Life Cycle Analysis – HT161

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A life cycle assessment approach on Swedish and Irish beef production

Group 1 - Emma Lidell, Elvira Molin, Arash Sajadi & Emily Theokritoff

Summary

This life cycle assessment has been conducted to identify and compare the environmental impacts arising from the Swedish and Irish beef production systems. It is a cradle to gate study with the functional unit of 1 kg of dressed weight. Several processes such as the slaughterhouse and retail in both Ireland and Sweden have been excluded since they are similar and cancel each other out. The focus of the study has been on feed, farming and transportation during the beef production. Since this is an attributional LCA, data collection mainly consists of average data from different online sources.

Smaller differences in the composition of feed were found for the two systems while a major difference between the two production systems is the lifespan of the cattle. Based on studied literature, the average lifespan for cattle in Sweden is 45 months while the Irish cattle lifespan is 18 months. The impact categories that have been assessed are: climate change, eutrophication, acidification, land occupation and land transformation. In all the assessed impact categories, the Swedish beef production system has a higher environmental impact than the Irish beef production system, mainly due to the higher lifespan of the cattle.

Acidification, which is the most significant impact category when analising the normalised results, differs greatly between the two systems. The Swedish beef system emits almost double the amount (1.3 kg) of SO_2 Eq for 1 kg of dressed weight compared to the Irish beef system (0.7 kg SO_2 Eq/FU). For 1 kg of dressed Irish beef, the greenhouse gas emissions that affect climate change are 45.6 kg CO_2 Eq whereas for 1 kg of dressed Swedish beef, the emissions add up to 67.3 kg CO_2 Eq. The impact of Swedish beef on climate change is therefore larger than the impact of Irish beef.

Methane, nitrous oxide and ammonia are greenhouse gases that are emitted during the beef production system. They are mainly emitted or leached during the enteric fermentation of the cattle and from the manure process. The greenhouse gases affect the impact categories climate change, eutrophication and acidification. Mitigation measures that could be implemented to reduce the environmental impacts includes having healthy animals that have a high calf birth rate which eat high fat, high digestive forage. Improving the quality of the feed has shown reduction in nitrous oxides in the manure. Covering the manure and turning it into biogas could also be implemented in order to reduce significant impacts.

Table of Contents

Summary 1

1. Introduction 4
- 1.1. Swedish context 4
- 1.2. Irish context 4

2. Goal and Scope 4
- 2.1. The Functional Unit 4
- 2.2. System Boundaries 5
- 2.3. Allocation 5

3. Methodology 6
- 3.1. LCA software: SimaPro 6

4. Process flowcharts 7
- 4.1. Feed Production 7
- 4.2. Breeding and Farming 8
- 4.3. Transport 8

5. Life Cycle Inventory Analysis 9
- 5.1. Data Collection 9

6. Life cycle impact assessment (LCIA) 13
- 6.1. Climate change (greenhouse gas emissions) 14
- 6.2. Acidification 15
- 6.3. Eutrophication 15
- 6.4. Land occupation 15
- 6.5. Land transformation 16

7. Social aspects 16

8. Results from SimaPro 18
- 8.1. Interpretation of normalised results 18
- 8.2. Interpretation of characterised results 20

9. Hotspots and mitigation measures 23
- 9.1. Mitigation measures 23

10. Sensitivity analysis 24
- 10.1. Results 25

11. Discussion 25

12. Conclusion 27

References 28

Appendix 1: Network diagrams for Ireland and Sweden 31

Appendix 2: Description of potential allocation 34

Appendix 3: Sensitivity analysis 35

List of figures

Figure 1: Flowchart of system processes 5
Figure 2: Flowchart of the Swedish and Irish systems 7
Figure 3: Beef transport from Ireland 8
Figure 4: Beef transport from Sweden 8
Figure 5: Impact categories and the possible endpoints..13
Figure 6: Usage of mg/kg of antibiotics worldwide (European Medicines Agency , 2011) 17
Figure 7: Comparative normalised results 18
Figure 8: Normalized results from Ireland 19
Figure 9: Normalised results from Sweden 19
Figure 10: Characterized results of climate change 20
Figure 11: Characterised results of terrestrial acidification 20
Figure 12: Characterized results of freshwater eutrophication 21
Figure 13: Characterized results of marine eutrophication 21
Figure 14: Characterized results of agricultural land occupation..21
Figure 15: Characterized results of natural land transformation..22

List of tables

Table 1: General information about the cattle in Sweden..9
Table 2: General information about the cattle in Ireland 10
Table 3: Data feed production Sweden..10
Table 4: Data feed production Ireland 11
Table 5: Breeding and farming Sweden 12
Table 6: Breeding and farming Ireland..12
Table 7: Transport from Ireland to Sweden 12
Table 8: GWP for the different greenhouse gases (IPCC, 2008)..14

1. Introduction

This study aims to examine the production of beef in Sweden and compare it to the production of beef in Ireland using a life cycle assessment perspective. The study was conducted to present the environmental impacts of both systems to the consumer who can then decide which option is more environmentally sounds since the impacts are quantified but not weighted. Meat is an important source of protein and iron in the human diet, but a large consumption can have negative health effects. Besides the negative health effects caused by excessive meat consumption, the environmental aspects need to be considered. 1kg of beef produces between 5 to 8 kg of greenhouse gas emissions (GHG) (Livsmedelsverket, 2016) which is much higher if compared to same amount of pork, chicken, eggs or milk (De Vries & De Boer, 2009).

1.1. Swedish context

Nowadays, the average Swede consumes between 50 and 55 kg of meat per person and year (Livsmedelsverket, 2016). The recommended intake of meat from the National Food Administration (NFA) in Sweden is 500g per week which is not more than 26 kg per year (Livsmedelsverket, 2016). The Swedish population consumes less meat per person than the average European citizen, but the share of beef is higher than the average. Due to the price difference between the Swedish meat and internationally produced meat, the import has gradually increased (Jordbruksverket, 2016). In 2015, 425,000 bovines were raised for the production of meat (Svenskt Kött, 2016), 405 324 grown cattle were slaughtered as well as an additional 21 751 veals in Sweden (Jordbruksverket, 2016). The production of beef increased by 1,500 tons from 2014 to 2015, resulting in a total of 133,100 tons. In parallel, the import grew twofold with a total of 139,400 tons imported beef (Svenskt Kött, 2016).

1.2. Irish context

In the Irish the agriculture industry, the second most important sector is beef. In 2015, there were 6.96 million cattle in Ireland, representing a 0.5% increase on the level of previous years (Bord Bia, 2016). The beef self-sufficiency is estimated to be over 640%, which makes Ireland one of the largest beef exporters in the world and the largest beef exporter in Europe (Bord Bia, 2016). Ireland exported approximately 500,000 tonnes of beef worth €2.41 billion in 2015 (Bord Bia, 2016). According to *Statistics Sweden*, Ireland exported over €85 million of beef to Sweden last year (Higgins, 2016). The quality of Irish beef comes from the fact that a large share is produced from grass, the cattle graze outdoors during the summer time and are fed grain and silage indoors during the winter (Casey & Holden, 2006).

2. Goal and Scope

The goal of this study is to conduct a life cycle assessment and compare the environmental impacts in terms of climate change, acidification, eutrophication and land use & land change of beef production in Sweden and imported beef from Ireland. The hotspots, which are the parts of the production with greater environmental impact, will be identified and mitigation measures suggested.

2.1. The Functional Unit

The functional unit for this LCA study is based on the dressed weight of the cattle after it has been at the slaughterhouse. The dressed weight is a fraction of the total weight of the animal and it refers to the weight of the cattle after removing the organs and the inedible parts of the animal. The dressed weight includes the bone and gristle that is left on the animal after being partially butchered. The functional unit in this study is *1 kg of dressed weight*. The mass (1 kg) is a straightforward and simple way of measuring the quantity of beef. With the chosen functional unit of 1 kg of dressed weight, estimations and evaluation on the environmental impacts up to the distributor will be conducted.

2.2. System Boundaries

The system boundaries are defined as from cradle to gate which in this case means up to the point of transportation to the distributor *Norvida* in Stockholm, Sweden. This includes:

- Feed production - All factors included in the production the feed.
- Breeding/Farming - The processes included in raising and feeding the cattles.
- Retail – The cooling, transport and storage of the beef to the distributor, for both Swedish and Irish producers.

The process in the slaughter house and the stage up to the consumer are exlcuded since they are assumed to be similar in the Irish and the Swedish case.

