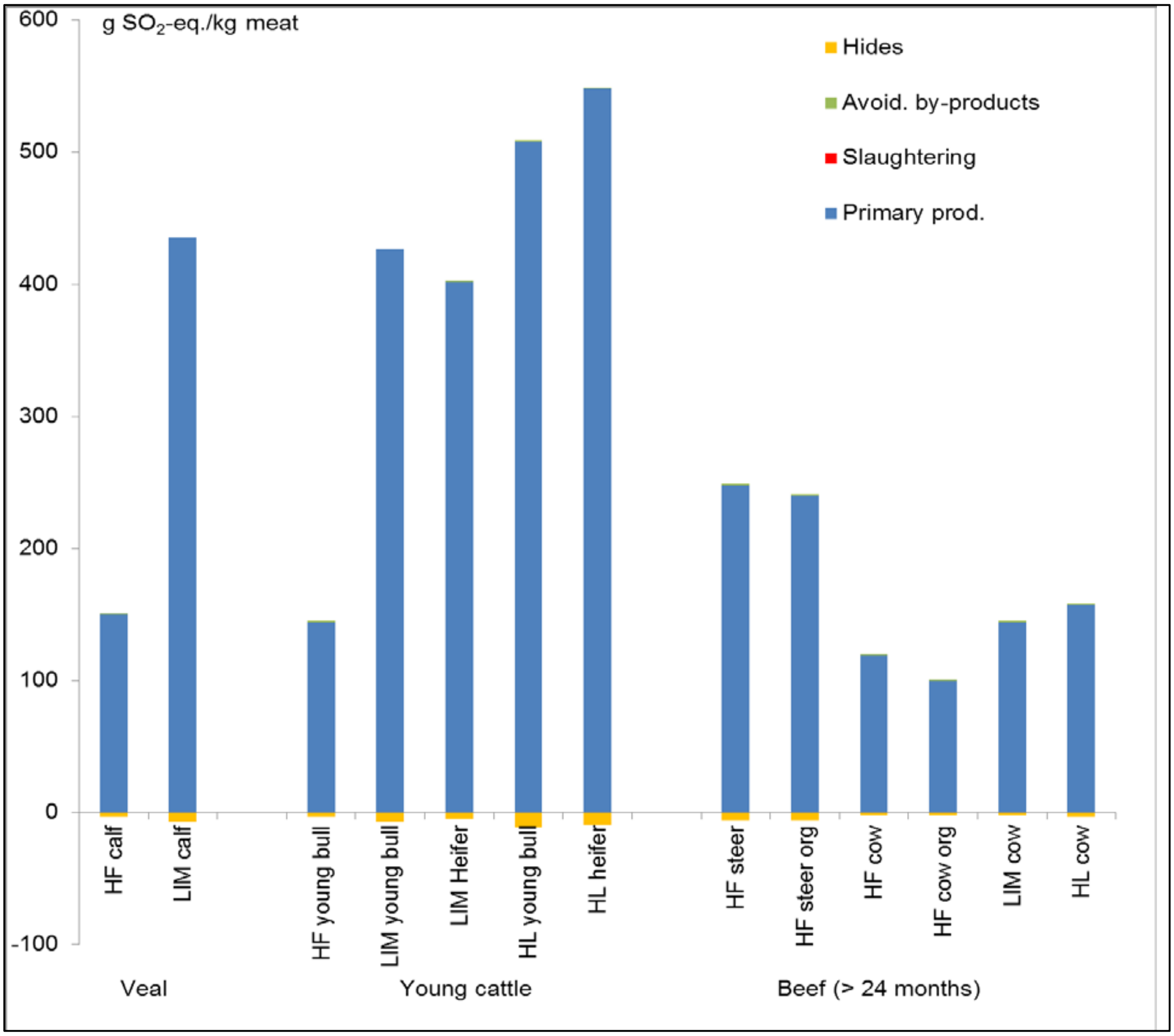

Figure 11. Acidification from beef, g SO_2-eq. per kg meat.

4. Discussion and conclusion

4.1. Slaughterhouse, utilization of carcass

Beef is one of the foods with the highest environmental impact per kg edible products. When an animal is ready for slaughtering, only around half (44.6-57.5%) of the amount of live weight will end up as edible products. If it is possible to increase the amount of the live weight (LW) that is utilized, it can have huge impact on the environmental impact measured per kg edible product.

In Table 15 the total output of edible products was presented for the 13 types of cattle slaughtered based on data from Danish slaughterhouses (Pontoppidan and Madsen, 2014). These numbers represent the 'actual utilization' of the slaughtered animal at real markets. Besides that, Pontoppidan and Madsen (2014) also give data for 'optimal utilization' of the slaughtered animal. That includes an estimate for which by-products that at the moment are used for something else, but has a potential for use for human consumption at a global marked in the future. To reach that optimal utilization, increased demand is needed for these products. Probably these by-products also need some treatment before sale. Such possible extra resources are ignored in the following since as already shown; the main impact comes from the primary production at the farm.

In order to illustrate that this increased utilization of the slaughtered animal is a potential mitigation option, GWP per kg edible product are presented in the two situations in Figure 12. For example for a Holstein veal calf, at present 49.5% of the 391 kg live weight of the animal is utilized as edible products. With optimal utilization it was estimated that 62.7% of LW could be utilized. If that is possible, GWP /kg meat could be reduced by 20 % from 10.4 to 8.3 kg CO_2/kg meat. Even if this production of more human products from the by-product cost double amount of resource input at slaughterhouse, it would only have minor effect on the GWP. Similar mitigation could be obtained for the other types of cattle resulting in a 17 to 23% lower GHG emission per kg meat (Figure 12).

Table 15. Output of 'edible products' per slaughtered animal with actual and optimized utilization.

Trade mark/sub-classes/production system	**Live weight, kg**	**Actual utilization, edible products, kg**	**Optimized utilization, edible products, kg**	**System Id[3)]**
Veal (8-12 months at slaughter)				
Danish calf[1)]	391	193	245	1
Calf, Limousine (free range)	491	283	339	10
Young cattle (12-24 months at slaughter)				
Young bull, dairy based[1)]	458	222	287	2
Young bull, Limousine	533	305	366	11
Heifer, Limousine	504	276	342	12
Young bull, Highland	432	210	272	7
Heifer, Highland	354	172	223	8
Beef (> 24 months at slaughter)				
Steers, dairy based[1)]	611	290	379	3
Steers, organic, dairy based[1)]	600	284	371	4
Dairy cow[1)]	653	294	381	5
Dairy cow, organic[1)]	655	292	379	6
Beef cow, Limousine	687	360	444	13
Beef cow, Highland	436	204	263	9

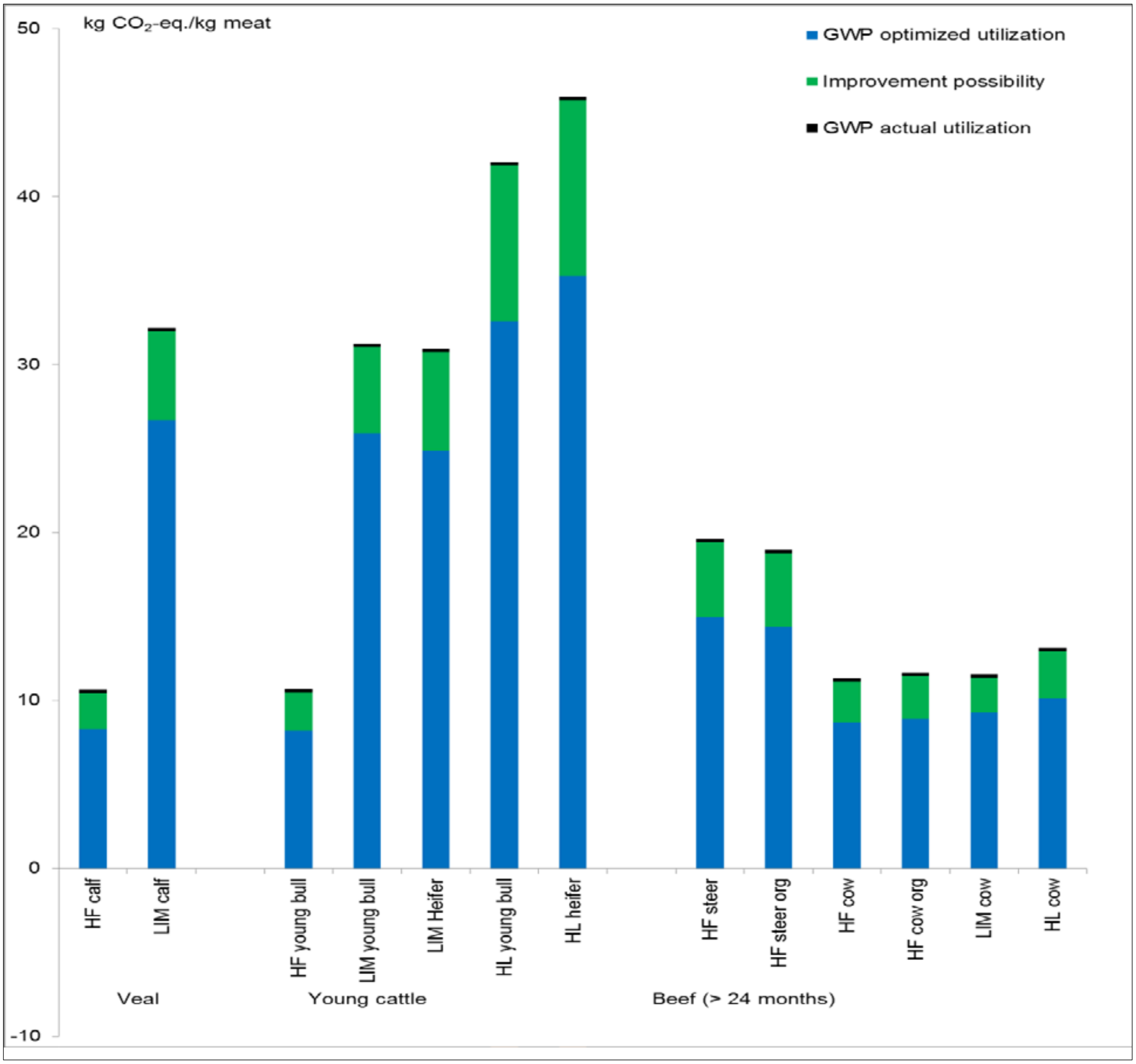

Figure 12. GWP per kg 'edible products' with actual and optimized utilization of the slaughtered animal (the difference 'in green' is the improvement option).
Actual utilization: blue + green, Optimized utilization: blue

4.2. Allocation between co-products

In a production like milk production or beef cattle production, which produces more than one product, it is necessary to distribute the total environmental impact from the production system between the various products. In this project we use a new method which is an adaptation of the allocation method suggested by IDF based on the mindset that a production system typically is established primarily to produce one main product, but that besides, there is a production of co-products. The resource consumption for the main product is compensated in the environmental assessment for the resource consumption for the by-products. This method is a development of ISO 14044 step 2, based on an underlying physical relationship, here feed consumption for the various products.

The logic is that the main product 'pay' all environmental costs, including maintenance requirements (and emissions related hereto) for the animals, with a correction for 'marginal cost' for production of co-products. For dairy, milk is the main product, while the co-products; (live weight from cull cows sent to slaughter and newborn calf) only pay the theoretical feed requirement need for their production corrected for a typical feed efficiency. For beef systems, the calf weaned at 6 months is the main product and must pay the full environmental bill, except the theoretical needs to cow's growth.

4.2.1. Allocation in the dairy system

In table 16 is illustrated how the choice of allocation method affect carbon footprint of the different products. Using an allocation based on protein output as suggested by FAO for sector analysis allocates 12% of the GHG emissions of the entire system to the meat originating from the culled cows, whereas the IDF method allocates almost 17% of the burden to cow's meat. Our proposed method allocates 14%. Even if it might be seen only a few percentage in difference the methods have huge impact when expressed per kg meat. Thus, the GWP of meat from the culled cows range between 10 and 13 kg CO_{2eq} dependent on allocation method.

Table 16. Effect of allocation method on carbon footprint of the different products.

Method	Allocation per product, %			Carbon footprint, kg CO_2		
	Cow (Meat)	Milk	New born calf	Cow, CF/kg edible products	Milk, CF/kg	1 Calf,
Protein in products[1)] (FAO)	12.2	85.7	2.1	9.6	0.90	190
Biological (IDF) [2)]	16.7	80.8	2.4	13.1	0.85	223
New method in the present study [3)]	14.4	83.8	1.8	11.3	0.88	165

1) Assumptions behind the allocation method based on protein in products (FAO):
   Protein in milk: 9300 kg with 3.38% protein = 314 kg (85.7%)
   Protein in the calf: 40 kg calf with 189 g protein / kg LW = 8 kg (2.1%)
   Protein in the culled cow: 274 kg LW sent for slaughter per year, 163 g protein / kg LW = 45 kg protein (12.2%).
   A total of 367 kg protein
2) Assumptions behind the allocation method based on IDF (2010): Allocation factor for milk = 1 – 5,771 *(kg LW gain/kg ECM)= 1 – 5,771 *((274 + 40)/9486)= 0,808
3) Calculations are given in section 3.1

4.2.2. Allocation in the beef breed systems

For the beef breed systems, we are not aware of well described methodology for allocation. We argued in this work, that the calf weaned at 6 months is the main product and must pay the full environmental bill, except the theoretical needs to cow's growth. By this method a beef breed cow arrives at almost the same GWP as dairy cow. Alternatively one could argue that all types of meat from a beef system should have the same GWP. The advantage of working only with an average value for the overall system is that it can be argued that meat products are actually equal in nutrition (interchangeable). The problem arises when production takes place in different production systems - such as calves exported to another country and fattened here. The above mentioned 'new' principle could be a viable option here.

4.2.3. Allocation at slaughterhouse between hides and beef products

In order to divide the overall environmental impact (from primary production and slaughterhouse) we have used system expansion to take into account the use of the by-products from the slaughtering process. The remaining environmental impact was allocated between the amount of hides and the amount of beef products for human consumption in relation to their share of total value on market based on a fixed ratio from literature. The price index used was the default values suggested by the Pet Food Pilot (1:7 for hides : food products)(JRC, 2014), as no Danish data was available from the slaughterhouse. This resulted in that a relative low share (1.2-2.3%) of the final emissions in the present study was allocated to hides. Other studies (Mila-i-Canals et al., 2002; Desjardins et al., 2012) have reported up to 7% of emissions allocated to hides also based on economic allocation. Which is similar to the higher allocation factor, which would be used if a mass balance allocation method was used.

4.3. Conclusion

In conclusion, the major environmental burden is related to the farm level stage and innovations to reduce impact should be given high attention. The slaughtering process itself is very energy- and resource efficient. The main innovation to reduce environmental impact of the meat produced will be to ensure a higher utilization of the animal into new edible products not conventionally produced. Also, for beef products there is a significant tradeoff between impact on GWP and impact on biodiversity. The importance of this needs more attention.

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Appendix 1. Emissions coefficients

Table 1.1a. Factors for estimation of emissions from beef and crop production and inventory from some input factors.