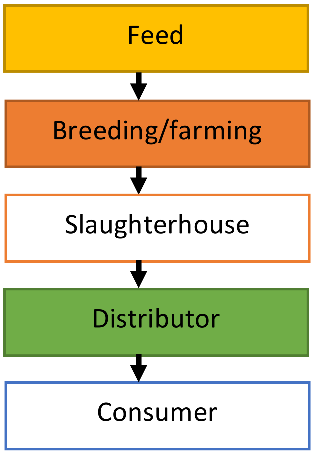


Figure 1: Flowchart of system

Certain delimitations were made within each process of the system due to the limited amount of time available for this project. Production and maintenance of buildings and machines are not included in this study. Pesticides and medicines like antibiotics are not included, due to the limited impact of the total emissions (Cederberg C., 2004). Although the antibiotics are not considered in this LCA, their environmental impact could be an interesting aspect to assess. Animal welfare including ethical questions are not usually included in a LCA, but it is an important aspect to consider for the public and the stakeholders involved in beef production (Mårtensson, 2009). For further elaboration on the use of antibiotics and animal welfare see the Social aspects section.

2.3. Allocation

One of the most common methodological problems in a LCA is allocation. It appears when a service or product has multiple functions and the environmental burdens have to be allocated amongst it functions. The allocation problem refers to the multi-functional process of deciding how the burdens should be distributed. Arbitrary allocations could lead to misleading results in the LCA (Bert, Reap, Duncan, & Roman, 2008).

Thus, to deal with the allocation problem, ISO 14040.2006 recommends that LCA practitioners follow the following stepwise procedure:

- Avoid allocation when possible by (1) dividing the unit processes into sub-processes and gathering the required environmental burden data and/or (2) expanding the product system boundaries to include additional functions related to the co-products.
- If allocation cannot be avoided, allocate the environmental burdens of each product based on their underlying physical relationships.
- If allocation based on physical relationships cannot be done, allocate the environmental burdens of each product based on other relationships.

3. Methodology

A life cycle assessment is a tool used to identify environmental impacts, determine how they transfer from one medium to another and detect potential impacts (Curran, Life Cycle Assessment Student Handbook, 2015). In a LCA process, data is collected and evaluated to assess the environmental performance of a product or service over its entire life span, from cradle to grave (Lehtine, Saarentaus, Rouhiainen, Pitts, & Azapagic, 2001). LCA splits the system into processes and assemblies to carefully analyse each step. Without separation of the different steps, it would be hard to properly recognize all the impacts and some might remain neglected. Due to the close linkage and interconnectedness of impacts, LCAs happen to have non-intuitive results (Curran, Life Cycle Assessment Student Handbook, 2015).

LCAs allow to get an overlook at the environmental impacts as well as the flow of resources through the chosen system. It facilitates the reduction and mitigation of impacts. In comparison to others tools that detect environmental impacts, LCAs do not only look at the affected part but at the complete system. The LCA is also quantitative and more general then other forms of evaluation systems (SLU, 2016).

A LCA could be used as a base for decision making for companies, research, product design and for labelling purposes. The actual process of making a LCA includes the definition of a goal and scope for a study, making a list of inventories to be included in the system flow, designing the flowchart of the system, quantifying the environmental impacts in relation to a chosen functional unit and finally interpreting the result. Many details have to be taken into account in a LCA although some aspects always remain neglected. It is therefore important to analyse the results, adjust the inputs and review the effects of these small changes leading sometimes to the adjustment of the goal and scope (SLU, 2016).

This is a comparative LCA study and it is an attributional study since it describes the system as it is using average data. On the other hand, the option of doing a consequential study describing the consequences due to change by using marginal data was not chosen (Björklund, 2016). Generally, it is recommended to make a cradle to grave LCA, but for this study a cradle to gate analysis has been done. This means that waste handling has not been taken into consideration. Further on, in this study it has been decided to set the gate at the distributor since the two systems are very similar in both cases.

Three main areas are of focus were selected in this LCA since the other processes are very similar for the two systems and would therefore cancel each other out (the slaughterhouse process for example). The tree main areas are: breeding and farming, the feed production and the transportation. A literature review has been made focusing on previous LCA studies on meat and beef production. In addition, statistics and numbers were found for the creation of the inventory. In addition, to collect data several experts from various institutions were consulted.

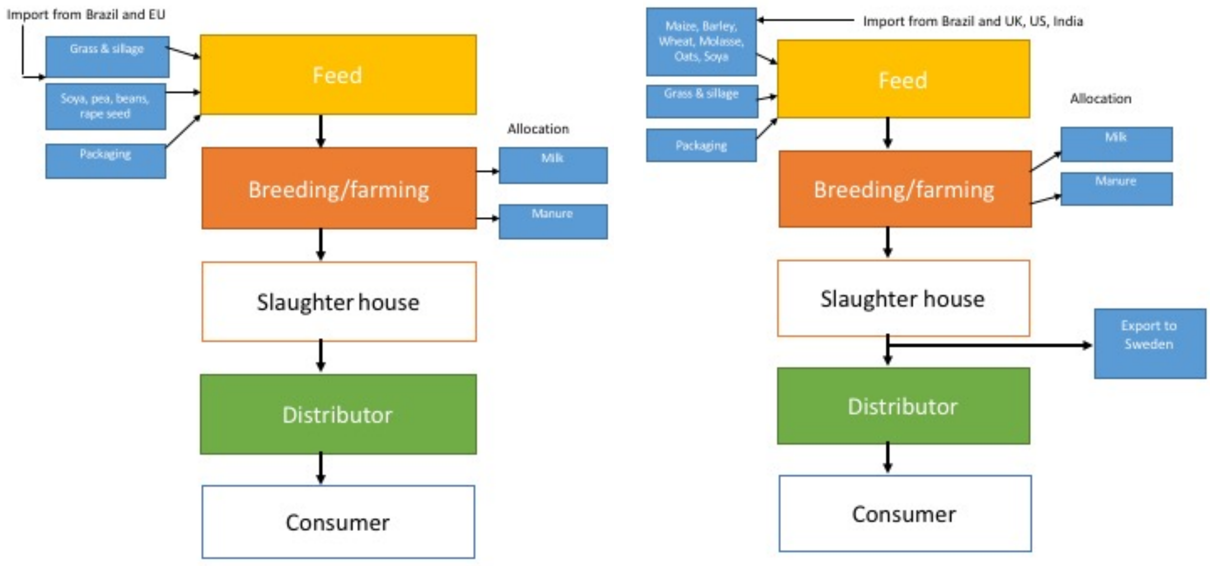
3.1. LCA software: SimaPro

This LCA has been conducted using the software SimaPro, a tool to collect data, to be able to monitor the performance of a chosen system. It is widely used in LCA processes and was developed to help detect which steps in a system that have the most significant environmental impacts. With that knowledge, it is easy to take measures and mitigate these impacts (Pré Sustainability, 2015). The wide range of impacts or eco-indicators are modelled against a single value and can be weighted to further see their relative impact. The weighting is done by the people undertaking the study and the result is therefore not objective (Lehtine, Saarentaus, Rouhiainen, Pitts, & Azapagic, 2001). The software offers a standardisation and with the visualization of the system it is easy for the stakeholders to understand and trust the result. In this study, we have used the database Ecoinvent which the database that is the most up to date in the world today (SimaPro UK, 2015). ReCiPe H midpoint 2008 Europe has been used for the impact assessment method.

4. Process flowcharts

Figure 2 below illustrates both the Swedish and Irish systems through process flowcharts.

Figure 2: Flowchart of the Swedish and Irish systems



Swedish flowchart Irish flowchart

4.1. Feed Production

In both Sweden and Ireland, the cattle graze outdoors during the summer and are fed silage and force feed for energy supplementation during the winter months. Therefore, the largest part of the feed for the cattle comes from grass in both cases. Differences in the composition of the force feed between Ireland and Sweden were observed. In Ireland, the force feed is composed of barley, wheat, molasses, rape, oats, soya, and maize. The composition of this force feed was developed from the ingredients commonly used by feed suppliers in Ireland. The ingredients for the force feed were assumed to be shipped from the UK, India, Brazil, USA (Casey & Holden, 2006). In Sweden, soya, broad bean, pea, and rapeseed were assumed to be the main components of the force feed. The soya is imported from Brazil, the broad beans come from the EU, and in the calculations, it was assumed that they were transported from France. The peas and rapeseeds are produced within Sweden (Swensson, 2016). The transportation of the feed from their countries of origin were considered during the modelling process in SimaPro.