	Pullutant	Amount	Emission Factor (EF)	Reference EF
N_2O-N_{direct}, kg	Stable			1)
	- Slurry below flatted flor	Kg N in manure ex animal	0.002	
	- Deep litter, no mixing		0.01	
	Storage			
	- Slurry in tank with cover	Kg N in manure ex stable	0.005	
	- Deep litter (solid storage)		0.005	
	Application			1)
	- Slurry	Kg N in manure ex storage	0.01	
	- Deep litter		0.01	
	- At pasture during grazing		0.02	
	- Fertilizer		0.01	
	Crop residues	kg N in CR pr. ha pr. year [11)]	0.01	
NH_3-N, kg	Stable			2)
	- Slurry	Kg N in manure ex animal	0.08	
	- Deep litter		0.06	
	Storage			
	- Slurry [13)]	Kg N in manure ex stable	0.022	
	- Deep litter		0.25	
	Application			
	- Slurry [12)]	Kg N in manure ex storage	0.12	
	- Deep litter		0.06	
	- At pasture during grazing		0.07	
	- Fertilizer		0.022	
N_2-N, kg (sandy soil)	Stable			14)
	- Slurry below flatted floor			
	- Deep litter, no mixing	kg N in manure ex animal	0.006	
	Storage		0.03	
	- Slurry in tank with cover			
	- Deep litter (solid storage)	kg N in manure ex stable	0.015	
	Application		0.015	
	- Slurry			
	- Deep litter	kg N in manure ex storage	0.03	
	- At pasture during grazing		0.03	
	Fertilizer		0.06	
			0.03	
	Crop residues	kg N in CR pr. ha pr. year[11)]	0.03	
NO-N, kg	Stable			15)
	- Slurry below flatted floor	kg N in manure ex animal	0.002	
	- Deep litter, no mixing		0.01	
	Storage			15)
	- Slurry in tank with cover	kg N in manure ex stable	0.005	
	- Deep litter (solid storage)		0.005	
	Application			16)
	- Slurry	kg N in manure ex storage	0.001	
	- Deep litter		0.001	
	- At pasture during grazing		0.002	
	Fertilizer		0.007	17)
	Crop residues	kg N in CR pr. ha pr. year[1)]	0.001	15)

Table 1.1b. Factors for estimation of emissions from beef and crop production and inventory from some input factors.

	Pullutant	**Amount**	**Emission Factor (EF)**	**Reference EF**
N_2O, Indirect kg	From NH_3	NH_3-N	0.01	1)
	From leaching	$N0_3$-N 8)	0.0075	1)
	NO_3-N leaching			
	Crop system	N surplus - N losses - N build-up in soils		
	Beef system	N surplus – N losses – N build-up in soils - fertilizer N substitution		
	PO_4-P			
	Crop system	P surplus – P absorbed in soil particles		
	Beef system	P surplus – fertilizer P substitution		
CH_4 enteric	*Se text*			4)
CH_4 manure	Kg CH_4= (Feed organic matter + bedding organic matter) * 0,67 * B_o * MCF 10)			2) + 1)
	MCF:			
	- Slurry		0.1	
	- Deep litter		0.1	
	- Pasture		0.01	
			GWP, kg CO_2-e	
Carbon Footprint of Input	N in fertilizer (per kg N)		4.37	5)
	P in fertilizer (per kg P)		2,69	7)
	K in fertilizer (per kg K)		0.804	7)
	Diesel (per l)		3.309	7)
	Electricity (DK from gas, per kWh)		0.655	7)

1) IPCC, 2006
2) Mikkelsen et al., 2006; Mikkelsen et al., 2005
3) Gyldenkærne & Albrektsen, 2008
4) Nielsen et al., 2013
5) Elsgaard, 2010
6) EcoInvent, 2010
7) Nielsen et al., 2003
8) Leaching: as the difference = N surplus – other losses
9) DMI = Dry matter intake, FA = fatty acids
10) Bo = 0.24 [1)], MCF = 1% though 10 % for slurry [2)]
11) Amount of N in crop residues was based on amount of CR and protein content given by Djurhus & Hansen (2003)
12) Factor for slurry application is a an average of different methods (EF=0,02 if injection, EF up to 0,255 with drag horses depended on time of the year). For deep litter application in late summer-autumn was assumed.
13) EF for slurry is a Danish typical average for storage with cover (EF=0,02) and with no cover (EF=0,06). In EF for deep litter it was taken into account that only 35% of the deep litter is stored in manure heap in field and the remaining 65% is applied directly to field
14) Vinther, F.P., 2005.
15) Dämmgen, U., Hutchings, N.J., 2008.
16) Nemecek, T., Kägi, T., 2007.
17) EEA, 2007.

Table 1.2. Impact categories - AP, EP, and NRE - common stressors and equivalency factors (EPD, 2013; EPD, 2008).

Impact categories	Common stressors	Equivalency factor	Processes dominantly contributing to the impact category
Acidification potential (AP), g or kg SO_2 eq	SO_2 NO NO_2 NH_3	1 1.07 0.7 1.88	- fertilizer production; coal-based electricity use; transport - fertilizer production; electricity use; transportation - fertilizer production; electricity use; transportation - manure deposit and application; fertilizer application
Eutrophication potential (EP), g or kg PO_4 eq	NO_3 NO NO_2 NH_3 PO_4	0.1 0.2 0.13 0.35 1	- leaching from fertilizer application and manure discharge, run-off or application - fertilizer production; electricity use; transportation - fertilizer production; electricity use; transportation - manure deposit and application; fertilizer application - leaching from fertilizer and manure discharge, run-off or application
Non-renewable energy use, MJ	Coal Oil Natural gas	8-29.3 MJ/kg 41-45.8 MJ/kg 30.3-49.8 MJ/m^3	- fertilizer production; farming operation; feed crop processing; manure management; slaughtering; transportation

Tabel 1.3. Environmental footprint of major inputs to feed crop/beef production systems.

	unit	AP g SO_2 eq	EP g PO_4 eq	NRE MJ eq	Data sources, adapted or taken directly from
Fertilizer N (CAN)	kg N	37.3	19.5	43.8	Modified from Blonk Agri-footprint BV (2014a,b)
Fertilizer P (TSP)	kg P_2O_5	21.9	12.1	24	Ecoinvent (2013)
Fertilizer K (KCl)	kg K_2O	3.3	1.0	6.6	Ecoinvent (2013)
Traction	MJ	0.5	0.09	1.1	Blonk Agri-footprint BV (2014a,b)
Electricity (NG)	kWh	0.4	0.09	9.8	Ecoinvent (2013)
Heat (light fuel oil)	MJ	0.18	0.02	1.4	Ecoinvent (2013)
Truck 7.5-16 t	tkm	1.05	0.2	3.6	Ecoinvent (2013)
Transoceanic ship	tkm	0.24	0.023	0.17	Ecoinvent (2013)

Appendix 2. Production of feed and environmental impact of feed

Tabel 2.1. Annually resource use, output and carbon sequestration from growing 1 ha conventionally.

Feed	Barley Straw harvested	Rape	Grass clover Silage	Grass clover grazed	Perma-nent grazed	Nature grazed	Maize silage	Maize Cob	Barley silage	Soy bean
Input										
Mineral fertilizer, kg N/ha [1)]	114	181	221	65	0	0	151	151	116	0
Mineral fertilizer, kg P/ha	23	32	36	36	9	2	45	45	30	13
Mineral fertilizer, kg K/ha	49	82	211	211	32	8	139	139	158	25
Manure from grazing, kg total N [2)]	-	-	-	223	54	14	-	-	-	0
Seed, kg	150	4	13	13	0	0	5	5	150	106
Lubricant oil, l	11	13	11	1	1	1	18	18	15	
Electricity for irrigation, kWh	75	90	150	160	0	0	70	70	100	
Energy for drying, electricity, kWh	92	65	-	-	-	-	-	-	-	
Energy for drying, oil, l	7.1	5.1								
Diesel for field work, l	83	97	79	7	3	0	130	130	107	26?
Output										
Net crop yield, kg DM/ha [3)]	4110	3170	8272	7070	2320	580	11150	8127	7424	2300
SFU/ha net (kg)	(4840)	(3430)	7586	6864	2000	500	10230	8695	5800	
Kg DM/SFU			1.09	1.03	1.16	1.16	1.09	0.93	1.28	
Protein in DM, %	10.8	19.4	17.9	24.0	20.0	20.0	7.9	8.5	10.0	41.1
Total losses, % of DM [12)]	1	1	20	40	40	70	13	3	13	1
- from this losses left in fields,% point	1	1	14	40	40	70	7	3	7	1
Total yield, kg DM/ha [4)]	4152	3202	10340	11783	3867	1933	12816	8378	8533	2323
Total straw yield, kg DM/ha [5)]	2267	2624	-	-	-	-	-	4438	-	
C sequestration										
Crop residues, kg DM										
Total above ground (AG)	1432	3406	4118	4713	1547	1353	1767	5608	1467	4370
- Losses left in field	42	32	1448	4713	1547	1353	897	300	597	23
- Straw left in field [6)]	0	2624		0	0	0	0	4438	0	3715
- Stubble and chaff	1390	750	1670	0	0	0	870	870	870	632
- Leaves senescence			1000	0	0	0	0	0	0	0
Below ground (BG) [11)]	1650	4030	3180	3180	3094	3014	1650	1650	1650	830
C input to soil, kg C										
- From AB and BG residues [7)]	1387	3347	3284	3552	2088	2001	1538	3266	1403	2340
- From manure	0	0	0	2329	564	146	0	0	0	0
C that remain in soil 100 year, kg C [8)]	139	335	328	588	265	215	154	327	140	234
- Land use factor (IPCC,2006) [12)]	0.8	0.8	0.93	0.93	1.0	1.0	0.8	0.8	0.8	0.64

										Tropical
- Tillage factor (IPCC, 2006)[12)]	1.0	1.0	1.10	1.10	1.10	1.10	1.0	1.0	1.0	1.0
Kg C scaled to 'barley' as 0-level (-240) [9)]	-129	28	96	362	52	0	-117	22	-128	-90
Carbon sequestration										
Kg CO_2/ha/year [10)]	473	-102	-350	-1326	-189	0	428	-79	469	331

1) N norm for crops (Anonymous, 2013)
2) N : P : K in manure 7,5 : 1,3 : 4,5 (Anonymous, 2013 Pl Dir). N input from N deposited at pasture is calculated as the input of fertilizer with an amount of N corresponding to that of plant available N deposit
3) Net yield is amount fed to cattle
4) Energy yield (SFU) in maize cob for silage is 85% of that of whole maize crop for silage (Mikkelsen et al., 2008). Same total DM yield is assumed for maize for whole crop or cob silage (cob + straw)
5) Total yield before losses
6) Straw from rape, soybean and maize cob is assumed left in field
7) 45% of DM is C
8) 10% in a 100 year perspective (Petersen et al., 2013),
9) The results are giving as the difference to that of 'barley with no straw removed and no manure input' corresponding to 240 kg C/ha/year (Mogensen et al., 2014).
10) From C to CO_2 by multiplication with 44:12
11) BG residues based on Djurhus & Hansen (2003).
12) Land use factor: Permanent grassland (and nature) is assigned a land-use factor of 1,0 (IPCC, 2006, Table 6.2) and of 0,87 for cropland managed predominantly as annual crops (Table 5.5) – for grass-clover in rotation was assumed a land use factor of 0,93 like for 'set aside annually cropland'. Regarding tillage factor: full tillage with frequent tillage operation within year the factor is 1,0 (IPCC Table 5.5) and 1,10 for grass-clover in rotation which is under sown in the crop before.
13) Total DM losses. Grass clover silage 20%, herof 14% in field, 40% for grass grazed in rotation and permanent, 70% was assumed for nature grass as these fields contain more crops that are not utilized for grazing (based on Parson & Penning, 1988 and Kristensen, I.S. 1993).

Tabel 2.2. Annually resource use, output and carbon sequestration from growing 1 ha organically.

Feed	**Barley**[3)] Straw harvested	**Rape**[4)]	**Grass clover Silage**	**Grass clover grazed**	**Maize silage**	**Barley silage**	**Soy bean** [6)]
Input							
Mineral fertilizer, kg N/ha [1)]	81	81	81	0	81	81	0
Mineral fertilizer, kg P/ha	20	20	20	44	20	20	13
Mineral fertilizer, kg K/ha	70	70	70	151	70	70	25
Manure from grazing, kg N [2)]	-	-	-	176	-	-	0
Seed, kg (same as conventional)	150	4	13	13	5	150	106
Lubricant oil, l (same as conventional) Electricity for irrigation, kWh	11 75	13 90	11 150	1 160	18 70	15 100	
Energy for drying, electricity, kWh Energy for drying, oil, l (from conventional adjusted for yield difference)	78 6.0	55 4.3	-	-	-	-	
Diesel for field work, l (same as conventional)	83	97	79	7	130	107	26
Output							
Net crop yield, kg DM/ha [7)]	3476	1697	6524	5577	7085	5248	2300
SFU/ha net (kg) Kg ts/FE	(4100)	(1836)[2]	5985 1.09	5415 1.03	6500 1.09	4100 1.28	(2544)
Protein in DM, %	10.8	19.4	17.9	24.0	7.9	10.0	41.1
Total losses, % of DM	1	1	20	40	13	13	1
- from this losses left in fields,% point	1	1	14	40	7	7	1
Total yield, kg DM/ha	3511	1714	8155	9296	8144	6032	2323
Total straw yield, kg DM/ha [5)]	1912	1409	-	-	-	-	3715
C sequestration							
Crop residues, kg DM							
Total above ground (AG)	1425	2176	3811	3719	1440	1292	4370
- Losses left in field	35	17	1141	3719	570	422	23
- Straw left in field	0	1409		0	0	0	3715
- Stubble and chaff(same as conventional)	1390	750	1670	0	870	870	632
- Leaves senescence(same as conventional)			1000	0	0	0	0
Below ground (BG) (same as conventional) [12)]	1650	4030	3180	3180	1650	1650	830
C input to soil, kg C							
- From AB and BG residues [8)]	1384	2793	3146	3104	1391	1324	2340
- From manure	0	0	0	2329	0	0	0
C that remain in soil 100 year, kg C [9)]	138	279	315	543	139	132	234
- Land use factor (IPCC,2006) [13)]	0.8	0.8	0.93	0.93	0.8	0.8	0.64 Tropical
- Tillage factor (IPCC, 2006)[13)]	1	1	1.1	1.1	1.0	1.0	1.0
Kg C scaled to 'barley' as 0-level (-240) [10)]	-130	-17	82	316	-129	-134	-90
Carbon sequestration							
Kg CO_2/ha/year [11)]	475	62	-300	-1158	472	493	331

1) 81 kg plant available N = 116 kg total N in manure. N : P : K in manure 7,5 : 1,3 : 4,5 (Anonymous, 2013 Pl Dir):
2) Same as conventional – adjusted for crop yield difference

3) Economic allocation 95% to cereals and 5% to straw:
4) Economic allocation: 24% to rape seed cake, which is 62% of crop yield (1050 kg DM):
5) Soybean: IPCC, 2006 Table 11.2 AG residue:grain ratio 1.9 – 85% of that is assumed to be straw (Dalgaard, pers com):
6) Economic allocation: 66,3% to soy bean meal, which is 82,6% of crop yield (1965 kg DM).
7) Net yield is amount fed to cattle
8) 45% of DM is C
9) 10% in a 100 year perspective (Petersen et al., 2013),
10) The results are giving as the difference to that of 'barley with no straw removed and no manure input' corresponding to 240 kg C/ha/year (Mogensen et al., 2014).
11) From C to CO_2 by multiplication with 44:12
12) BG residues based on Djurhus & Hansen (2003).
13) Land use factor: Permanent grassland (and nature) is assigned a land-use factor of 1,0 (IPCC, 2006, Table 6.2) and of 0,87 for cropland managed predominantly as annual crops (Table 5.5) – for grass-clover in rotation was assumed a land use factor of 0,93 like for 'set aside annually cropland'. Regarding tillage factor: full tillage with frequent tillage operation within year the factor is 1,0 (IPCC Table 5.5) and 1,10 for grass-clover in rotation which is under sown in the crop before.