4.2. Breeding and Farming

The lifespans of the cattle greatly differ between Ireland and Sweden. In Ireland, the average lifespan of a cattle is only 18 months (Casey & Holden, 2006) whereas Swedish cattle lives on average 45 months (Svenskt kött, 2013). The grazing days are also a major difference during the raising of the cattle. In Sweden, due to the harsh climate, the cattle can only graze 180 days per year, from May to October (Jordbruksverket, 2011). The milder climate of Ireland allows the cattle to graze during approximately 240 days per year. Consequently, this impacts the bedding material, more than twice the amount is used in Sweden compared to Ireland. In addition, the amounts of manure and methane exhausts over the lifetime of the cattle are also greater in Sweden.

4.3. Transport

The total impact of the transport of beef is similar to the transport of other products but in this study there are differences in transport between the two systems that are of interest. The system with the Swedish beef needs much less transport, whilst the Irish beef needs to be transported further distances. Important aspects to look into are the type of transport being used such as trucks, rail or sea transport.

The beef coming from Ireland is transport intense, meaning the beef is transported in large volumes with both ferry and lorry using non-renewable energy sources which affect the climate. In 2015, the import of beef from Ireland to Sweden was about 25% (Jordbruksverket, 2016). The GHG emissions are dependent on what transport mode is used since different transport modes have different rates of energy intensity. For transport the unit ton*km is used which represents the work that is needed to transport one ton one km. Transport of feed often needs refrigeration that increases the use of energy. The longer down the supply chain, the less efficient the beef transport gets.

The Figure 3 and Figure 4 below show the differences in transport in the two systems where Figure 3 shows the Irish beef transport and Figure 4 that shows the Swedish beef transport system.

Figure 3: Beef transport from Ireland

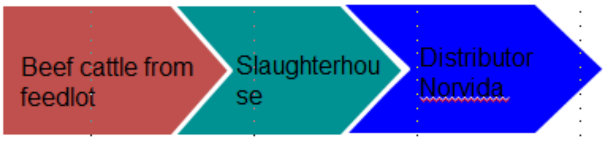


Figure 4: Beef transport from Sweden

The difference in the transport systems is that the beef from Ireland needs to be transported to Sweden. Data on how the beef is transported from Ireland has been collected by contacting Norvida which is one of Sweden's largest meat distributors. According to Calle Ramvall at costumer service in Norvida meat distributor, the beef from Ireland is first transported by truck and then the trucks are transported by ferry to the port of Hamburg. From Hamburg, the beef is transported with trucks to the distributor in Stockholm. For this LCA study the transport gate ends at the hands of the distributor which is Norvida in Stockholm. It is further assumed that the transport from the feedlot to slaughterhouse for both systems is the same. For the measured distances from the port in Dublin to Hamburg and from Hamburg to Norvida see the life cycle inventory list in Table 7.

5. Life Cycle Inventory Analysis

The result from the LCI is a compilation of the inputs (resources) and the outputs (emissions) from the product over its life-cycle in relation to the functional unit. When the goal and scope of the LCA are set, the data collection and the calculations of the life cycle impacts can start. To get an overview of the processes, a flow chart can be presented (Lindahl, Rydh, & Tingström, 2002). All inputs and outputs from the system, so called data categories are collected and their environmental effects are categorized. The chosen data categories in this study are climate change, acidification, eutrophication and land use.

The most time consuming part of an LCA is the collection of data. It can be done in different ways, by questionnaires, literature, calculations or measurements. It is crucial to use relevant data to get a representative result. If the analysis is general, average data can be used, but if the analysis is specific for a certain product, marginal data should be used. In order to give readers an idea of the relevance of the LCA, it is important to be transparent about how and from where the data originates. A framework for data collection and the presentation of data is stated in the ISO regulations (Björklund, 2016).

5.1. Data Collection

Table 1 to Table 7 below present the data collected with references and the assumptions made.

Table 1: General information about the cattle in Sweden

General data Sweden	Total	Amount per FU	Reference
Average dressed weight 1 cattle	288 kg		(Jordbruksverket, 2013)
Percentage of meat from dairy cattle	65 %		(Jordbruksverket, 2011)
Average life span of cattle	45 months		Assumption since life span 18 months for bulls and 60 months for dairy cattles (Svenskt kött, 2013)
Water usage	17657 l/kg	17657 l	(Chatterton, Hess, & William, 2010)
Number of cattle	1.43 million		(Jordbruksverket, 2011)
Days of grazing	180 days/year		Assumption May-October

Table 2: General information about the cattle in Ireland

General data Ireland	Total	Amount per FU	Reference
Average dressed weight 1 cattle	290 kg		(Naturvårdsverket, 2007)
Percentage of meat from dairy cattle	50 %		(Casey & Holden, 2006)
Average life span of cattle	18 months		(Casey & Holden, 2006)
Number of cattle	6.96 million		(Irish Food Board, 2015)
Days of grazing	240 days/year		(Naturvårdsverket, 2007)

Table 3: Data feed production Sweden

Feed Sweden	Total	Amount per FU	Country of origin	Reference
Amount of force feed/life time	13687 kg	9.48 kg		(Swensson, 2016) Assumption based on intake per cattle (10 kg per day)
Amount of soya	10kg/day (force feed) during May - October	0.188 kg	Brazil	(Swensson, 2016) Assumption based on total complete feed intake divided by number of cattle and then 2 % soya.
Broad bean		3.094 kg	EU	(Swensson, 2016)Assumption 2 % of force feed soya and the rest is broad been, rape seed or pea.
Pea		3.094 kg	Sweden	
Rape seed		3.094 kg	Sweden	
Amount of sillage based feed/life time	9450 kg	32.81 kg		(Dahlberg & Jarander) Assumption based on intake dairy cattles
Grass	21375 kg	74 kg		(Swensson, 2016) Assumption based on intake of 30 kg per day during grazing months
Transport				
Brazil - Sweden	9.6 tkm	Ship		(Sea Distance, 2016)
EU - Sweden	1.06 tkm	Ship		

Table 4: Data feed production Ireland

Feed Ireland	Total (kg)	Amount per FU	Country of origin	Reference
Barley	294.64	1.016	UK (Manchester)	(Casey & Holden, 2006) (Swensson, 2016) Assumption based on percentage of different grains and the intake of feed to make up 1 FU of beef (9 kg in a lifetime of 18 months)
Wheat	91.44	0.315	UK (Manchester)	
Molasse	50.8	0.175	India (Kolkata)	
Rape	152.4	0.526	USA (New Jersey)	
Oats	91.44	0.315	USA (New Jersey)	
Soya	121.92	0.420	Brazil	
Maize	213.36	0.736	UK (Manchester)	
Fresh grass/life time	12355 kg	19.1 kg	Ireland	(Casey & Holden, 2006) Based of feed intake throughout a lifetime per FU
Grass silage/life time	4983 kg	7.7 kg	Ireland	(Casey & Holden, 2006) Based of feed intake throughout a lifetime per FU
Plastic packaging feed Polyethene		25.5 kg		(Extension, 2016) Assumption based on packaging needed for 25 packages of sillage à 1000 kg. equivalent to 25 packs of silage. 1 pack 1000 kg = 1,5 m/kg sillage
Transport				
UK - Ireland	0.291 tkm	Ship		(Sea Distance, 2016)
India - Ireland	14.400 tkm	Ship		
USA - Ireland	5.930 tkm	Ship		
Brazil - Ireland	9.600 tkm	Ship		

Table 5: Breeding and farming Sweden

Breeding/farming Sweden			
Bedding material	270 kg	0.93 kg	Assumption 12/month indoors
Manure life time	487.5 kg/month		(Åkesson, 1971)
N2O nitrous oxide	1.3 g/day	0.006 kg	(Rohde, Baky, Olsson, & Norberg, 2012)
NH3 ammonia		0.041 kg	(Kirchmann & Lundvall, 1993)
CH4 methane	7 g/kg manure	0.53 kg	(Rohde, Baky, Olsson, & Norberg, 2012)
Methane exhaust	375 kg	1.30 kg	Assumption based on (Jordbruksverket, 2011), 100 kg/methane per year