Table 2.3. Environmental impact of conventionally grown feed ready to feed.

Feed	**Barley[1)]**	**Barley straw[1)]**	**Rape seed cake[2)]**	**Grass clover silage**	**Grass clover grazed**	**Perma-nent grazed**	**Nature grazed**	**Maize silage**	**Maize cob**	**Barley silage**	**Soy bean meal**
Contribution to GWP g CO_2/kg DM											
Growing	467	45	365	403	433	211	281	216	320	281	184
Processing	11	1	28	0	0	0	0	0	0	0	34
Transport[3)]	18	18	75	0	0	0	0	0	0	0	359
Total CF	496	64	468	403	433	211	281	216	320	281	577
C sequestration[4)]	109	10	-12	-42	-188	-81	0	38	-10	63	116
LUC [5)]	328	33	182	173	202	0	0	128	176	193	250
CF + C seq	605	74	456	361	245	130	281	254	310	344	693
CF + C seq + LUC	933	107	638	534	447	130	281	382	486	537	943
Land use, m^2 per kg DM	2.31	0.24	1.28	1.21	1.41	4.31	17.24	0.90	1.23	1.35	1.75
Acidification, g SO2-eq.[6)]	4.7	0.4	3.5	3.42	3.8	2.5	3.96	2.3	3.1	2.9	3.1
Eutrophication, g NO3-eq.[6)]	69	6	56	61	30	8	0	19	17	21	8
Energy, MJ [6)]	3.9	0.3	3.5	2.3	2.2	1.1	1.16	1.55	2.1	2.0	1.31

1) GWP for 'barley with 100% straw removed' economic allocation with 95% to barley and 5% to straw
2) GWP for 'rape seed', economic allocation with 24% to rape seed cake. Transport of rape seed to feed factory allocated too. 62% of yield (1965 kg DM)
3) Barley and rape are assumed grown in Denmark at crop farms. Barley is transported 25 km (16 t lorry) from 'growing farm' to feed factory and 25 km (28 t lorry) to farm where fed. Rape seed are transported 328 km from 'growing farm' to feed factory (28 t lorry) and rape seed cake 168 km from feed factory to 'farm where fed' (28 t lorry).
4) From table 2.1. and 2.2.
5) 143 g CO_2/m^2 (Audsley et al., 2009) only arable crops
6) Calculated by use of SimaPro. For nature grass, EP was assumed to be 0.

Table 2.4. Environmental impact of organically grown feed ready to feed.

Feed	**Barley**[1)]	**Barley straw**[1)]	**Rape seed cake**[2)]	**Grass clover silage**	**Grass clover grazed**	**Maize silage**	**Barley silage**	**Soy bean**[6)]	**Soy bean meal**
Contribution to GWP, g CO_2/kg DM									
Growing	444	42	410	252	473	221	301	184	148
Processing	11	1	28	0	0	0	0	0	34
Transport [3)]	18	18	75	0	0	0	0	359	359
Total CF	473	61	513	252	473	221	301	543	541
C sequestration [4)]	130	12	9	-46	-208	67	94	144	116
LUC [5)]	391	37	326	219	256	201	272	311	250
CF + C seq	603	73	522	206	265	288	395	687	657
CF + C seq + LUC	994	110	724	425	521	489	667	998	907
Land use, m^2 per kg DM	2.73	0.26	2.28	1.53	1.79	1.41	1.91	2.17	1.75
Acidification, g SO_2-eq.[7)]	4.6	0.4	3.9	1.9	4.0	2.4	3.2	3.0	6.93
Eutrophication, g NO_3-eq. [7)]	55	5	50	11	55	15	28	8	13
Energy, MJ[7)]	3.97	0.3	4.0	1.65	2.4	1.74	2.3	1.12	8.86

1) GWP for ‘barley with 100% straw removed’ economic allocation with 95% to barley and 5% to straw
2) GWP for ‘rape seed’, economic allocation with 24% to rape seed cake. Transport of rape seed to feed factory allocated too
3) Barley and rape are assumed grown in Denmark at crop farms. Barley is transported 25 km (16 t lorry) from ‘growing farm’ to feed factory and 25 km (28 t lorry) to farm where fed. Rape seed are transported 328 km from ‘growing farm’ to feed factory (28 t lorry) and rape seed cake 168 km from feed factory to ‘farm where fed’ (28 t lorry).
4) From table 2.2
5) 143 g CO_2/m^2 (Audsley et al., 2009) only arable crops
6) 2 crops per year
7) Calculated by use of SimaPro

Table 2.5. Carbon footprint and composition of four types of concentrate mixtures.

Feed, % of kg	**Small calves [1)]**		**Young bulls [2)]**	**Dairy conv.**
	Conv.	**Org.**	**Conv.**	**Conv.**
Kg DM/kg	*0.82*		*0.84*	
Crude prot, g/kg DM	*207*	*207*	*173*	*218*
FE/kg - intern	0.93	0.93	0.96	0.99
Kg TS,%	86	86	86.7	87.2
Rapseseed cake	0	0	9	17.5
Cereals (value for barley	54	54	62.9	39.0
Soybean meal	21	21	9	14.0
sojaskaller	0	0	0	7.6
Beet pulp dried (roepiller)	7	7	10.5	15.8
Grass pellet	5	5	3	2.0
Molasses	8	8	1.5	1.8
Fat	0.5	0.5	1.4	1.2
Minerals	4.5	4.5	2.7	1.1
Carbon footprint, g CO_2/kg				
Growing	287	277	330	277
Processing	87	87	78	87
Transport	107	107	73	123
Total	**481**	**471**	**481**	**487**
Soil C	70	79	66	52
LUC,	215	243	229	186
Land use, m^2	1.5	1.7	1.6	1.3
LUC pas2050 [3)]	410	0	176	273

1) Typical concentrate mixture for small calves (Dlg, 2012)
2) Vestergaard et al., 2009.
3) LUC for Soy bean meal from Argentina: 0,93 kg CO_2/kg, from Brazil: 7,69 kg CO_2/kg. In Denmark: 72,5% from Argentina and 16,6% from Brazil, eg LUC = 1,95 kg CO_2/kg soybean meal

Appendix 3. Carbon footprint of new born dairy calves for the fattening systems

In the 4 males systems (system ID 1-4) there is an input of a calf from a dairy farm.
GHG contribution from the cow's production of the fetus is determined by allocating the total climate contribution from the dairy system (system 5 and 6) between calf, beef cull cows and milk. Carbon footprint from the 40 kg calf is shown in Table 3.1.

Tabel 3.1. Carbon footprint from a newborn 40 kg dairy calf.

	Production of 1 calf, 40 kg	
	Conventional	Organic
Carbon footprint, kg CO_2	165	169
LUC_{area}	28	41
Soil C	-8	-10
Land use		
Total, m^2	194	289
Grass in rotation, m^2	66	152

Appendix 4. Beef production systems – primary production

Further description of the 13 beef production systems regarding primary production is given in Table 4.1-4.6.

Table 4.1. Input and output in bull-fattening system 1-4 based on dairy calves, all numbers given per produced animal.

System nr.	**1**	**2**	**3**	**4**
Animal group	**Bull calf**	**Young Bull**	**Steer Conv.**	**Steer Org.**
Slaughter age, months	**8.9**	**13.5**	**26.3**	**26.5**
Days in the fattening system	271	411	799	806
Feed Intake, SFU				
Maize silage	0	0	0	0
Grass clover silage	10	10	1688	1655
Straw	31	38	55	53
Barley	0	0	435	427
Rape seed cake/expo	0	0	110	107
Grazing, rotation	0	0	1526	1495
Grazing, semi-natural pasture	0	0	0	
Milk powder	35	35	34	34
Concentrate mixture for small calves	109	109	9	9
Concentrate mixture for young bulls	1305	1751	0	
Fresh milk	36	36	36	36
Total SFU	**1526**	**1979**	**3893**	**3816**

Table 4.2. Productivity in system 1-4.

System	**1 Bull calf**	**2 Young Bull**	**3 Steer Conv.**	**4 Steer Org.**
Slaughter age, months	8.9	13.53	26.3	26.5
Days in the fattening system (only days > 30 d)	241	381	769	776
Live weight gain in fattening system				
Kg/animal	336	403	556	545
g/day	1394	1058	723	702
At pasture				
Number of days	0	0	339	336
Gain, g/day			730	715
Total gain, kg			247	240
At stable				
Number of days	241	381	373	375
Gain, g/day	1394	1058	640	625
Total gain, kg	336	403	239	234
Fattening before slaughter				
Number of days	0	0	63	65
Gain, g/day			1100	1086
Total gain, kg			69	71
Feed use in the system (> 30 days old)				
SFU/kg gain	4.41	4.80	6.92	6.92
DM, kg/kg LW gain	4.32	4.68	7.47	7.47
DM, kg/kg carcass weight	7.22	7.97	13.45	13.44
Roughage, % of DM	10	9	88	88
N input feed, kg	36	47	129	125
Crude protein, g/SFU	152	152	207	207

Table 4.3. Feed ration per animal per year for cows and replacement heifers in system 5 and 6, beef from culled dairy cows.

Systems	**5. Conv. dairy cow**		**6. Org. dairy cow**	
Animal group	**Cow**	**Heifer for replacement**	**Cow**	**Heifer for replacement**
Feed Intake, DM kg/animal/year (SFU)				
Barley	820 (910)	117 (130)	1611 (1788)	32 (35)
Rape seed cake	969 (1147)	84 (100)	0	0
Soybean meal	352 (491)	0	302 (422)	0
Conc, small calves	0	50 (54)	0	35 (38)
Concentrate mixture	494 (561)	0	0	0
Fresh Milk	0	23 (40)	0	36 (63)
Grazing, rotation	0	567 (550)	932 (905)	889 (863)
Grass silage	2072 (1901)	489 (449)	2685 (2463)	775 (711)
Maize silage	2123 (1948)	588 (539)	941 (863)	0
Whole crop silage	0	0	0	208 (152)
Straw	0	0	188 (43)	0
Total kg DM	**6830**	**1918**	**6659**	**1939**
Total SFU/animal/year	**6958**	**1862**	**6484**	**1862**
SFU/1 produced heifer	**-**	**4034**	**-**	**4034**
Minerals, kg/year	36	24	36	24
Straw bedding, kg	10	220	10	220
Deep litter : slurry (% of N)	**0:100**	**25:75**	**0:100**	**25:75**

Table 4.4. Productivity of the two dairy cow systems (system 5 and 6).

Systems	**5. Conv. dairy cow**		**6. Org. dairy cow**	
Animal group	**Cow**	**Heifer for replacement**	**Cow**	**Heifer for replacement**
Animal/year	1	1	1	1
Live weight gain per year				
Kg/animal/year	15	268	15	268
g/animal/day	41	735	41	735
At pasture				
Days/year	0	150	150	150
Gain, g/day		735	41	735
Total gain, kg		110	6	110
At stable				
Days/year	365	215	215	215
Gain, g/day	41	735	41	735
Total gain, kg	15	158	9	158
Feed use				
SFU/kg gain		6.95		6.95
DM, kg/kg LW gain		7.01		7.24
N input feed, kg Crude protein, g/SFU	202 181	53 176	180 173	62 207

Table 4.5. Annual input and output of beef breed systems, Highland cattle (system 7-9) and Limousine (system 10-13).

	Highland Cattle *(system 7, 8, 9)*						**Limousine** *(system 10, 11, 12, 13)*						
System **Animal group**	**9** **Cow**	**(9)** **Heifer replace-ment**	**(9)** **Heifer**	**(9)** **Bull**	**8** **Heifer Slaughter**	**7** **Bull**	**13** **Cow**	**(13)** **Heifer replace-ment**	**(13)** **Heifer**	**(13)** **Bull**	**12** **Heifer Slaughter**	**11** **Bull**	**10** **Bull**
Age, months	36-65	6-36	0-6	0-6	6-24	6-18	36-68	6-30	0-6	0-6	6-20	6-14.4	6-10.5
Input per year		0.2	0.45	0.45	0.25	0.45		0.25	0.5	0.5	0.25	0.5	0.5
Months in the system		30 m	6 m	6 m	18 m	12 m		24 m	6 m	6 m	14 m	8.4 m	4.5 m
'Animal year' 1)	1	0.5	0.225	0.225	0.375	0.45	1	0.50	0.25	0.25	0.292	0.35	0.188
Feed intake/animal/ Year ,SFU (kg DM) 1)													
Grass clover silage	968 (1055)	466 (508)			567 (618)	642 (700)	1200 (1308)	738 (804)			917 (1000)	934 (1018)	1360 (1481)
Straw	97 (424)	66 (289)			72 (315)	92 (403)	100 (438)	19 (83)			30 (131)	0	0
Barley	0	8 (7)		224 (202)	43 (39)	239 (215)	250 (225)	178 (160)	0	240 (215)	276 (248)	1274 (1131)	1969 (1772)
Rape seed cake	0	0			0	92 (77)	50 (42)	50 (42)			69 (58)	297 (249)	476 (400)
Grazing, rotation	0	0			0	0	400 (412)	263 (271)	120 (124)	176 (181)	300 (309)		
Grazing, permanent	774 (898)	160 (186)	240 (278)	400 (464)	173 (201)	1176 (1364)	1000 (1160)	525 (609)	400 (464)	526 (610)	626 (726)	0	0
Grazing, nature	436 (505)	520 (603)	160 (186)		525 (609)	0	0	0			0	0	0
Total kg DM 3)	2888	1593	669	870	1782	2760	3585	1969	895	1351	2472	2417	3658
Total SFU3)	2275	1220	760	984	1380	2241	3000	1773	1060	1522	2218	2505	3805
SFU/produced animal	-	3050	380	492	2070	2241	-	3543	530	760	2587	1754	1427
Cow milk, SFU (kg/year)	0	0	360 (1516)	360 (1516)	0	0	0	0	540 (2273)	540 (2273)	0	0	0
Minerals, kg/year	36	12	6	6	12	12	36	18	6	6	18	18	18
Straw, kg 2)	961	523	0	0	632	857	1308	708	0	0	934	1427	1571
Energy for manure handling	0	0	0	0	0	0	0	0	0	0	0	0	0
Output													
No slaughtered/year	0.2	0	0	0	0.25	0.45	0.25	0	0	0	0.25	0.5	0.5
Live weight, kg per animal	436	448	129	158	354	432	687	600	177	260	504	533	491
Carcass, %	48.04	50.52	50.52	51.9	50.52	51.9	55.03	57.86	57.86	59.72	57.86	59.72	60.73
Carcass, kg/year	41.9	0	-	-	11.7	100.9	94.5	0			72.9	159.2	149.1
Deep litter:slurry (% of N)	100:0	100:0	At pasture	At pasture	100:0	100:0	100:0	100:0	At pasture	At pasture	100:0	100:0	100:0

1) One animal in one year is 365 feeding days
2) Amount of straw for deep litter; 0,65 kg straw per kg DM feed at stable based on Danish data for cows (Håndbog for Kvæg, 2013)
3) Including fresh milk

Table 4.6. Productivity of of beef breed systems, Highland cattle (system 7-9) and Limousine (system 10-13).