Table 6: Breeding and farming Ireland

Breeding/farming Ireland			
Bedding material	96 kg	0.33 kg	Assumption 12/month indoors
Manure life time	487.5 kg/month		
N2O nitrous oxide	1.3 g/day	0.002 kg	(Rohde, Baky, Olsson, & Norberg, 2012)
NH3 ammonia		0.041 kg	(Kirchmann & Lundvall, 1993)
CH4 methane	7 g/kg manure	0.21 kg	(Rohde, Baky, Olsson, & Norberg, 2012)
Methane exhaust		1.03 kg	Assumption based on (Jordbruksverket, 2011), 100 kg/methane per year

Table 7: Transport from Ireland to Sweden

Transport Irish beef to Sweden	**Mode of transport**	**Fuel**	**Reference**
1632 tkm	Ship		(Sea Distance, 2016)
979 tkm	Truck	Diesel	(Google, 2016)

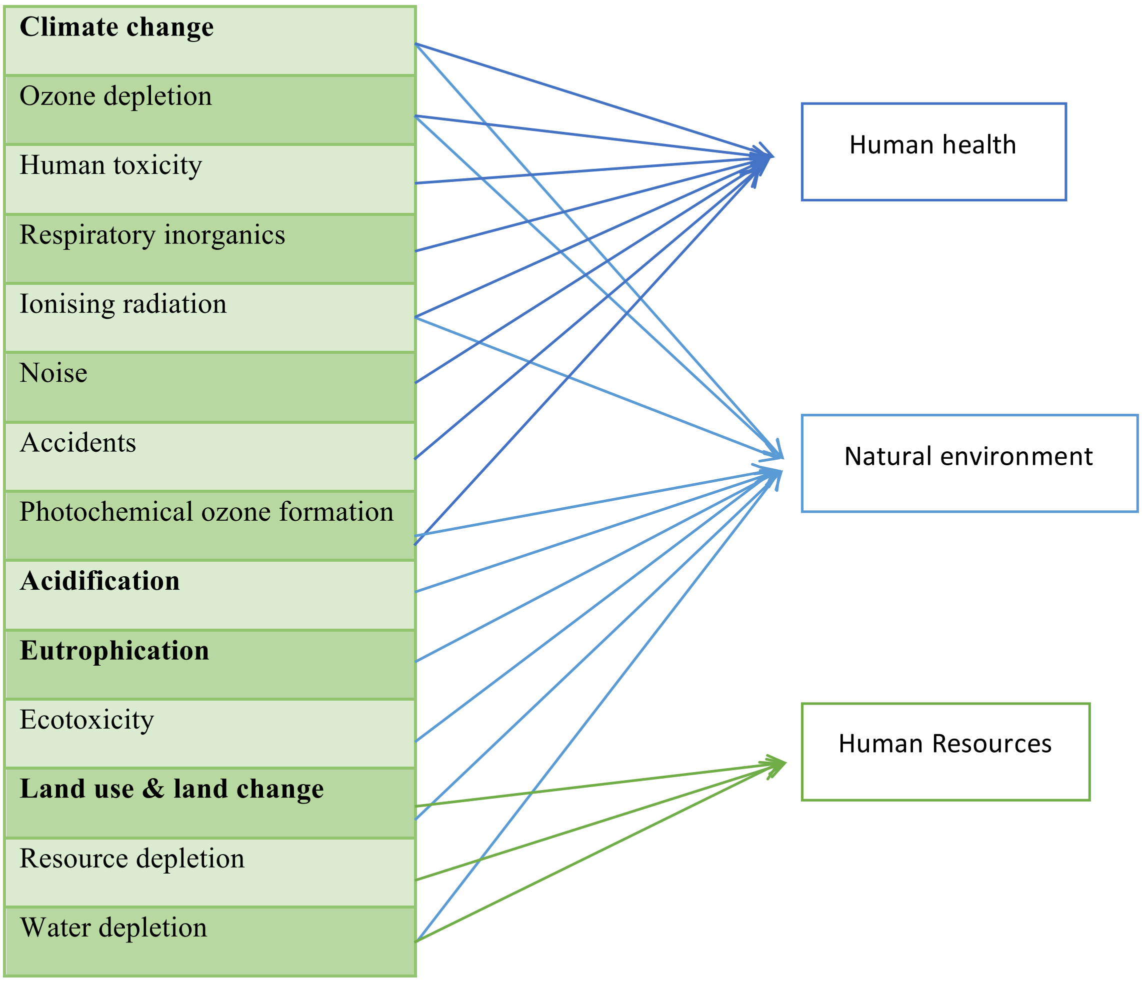
6. Life cycle impact assessment (LCIA)

ISO 14044:2006 specifies the different requirements and suggests guidelines for performing life cycle assessments. It covers life cycle assessment and life cycle inventory studies. Amongst other parts it also includes the life cycle impacts assessment (LCIA) phase where different environmental impacts are mentioned (ISO, 2016). The European platform on life cycle assessment (EPLCA) also provides a handbook for analyzing existing environmental impacts assessments and provides different methodologies (Commission, 2010). In the LCIA the inventory will be analyzed for the different environmental impacts. The focus has been to select the environmental impacts that are relevant and related to the subject of study in the LCA which in this case is beef production.

The selection of the significant environmental impacts for the current LCA has partly been based on the suggested impacts in ISO 14044:2006. Also, previous literature on former LCA´s that have studied beef production have been of great use in defining the environmental impacts that reflects the subject of study.

Figure 5 below illustrates the different life cycle impact assessment categories that can be found on the European platform on life cycle assessment. It also shows the three different damage categories, so called endpoints that need to be protected. For this life cycle assessment midpoint and not endpoint categories have been chosen.

Figure 5: Impact categories and the possible endpoints



By studying previous LCA studies such as the beef production report from Alberta prepared by Consestoga-Rovers Associates (Associates, 2010) and through discussions in the assessment group, 4 main impact categories have been identified. The four impact categories (highlighted in Figure 5 are listed below and described more in detail:

- Climate change (greenhouse gas emissions)
- Acidification
- Eutrophication
- Land use & land change.

6.1. Climate change (greenhouse gas emissions)

Regarding beef production, there are three main greenhouse gases leading to global warming and causing the climate to change. These are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2H). The greenhouse gases have different absorption potential towards radiation and thus they affect the global warming and the climate change differently. To be able to compare the effects of the different gases the global warming potential (GWP) was developed (Palm, 2014).

It is a value that illustrates how much a greenhouse gas emission contributes to global warming compared to CO_2 since CO_2 is the reference used and assigned the GWP of 1. The warming potential of the two other gases can through the GWP be stated on a basis of CO_2-eqvivalent. The GWP is set for 100 years and the table below shows the GWP for the different greenhouse gases mentioned as they are stated in the 4th assessment report from the IPCC in 2007.

Table 8: GWP for the different greenhouse gases (IPCC, 2008)

Greenhouse gas	Global Warming Potential (GWP)
CO_2	1
CH_4	25
N_2O	298

Most of the time attention is predominantly focused on CO_2 emissions but as Table 8 illustrates both methane and nitrous acid are much more potent and harmful and have a larger impact on global warming than does CO_2. This fact is of great significance since large amounts of both those gases, especially CH_4 are emitted during the production of beef.

CO_2 emissions coming from animal agriculture are mainly emitted during the burning of fossil fuels for production of fertilizer for feed crops, feed transports, beef processing, energy used on the farm and the changes in land use. Each and one of these categories contribute to large amounts of CO_2 to be emitted during the beef production cycle. Another important aspect that is related to CO_2 emissions but also impacts the climate in general is the changes in the nitrogen cycle that occurs during the feeding process of the animals. 80% of the global soybean and 50% of all the corn crop is needed to feed the worlds livestock. Both the soybean and the corn rely on nitrogen based fertilizers. The naturally existing amounts of nitrogen are not enough and artificial nitrogen fertilizers is currently being produced by machines that rely on fossil fuels which leads to the emission of CO_2 at the same time as creating a change and disturbance in the natural nitrogen cycle (Nierenberg, 2008).

CH_4 is produced during the enteric fermentation when ruminants such as cattle consume and digest the feed. When the microorganisms in the ruminants reduce the cellulose in the feed into other substances that it can use methane is formed and emitted. The methane emitted depends on several factors:

- The quality of feed that is given to cattle, in feedlots, are comprised of an unnatural diet that can affect their digestion process, leading to an increase in methane emission.
- Cattle growth – If the cattle grow slowly then more methane will be emitted because more feed will be needed to maintain the lifespan of the cattle without having any meat production (Sonesson U. , 2009).
- The amount of methane emitted by one cattle during digestion is very low but when considering that there are approximately 1 billion cattle (Cook, 2016) worldwide the amount of methane is exponentially increased. According to Pierre Gerber (Gerber, 2006) the feed digestion process of cattle worldwide results in 86 million tons of methane being emitted per year.
- The cattle manure which leads to waste that requires both storage and discarding is also an important contributor to the emission of greenhouse gases because it contains large amounts of both CH_4 and N_2H. Since N_2H is the gas with the highest global warming potential, it becomes an important factor to consider. Regarding the manure, observations have shown that manure coming from beef cattle in feedlots contain much larger amounts of CH_4 than of beef cattle that have been raised on pasture, eating a more natural diet (Nierenberg, 2008).

6.2. Acidification

The anthropogenic emissions of NO_x, SO_2 and ammonia (NH_3) lead to acid deposition which in turn damages the ecosystems close to the farms where the cattle are raised. Both freshwater and forests are sensitive to acidification. Both in the cattle manure and the fertilizers that are used in the crop cultivation process there are gaseous NH_3 emissions that react with sulfur dioxide (SO_2) to result in ammonium sulfate which in turn leads to acidification. Further when NH_3 reacts with nitric or sulfuric acid in the air, it can travel distances as far as thousands of kilometers. Ammonia (NH_3) represented 35% of all acidification effects in Sweden in the year of 2005 (Arcand, 2012). The acidification potential will be converted to SO_2 equivalent (SO_2-Eq) factors though the multiplication of the life cycle inventory data by a SO_2 characterization factor.

6.3. Eutrophication

Eutrophication which is the process where nutrients such as phosphorus and nitrous is added to different forms of water bodies such as lakes and streams (Foster, 2006). The exceed of nutrients in the waterbody results in an extreme plant growth (algal bloom) which in turn decreases the dissolved oxygen that exists in water which leads to the death of other organisms and disturbance of important ecosystem services. The nutrients that cause eutrophication in the beef production system mostly derive from the phosphorous and nitrous that is added through the fertilizers. The eutrophication potential will be converted to PO_4 equivalent (PO_4-Eq) factors though the multiplication of the life cycle inventory data by a PO_4 characterization factor.

6.4. Land occupation

Land occupation describes the continuous use of land area for a human-controlled purpose such as construction, agriculture or forestry over a certain period of time (Tuomas Mattila, 2011). In this study, the purpose is the production of beef, calculated in m^2 per year per FU. Land occupation contributes to a large ecological footprint share linked to both the production of feed and the grazing of the cattle.

6.5. Land transformation

Land transformation describes "the change from one land use category to another" (Tuomas Mattila, 2011). The plantation of a forest on land that had previously been used for agricultural purposes is an example of land transformation. It is commonly referred to land use change, which refers to "a change in the use or management of lands by humans, which may lead to a change in land cover" (IPCC, 2007). Land use changes can have impacts on surface albedo, sources and sinks of greenhouse gases, evapotranspiration and other climate system properties locally and globally (Tuomas Mattila, 2011).

7. Social aspects

When performing a LCA it is the environmental impacts that are assessed. Economical and social aspects are often excluded in the analysis (Christiansen K., 2006). The fact that economic and social aspects are excluded when conducting a LCA study makes it less useful as a tool for aiming towards a sustainable future in society. Sustainability is more than the environmental aspects and to be fully useful some social and economic aspects need to be integrated.

When conducting the current LCA where beef production is being evaluated, it becomes even more important to mention the social aspects since it is an important factor to consider next to the environmental aspects, although social impacts might be difficult to quantify (Swarr, 2009). It is not the aim of the study to conduct or include a complete societal LCA since social concerns vary significantly and have many indicators. These can be weighted differently depending on who is doing the weighting process which introduces further complexity in conducting a societal LCA next to the environmental LCA. The aim of including some of the social aspects linked to the beef production system is to facilitate learning and inform different stakeholders about the societal factors without being biased.

Today 38% of the ice-free land in the world is used for agriculture, another 30% is covered by forests while the rest mainly consist of deserts, mountains, tundra, or urban areas. 80% of the cultivated land is used for animal production, either as land for grazing or for the cultivation of feed. The energy efficiency when producing beef is very low. Only 1% of the amount of energy input by the feed is returned when consuming the meat.

The need for new fertile land contributes to an increase in the price of land. The consequences are severe for people and the environment since the incentives to fell forests are intensified in the search for new land, the food prices rise, and there is an increased incentive for the issue of large-scale land acquisitions, so called land grabbing (Björk I., 2013).

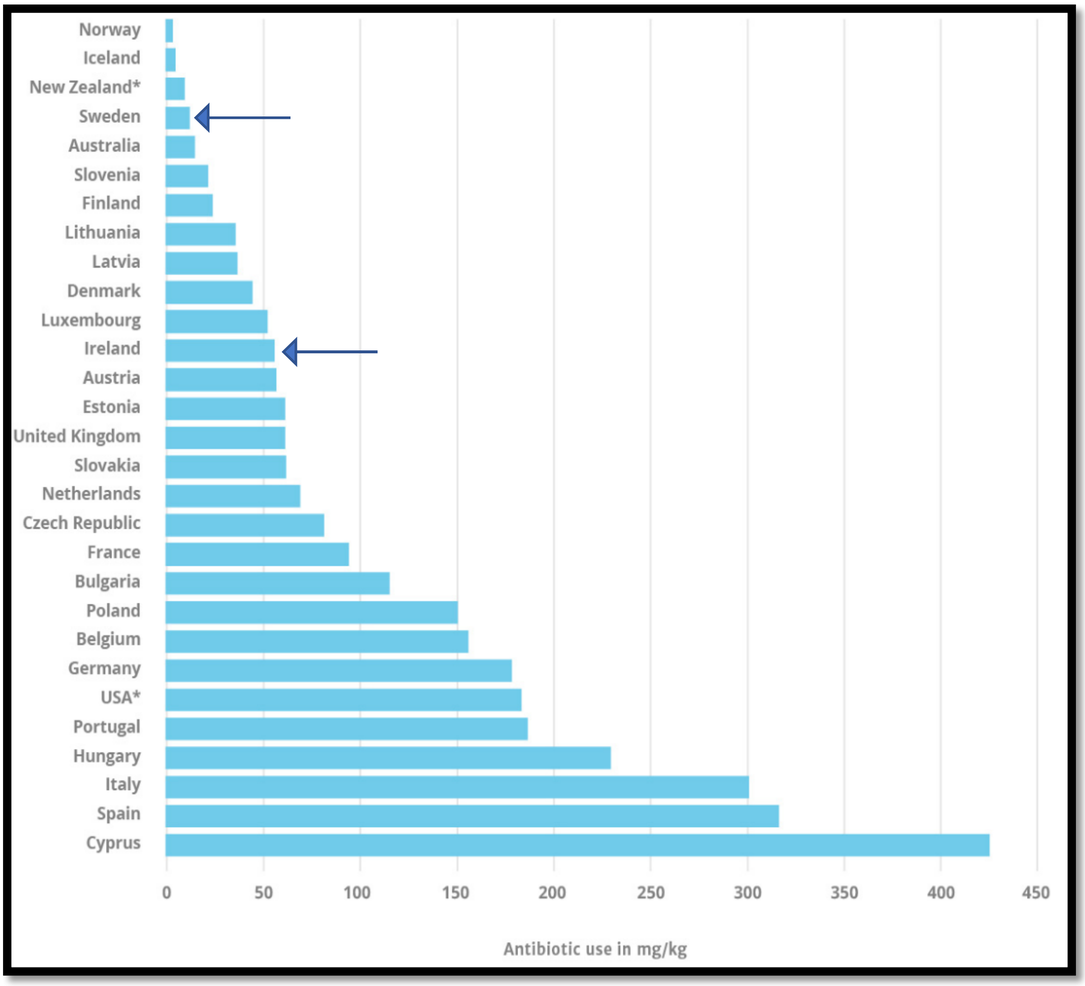
In 2009, there were 222 million tons of soya produced in the world in total. Divided by the world population in 2009 it accounted for about 1 hectograms of soy per day per person. Due to the high protein content of the soybean (40%) and the many essential amino acids it contains it would satisfy the daily human intake of protein. This would mean that the soy production could replace the meat and fish consumption entirely if it would be based on the desired protein content (Öhman, 2011). However, it is merely a small amount of the total soy production that is directly turned into human feed. Around 75% of the total soy production is used for animal feed since it is cheap and allows the animals to grow faster (Parker, 2016). About 173 g of soy are used to yield 1 kg of beef.