	Highland cattle *(system 7, 8, 9)*						**Limousine** *(system 10, 11, 12, 13)*						
System ID **Animal group**	**9** **Cow**	**(9)** **Heifer** replace	**(9)** **Heifer**	**(9)** **Bull**	**8** **Heifer** **Slaughter**	**7** **Bull**	**13** **Cow**	**(13)** **Heifer** replace	**(13)** **Heifer**	**(13)** **Bull**	**12** **Heifer** Slaughter	**11** **Bull**	**10** **Bull**
Age, months	**36-65**	**6-36**	**0-6**	**0-6**	**6-24**	**6-18**	**36-68**	**6-30**	**0-6**	**0-6**	**6-20**	**6-14.4**	6-10.5
Animal/year	1	0.5	0.225	0.225	0.375	0.45	1	0.50	0.25	0.25	0.292	0.35	0.188
Live weight gain													
Kg/animal/year	0	128	200	256	150	274	23	212	274	440	280	390	616
g/animal/day	0	350	550	700	411	751	62	580	751	1200	768	1071	1701
At pasture													
N days/year	180	143	365	365	119	180	150	154	300	300	150	0	0
Gain, g/day	0	450	550	700	450	800	150	675	750	1200	800	0	0
Total gain, kg	0	64	200	256	54	144	23	104	225	360	120	0	0
At stable													
N days/year	185	222	0	0	246	185	215	211	65	65	215	365	365
Gain, g/day	0	287			390	702	0	513	750	1200	744	1071	1701
Total gain, kg	0	64			96	130	0	108	49	78	160	390	616
Feed use (incl milk)													
SFU/kg gain		9.6	3.84	3.84	9.2	8.2		8.36	3.87	3.45	7.92	6.42	6.18
DM, kg/kg LW gain	-	12.4	3.35	3.40	11.9	10.1	-	9.29	3.27	3.06	8.83	6.19	5.94
Roughage, % of DM	100	100	69	47	98	89	93	90	66	46	88	37	36
N input feed, kg	78	42	24	27	46	74	99	59	33	44	72	63	96
Crude protein, g/SFU	214	214	193	172	210	207	207	207	192	180	203	157	157

Appendix 5. Environmental impact from the whole chain of beef production.

Table 5.1. Carbon footprint from beef, contribution from the whole chain (without soil C and LUC), presented as kg CO_2 /kg meat[1)].

Contribution from	Primary production	Slaughtering process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	10.6	0.2	-0.1	-0.2	10.4	**1**
Young bull	10.6	0.2	-0.1	-0.2	10.5	**2**
Steer	19.8	0.2	-0.1	-0.5	19.4	**3**
Steer, org.	19.2	0.2	-0.1	-0.4	18.8	**4**
Cow	11.3	0.2	-0.1	-0.2	11.1	**5**
Cow, org.	11.7	0.2	-0.1	-0.2	11.5	**6**
Beef breed Limousine						
Calf	32.4	0.2	-0.1	-0.5	32.0	**10**
Young bull	31.5	0.2	-0.1	-0.5	31.0	**11**
Heifer	31.1	0.2	-0.1	-0.4	30.8	**12**
Cow	11.5	0.1	-0.1	-0.2	11.3	**13**
Lim. System with 10.5 m bull[2)]	*25.8*	*0.2*	*-0.1*	*-0.4*	*25.5*	*10+12+13*
Lim. System with 14.4 m bull[2)]	*25.6*	*0.2*	*-0.1*	*-0.4*	*25.3*	*11 +12+13*
Beef breed highland						
Young bull	42.7	0.2	-0.1	-0.9	41.9	**7**
Heifer	46.4	0.2	-0.1	-0.7	45.8	**8**
Cow	13.1	0.2	-0.1	-0.3	12.9	**9**
Highland system [2)]	*36.8*	*0.2*	*-0.1*	*-0.7*	*36.2*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year

Table 5.2. Land use (total area) from beef, contribution from the whole chain, presented as m^2 per kg meat[1).

Contribution from	Primary production	Slaughter-ing process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	14.5	0.0	-0.1	-0.3	14.1	**1**
Young bull	16.0	0.0	-0.1	-0.3	15.5	**2**
Steer	20.5	0.0	-0.1	-0.5	19.9	**3**
Steer, org.	27.2	0.0	-0.1	-0.6	26.4	**4**
Cow	13.1	0.0	-0.2	-0.2	12.7	**5**
Cow, org.	20.0	0.0	-0.2	-0.4	19.4	**6**
Beef breed Limousine						
Calf	58.6	0.0	-0.1	-0.9	57.6	**10**
Young bull	56.0	0.0	-0.1	-0.9	55.1	**11**
Heifer	57.9	0.0	-0.1	-0.7	57.1	**12**
Cow	22.1	0.0	-0.1	-0.3	21.7	**13**
Lim. System with 10.5 m bull [2)	*47.5*	*0.0*	*-0.1*	*-0.7*	*46.7*	*10+12+13*
Lim. System with 14.4 m bulll[2)	*46.6*	*0.0*	*-0.1*	*-0.7*	*45.9*	*11 +12+13*
Beef breed highland						
Young bull	172.4	0.0	-0.1	-3.7	168.6	**7**
Heifer	244.5	0.0	-0.1	-3.9	240.5	**8**
Cow	64.1	0.0	-0.2	-1.7	62.9	**9**
Highland system [2)	*165.0*	*0.0*	*-0.1*	*-3.3*	*161.7*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year

Table 5.3. Land use (arable land) from beef, contribution from the whole chain, presented as m^2 per kg meat[1)].

Contribution from	**Primary production**	**Slaughter-ing process**	**Avoided emissions from by-products**	**Emissions that goes to hides**	**Total/kg human product**	**System No**
Dairy Holstein Friesian						
Calf	14.5	0.0	-0.1	-0.3	14.1	**1**
Young bull	16.0	0.0	-0.1	-0.3	15.5	**2**
Steer	20.5	0.0	-0.1	-0.5	19.9	**3**
Steer, org.	27.2	0.0	-0.1	-0.6	26.4	**4**
Cow	13.1	0.0	-0.2	-0.2	12.7	**5**
Cow, org.	20.0	0.0	-0.2	-0.4	19.4	**6**
Beef breed Limousine						
Calf	24.9	0.0	-0.1	-0.4	24.4	**10**
Young bull	25.8	0.0	-0.1	-0.4	25.3	**11**
Heifer	21.9	0.0	-0.1	-0.3	21.5	**12**
Cow	7.7	0.0	-0.1	-0.1	7.5	**13**
Lim. System with 10.5 m bull[2)]	*19.1*	*0.0*	*-0.1*	*-0.3*	*18.7*	*10+12+13*
Lim. System with 14.4 m bull[2)]	*19.7*	*0.0*	*-0.1*	*-0.3*	*19.3*	*11 +12+13*
Beef breed highland						
Young bull	18.8	0.0	-0.1	-0.4	18.3	**7**
Heifer	19.5	0.0	-0.1	-0.3	19.0	**8**
Cow	5.4	0.0	-0.2	-1.7	5.1	**9**
Highland system [2)]	*15.9*	*0.0*	*-0.1*	*-0.7*	*15.5*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year

Table 5.4. Biodiversity (PDF-index)[1)] from beef, contribution from the whole chain, presented per kg meat[2)].