If the world´s growing population continues to demand a feed production system that is based on meat and beef, the production of soybean must continue to grow to be able to sustain the animal feed. Large amounts of the soy that is imported to Europe and Sweden comes from Brazil with smaller amounts from Argentine and China (Jordbruksverket, 2014). The soy production in Brazil has negative impacts on the environment since rainforest are cut down and used as farmland for soy which affects the biodiversity and many other environmental aspects. The question remaining is whether soybean could be used more efficiently to feed people directly rather than being used for animal feed.

Antibiotics are a drug used for both humans and animals to treat bacteria related infections, helping to save lives. Bacteria can however mutate and adjust to become resistant to the antibiotics used, reducing their efficiency. This is the case for several existing bacteria today and it is one of the greatest public health challenges in the world (WWF, 2016). According to WWF estimates, there are more antibiotics given to healthy animals than to sick people worldwide. This is because antibiotics are given to the whole group of animals to prevent bacteria diseases and to stimulate growth.

Since a long time, Sweden has tried to have a good animal welfare with healthy animals and a responsible use of antibiotics. Sweden was the first country in the world in 1986 to prohibit the use of antibiotics in the feed for animals to stimulate growth. It is only permitted to use it for medical purposes. It was not until 2006 that the European Union put in place the same law where the use of antibiotics in the feed for stimulating growth was prohibited in all countries in the EU (Svenskt kött, 2010). As it can be seen in Figure 6 below, both in Sweden and Ireland the usage of antibiotics is relatively low compared to other countries in the world.

Figure 6: Usage of mg/kg of antibiotics worldwide (European Medicines Agency , 2011)



8. Results from SimaPro

8.1. Interpretation of normalised results

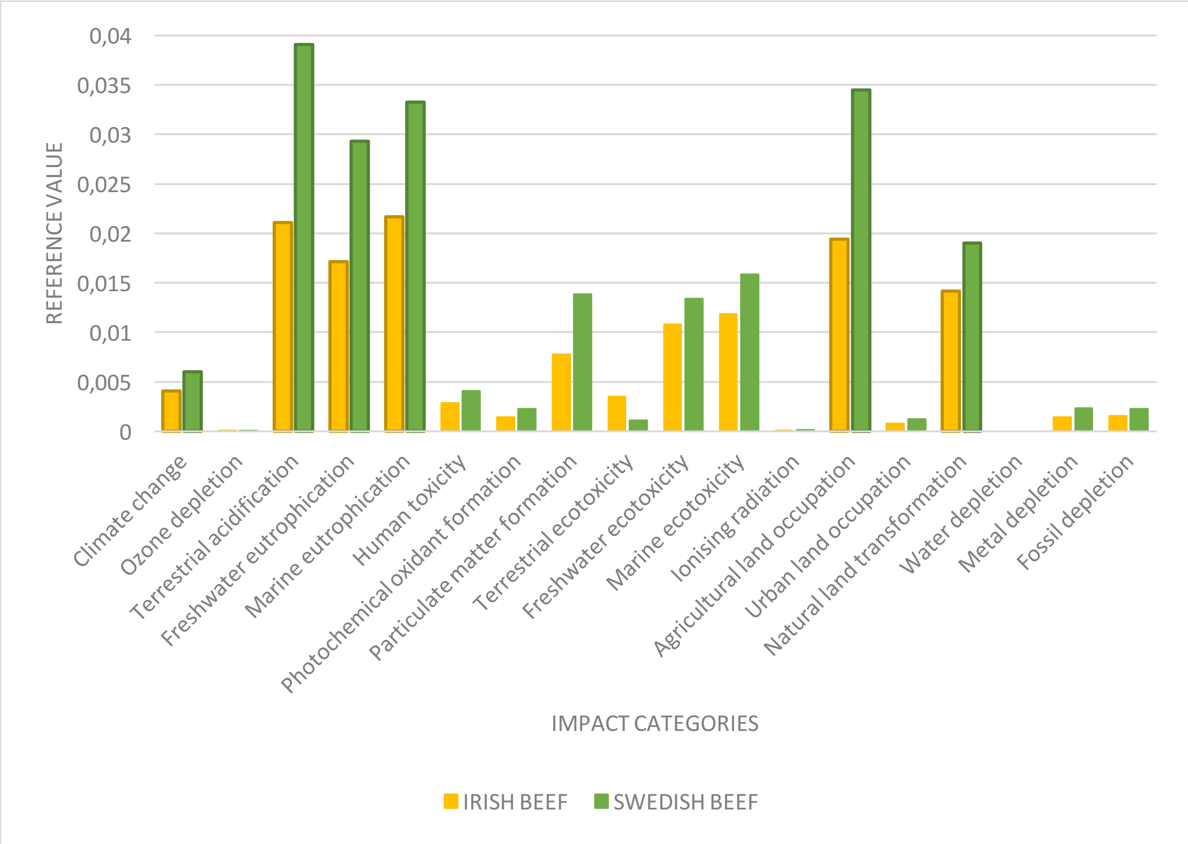


Figure 7: Comparative normalised results

Through normalization, the results in Figure 7 are given common dimensions and are placed in a broader context. The reference value is based on the average yearly environmental load in Europe divided by the number of inhabitants.

By comparing the normalized results of both the Irish and Swedish systems conclusions regarding their relative impacts can be drawn. The Swedish beef production has a higher contribution in 16 of the 18 impact categories, with the six major impact categories being:

- Terrestrial acidification
- Agricultural land occupation
- Freshwater eutrophication
- Marine eutrophication
- Agricultural land occupation
- Natural land transformation

These six main impact categories were selected below for closer analysis by comparing the characterized results for both Sweden and Ireland. A weighting process was not undertaken which is why the five largest impacts were selected together with climate change, due to its relevance in today's context.

Both Figure 8 and Figure 9 highlight that mainly the feed and partly the farming process impact the results and are the actual cause of the environmental impacts. For climate change, the largest impact comes from the farming process where the methane is the most significant compound. For the other impact categories, feed is the main contributor.

Figure 8: Normalized results from Ireland

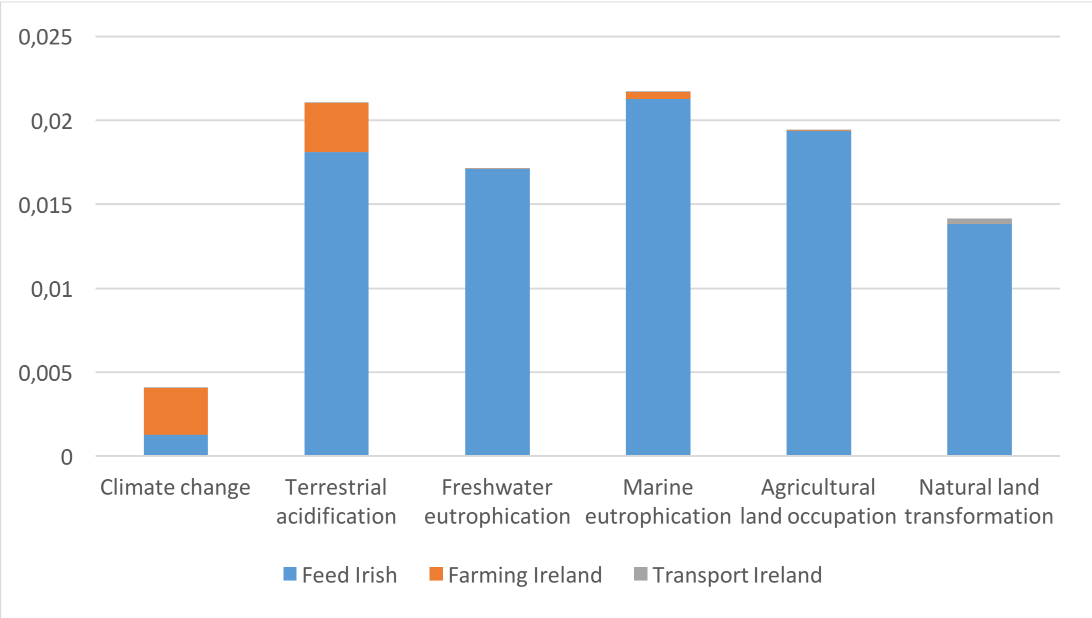
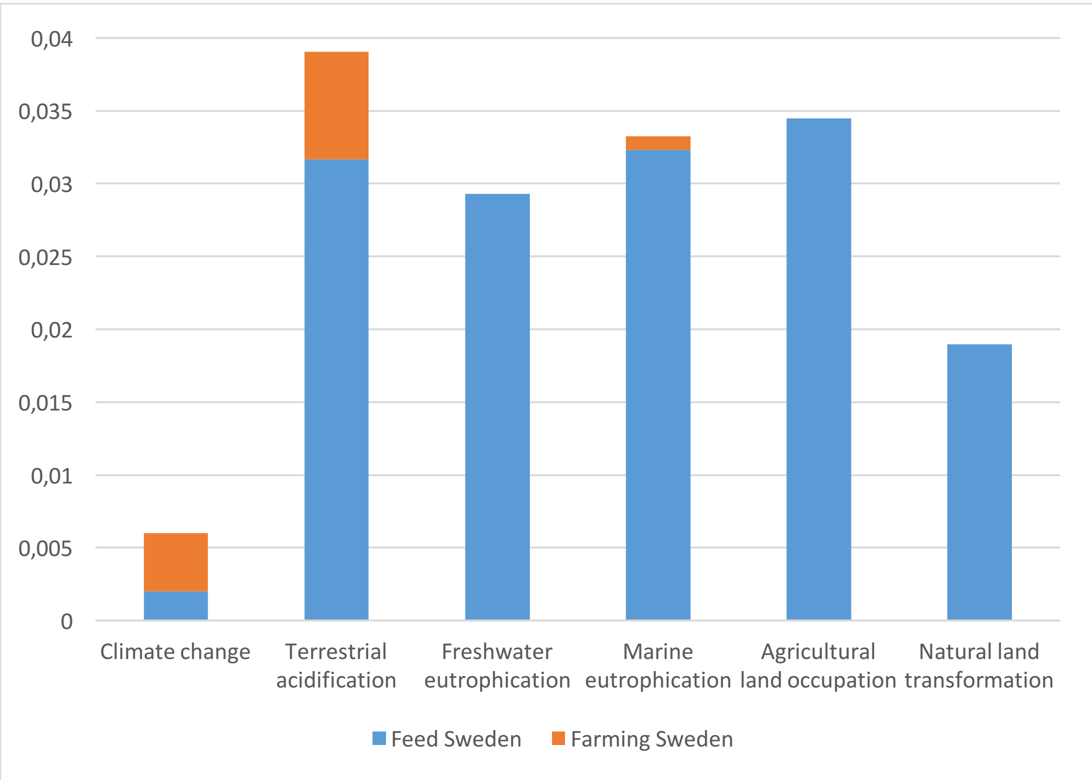


Figure 9: Normalised results from Sweden



8.2. Interpretation of characterised results

Figure 10: Characterized results of climate change

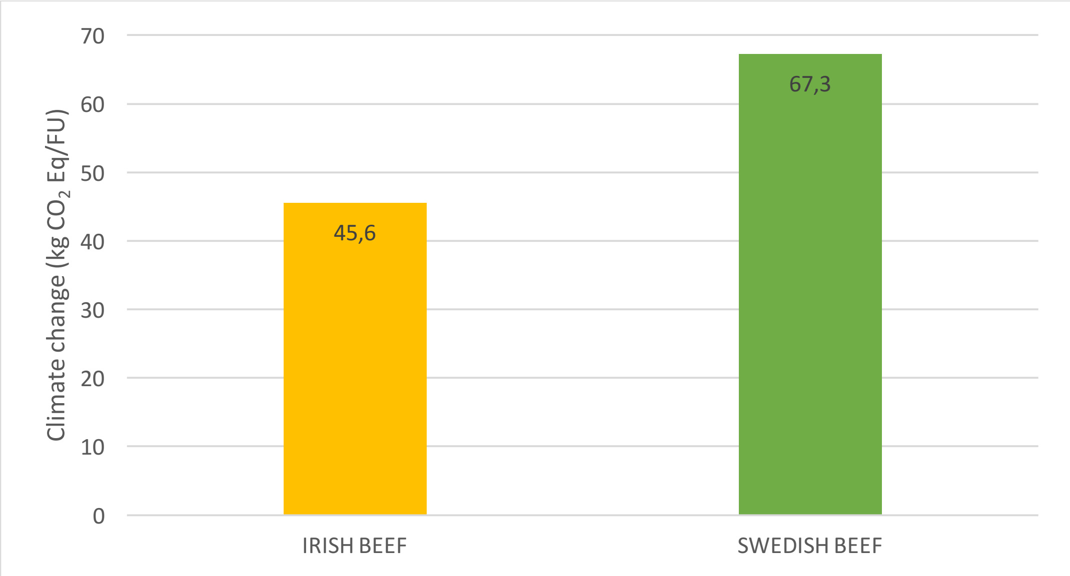
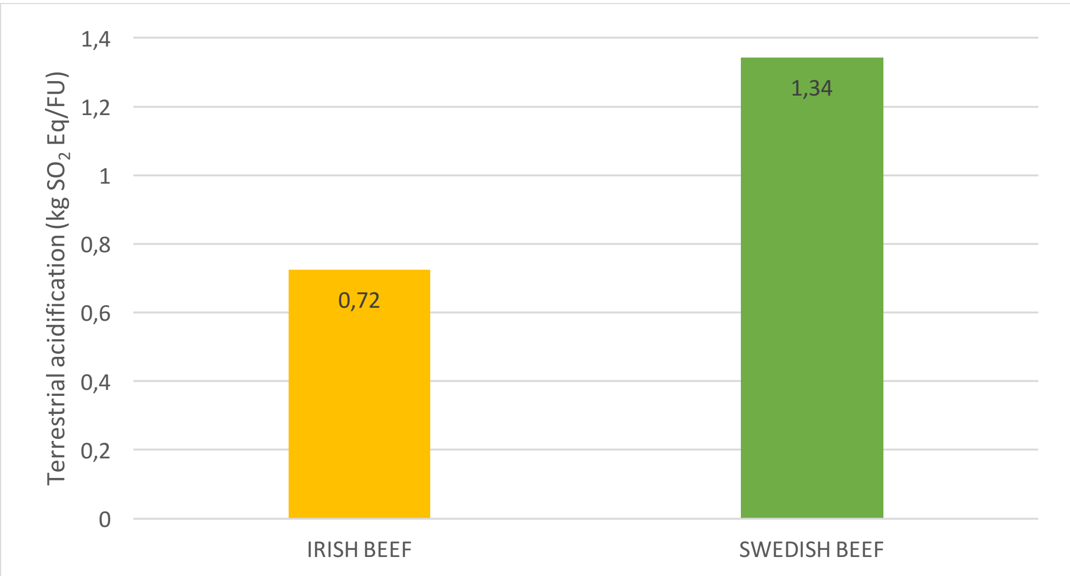


Figure 10 shows that for 1 kg of dressed Irish beef, the greenhouse gas emissions are 45,6 kg CO_2 Eq whereas for 1 kg of dressed Swedish beef, the emissions add up to 67,3 kg CO_2 Eq. The impact of Swedish beef on climate change is therefore larger than the impact of Irish beef. The CO_2 emissions during meat production mainly come from the methane (CH_4) emitted as the cattle digests the feed, the production of fertilizers and the transport of the feed from its country of origin. The longer lifespan of the Swedish cattle results in larger methane emissions and consumption of feed, resulting in higher greenhouse gas emissions.