Contribution from	Primary production	Slaughter-ing process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	7.4	0	-0.06	-0.16	7.2	**1**
Young bull	8.3	0	-0.06	-0.18	8.1	**2**
Steer	1.8	0	-0.01	-0.04	1.7	**3**
Steer, org.	-1.3	0	0.01	0.03	-1.2	**4**
Cow	4.7	0	-0.06	-0.09	4.6	**5**
Cow, org.	1.4	0	-0.01	-0.03	1.4	**6**
Beef breed Limousine						
Calf	-5.3	0	0.01	0.08	-5.2	**10**
Young bull	-4.5	0	0.01	0.07	-4.4	**11**
Heifer	-10.4	0	0.02	0.13	-10.3	**12**
Cow	-4.4	0	0.02	0.06	-4.3	**13**
Lim. System with 10.5 m bull[3)]	*-6.2*	*0.0*	*0.0*	*0.1*	*-6.1*	*10+12+13*
Lim. System with 14.4 m bull[3)]	*-5.8*	*0.0*	*0.0*	*0.1*	*-5.7*	*11 +12+13*
Beef breed highland						
Young bull	-51.7	0	0.03	1.12	-50.6	**7**
Heifer	-78.2	0	0.05	1.24	-77.0	**8**
Cow	-20.5	0	0.05	0.55	-19.9	**9**
Highland system [2)]	*-50.9*	*0.0*	*0.0*	*1.0*	*-49.9*	*7+8+9*

1) PDF-index = average PDF/m^2*total land use (m^2). A positive number means BD loss
2) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
3) Average impact from total meat output of the system during 1 year

Tabel 5.5. Non-renewable energy use from beef, contribution from the whole chain, presented as MJ primary energy per kg meat[1)].

Contribution from	Primary production	Slaughter-ing process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	36.7	2.7	-2.6	-0.8	36.0	**1**
Young bull	39.4	2.6	-2.5	-0.9	38.5	**2**
Steer	29.6	2.3	-2.6	-0.7	28.6	**3**
Steer, org.	27.3	2.3	-2.6	-0.6	26.3	**4**
Cow	31.4	2.3	-2.8	-0.6	30.2	**5**
Cow, org.	30.2	2.3	-2.9	-0.6	29.0	**6**
Beef breed Limousine						
Calf	37.2	2.2	-1.9	-0.6	37.0	**10**
Young bull	37.5	2.1	-1.8	-0.6	37.2	**11**
Heifer	30.4	2.3	-2.2	-0.4	30.1	**12**
Cow	10.1	2.0	-2.1	-0.1	9.9	**13**
Lim. System with 10.5 m bull[2)]	*27.5*	*2.2*	*-2.0*	*-0.4*	*27.3*	*10+12+13*
Lim. System with 14.4 m bull[2)]	*28.0*	*2.1*	*-2.0*	*-0.4*	*27.7*	*11 +12+13*
Beef breed highland						
Young bull	27.9	2.6	-2.5	-0.6	27.4	**7**
Heifer	28.9	2.9	-2.8	-0.5	28.6	**8**
Cow	7.7	2.7	-2.7	-0.1	7.5	**9**
Highland system [2)]	*23.5*	*2.7*	*-2.6*	*-0.5*	*23.1*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year

Tabel 5.6. Eutrophication from beef, contribution from the whole chain, presented as g NO_3-eq. per kg meat[1).

Contribution from	Primary production	Slaughter-ing process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	775	1	1	17	794	**1**
Young bull	789	1	1	-17	773	**2**
Steer	1493	1	0	-34	1460	**3**
Steer, org.	1273	1	0	-29	1245	**4**
Cow	723	1	0	-14	710	**5**
Cow, org.	582	1	0	-11	571	**6**
Beef breed Limousine						
Calf	2365	0	0	-35	2330	**10**
Young bull	2317	0	0	-37	2281	**11**
Heifer	2165	1	0	-26	2140	**12**
Cow	786	0	0	-10	776	**13**
Lim. System with 10.5 m bull [2)	*1846*	*0*	*0*	*-25*	*1820*	*10+12+13*
Lim. System with 14.4 m bull[2)	*1841*	*0*	*0*	*-27*	*1815*	*11 +12+13*
Beef breed highland						
Young bull	3346	1	1	-74	3273	**7**
Heifer	3193	1	1	-51	3143	**8**
Cow	848	1	0	-14	835	**9**
Highland system [2)	*2740*	*1*	*1*	*-55*	*2687*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year

Tabel 5.7. Acidification from beef, contribution from the whole chain, presented as g SO_2-eq. per kg meat[1)].

Contribution from	Primary production	Slaughter-ing process	Avoided emissions from by-products	Emissions that goes to hides	Total/kg human product	System No
Dairy Holstein Friesian						
Calf	150	0	1	-3	148	**1**
Young bull	144	0	1	-3	142	**2**
Steer	248	0	1	-6	243	**3**
Steer, org.	240	0	1	-6	235	**4**
Cow	119	0	1	-2	118	**5**
Cow, org.	100	0	1	-2	99	**6**
Beef breed Limousine						
Calf	435	0	0	-7	430	**10**
Young bull	427	0	0	-7	420	**11**
Heifer	402	0	1	-5	398	**12**
Cow	144	0	1	-2	143	**13**
Lim. System with 10.5 m bull[2)]	*340*	*0*	*1*	*-5*	*337*	*10+12+13*
Lim. System with 14.4 m bull[2)]	*340*	*0*	*1*	*-5*	*335*	*11 +12+13*
Beef breed highland						
Young bull	508	0	1	-11	498	**7**
Heifer	548	0	1	-9	540	**8**
Cow	157	0	1	-3	155	**9**
Highland system [2)]	*437*	*0*	*1*	*-9*	*430*	*7+8+9*

1) Meat include all edible products (meat without bones, other edible products not from carcass, and bones for food production)
2) Average impact from total meat output of the system during 1 year.

DCA - National Centre for Food and Agriculture is the entrance to research in food and agriculture at Aarhus University (AU). The main tasks of the centre are knowledge exchange, advisory service and interaction with authorities, organisations and businesses.

The centre coordinates knowledge exchange and advice with regard to the departments that are heavily involved in food and agricultural science. They are:

Department of Animal Science
Department of Food Science
Department of Agroecology
Department of Engineering
Department of Molecular Biology and Genetics

DCA can also involve other units at AU that carry out research in the relevant areas.

SUMMARY

It is well known, that the production of beef is related to a significant environmental impact, but also that there is a huge variation in the way beef production takes place at the farm, and this impacts considerable on the environmental profile of the meat produced. Comparatively less is known on how this translates into the environmental impact of different beef products as they appear when leaving the slaughterhouse.

In this work we established the life cycle impact of different types of meat and other beef products in relation to how they are marketed and dependent on the production system at the farm. It was the aim to cover the main types of beef production systems in Denmark, but also to show the influence of very different systems including some that are less common. In total we covered beef products from 13 different beef production systems and evaluated the environmental impact expressed per kg of edible product leaving the slaughterhouse (shortened meat) for each system.

The major environmental burden is related to the farm level stage and innovations to reduce this impact should be given high attention. The slaughtering process itself is very energy- and resource efficient. A main innovation to reduce environmental impact of the meat produced will be to ensure a higher utilization of the animal into new edible products not conventionally produced. For beef products there is a significant tradeoff between impact on GWP and impact on biodiversity. The importance of this needs more attention.

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