Figure 11: Characterised results of terrestrial acidification

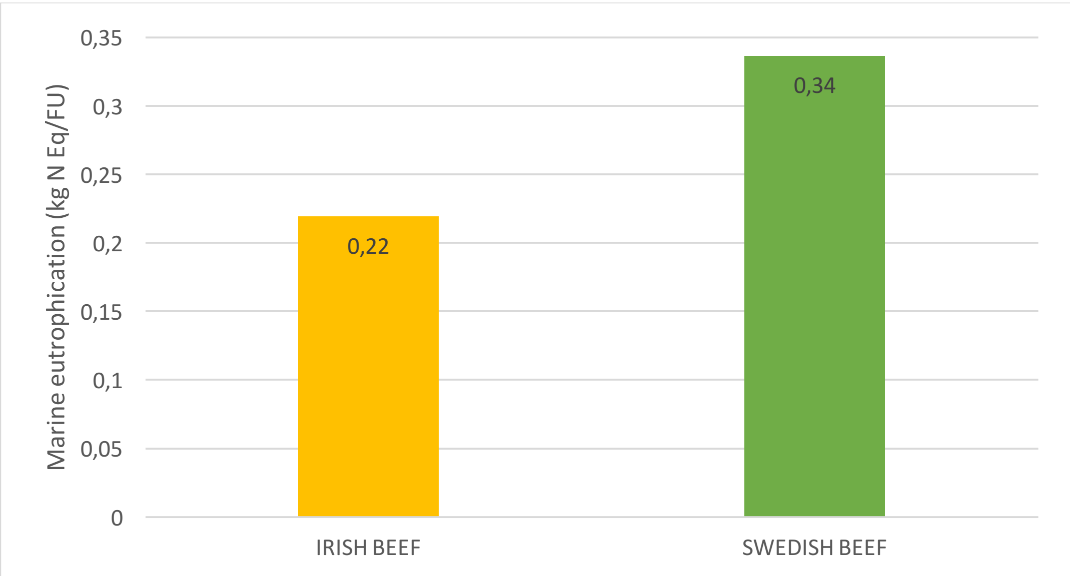


For terrestrial acidification, Irish beef emits 0,72 kg SO_2 Eq/FU and Swedish beef emits 1,34 kg SO_2 Eq/FU as highlighted in Figure 11 The cattle manure and fertilizers lead to acidification of both sensitive freshwater sources and forests. In this case, the longer lifespan of the Swedish cattle can also be determined as the cause of larger emissions.

Figure 12: Characterized results of freshwater eutrophication

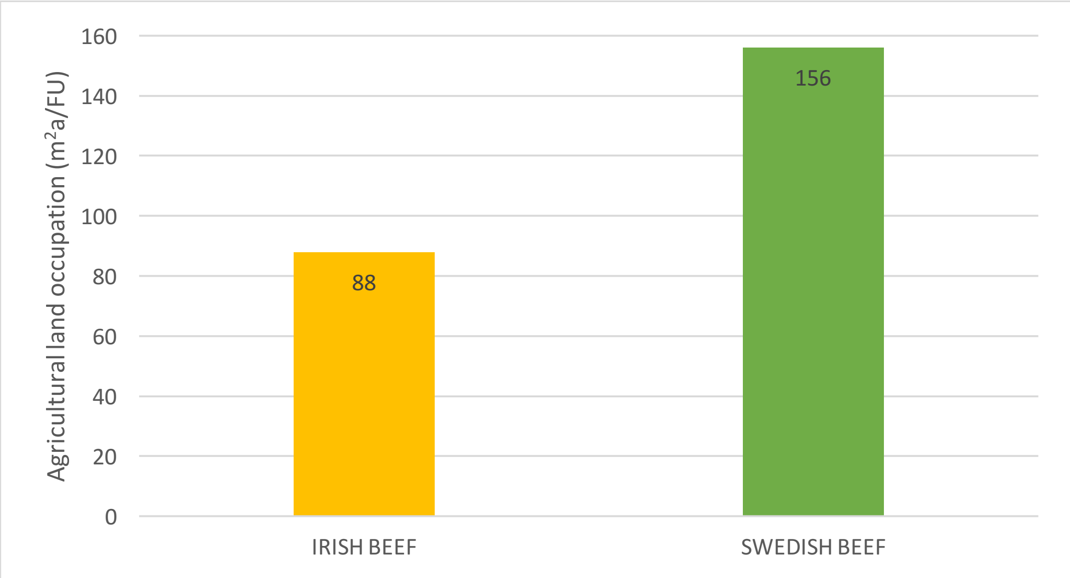
Eutrophication is triggered with the addition of phosphorous and nitrous to water bodies. These nutrients can be found in the fertilisers used during beef production. From Figure 12, Swedish beef generates 0,012 kg P Eq/FU whereas Irish beef only generates 0,007 kg P Eq/FU. Swedish cattle consume larger amounts of feed over their lifetime resulting in an increasing use of fertilizers, directly impacting the eutrophication of freshwater bodies.

Figure 13: Characterized results of marine eutrophication



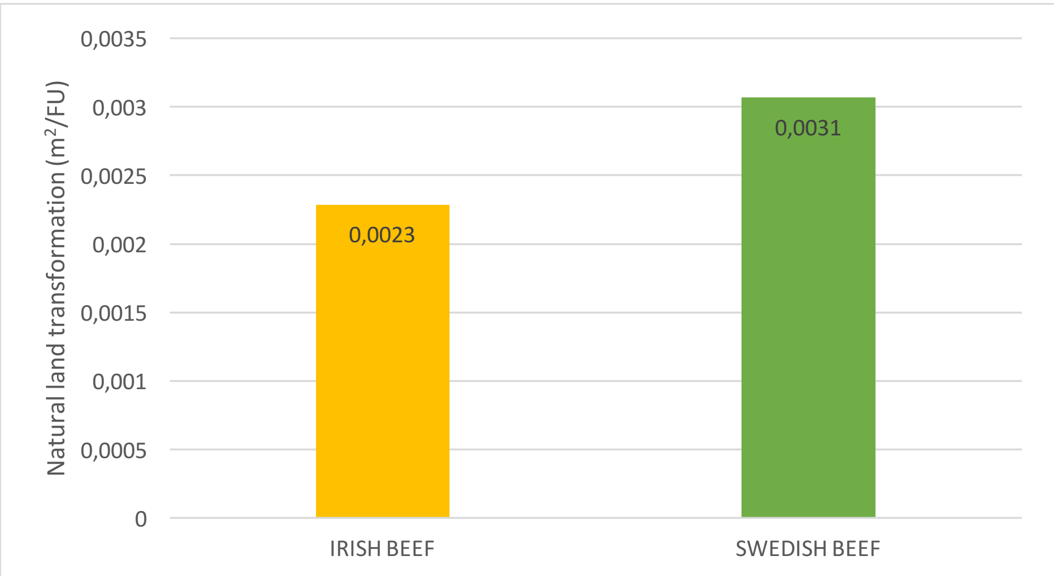
For marine eutrophication in Figure 13, Irish beef emits 0,22 kg N Eq/FU and Swedish beef emits 0,34 kg N Eq/FU. As above, the environmental impact comes from the fertilisers used and the higher consumption of feed for Swedish cattle explains the larger emissions for the Swedish production.

Figure 14: Characterized results of agricultural land occupation



The agricultural land occupation is larger in Sweden than in Ireland, with Swedish beef production using up to 156 m^2a/FU and Irish beef production 88 m^2a/FU (Figure 14). Swedish cattle graze more days compared to Irish cattle due to the harsher climatic conditions but since they live longer the agricultural land occupation is still larger. The production of feed also greatly impacts agricultural land occupation.

Figure 15: Characterized results of natural land transformation



As for agricultural land occupation, natural land transformation is larger for Swedish beef compared to Irish beef, with 0,0031 m^2/FU and 0,0023 m^2/FU respectively (Figure 15). Feed production and the grazing area of the cattle result in natural land transformation. Once again, Sweden has a higher natural land transformation area due to the longer lifetime of the cattle and larger feed production.

In short, the longer lifespan of Swedish cattle (Swedish cattle live on average two times longer than Irish cattle) is believed to be one of the main contributors to this important gap existing between Irish and Swedish meat production. A longer lifespan results in greater acidification since more cattle manure is produced and more feed will be needed using more fertilizers for crop cultivation which are the two main causes for acidification. Additional phosphorous and nitrous from the fertilizers also result in amplified eutrophication. The large impact on agricultural land occupation comes from the crop cultivation of the feed, which explains why the impact of Swedish beef is almost twice as large. In this LCA, allocation was avoided. However, the milk production of dairy cattle could have large impacts on the system evaluation. Therefore, a potential allocation calculation was conducted and can be found in Appendix 2: Description of potential allocation.

9. Hotspots and mitigation measures

9.1. Mitigation measures

From the interpreted results in this LCA study, several hot spots have been identified. Transport in both the Swedish and Irish system has a very small overall impact. Instead, it is the breeding that presents itself as a hot spot for the most significant impact categories. Acidification, eutrophication, land occupation and land transformation are the four impact categories that have been identified as having large environmental impact for both Swedish and Irish beef production. Climate change is also an impact category that needs to be regarded due to its vast impact on several other factors such as sea level rises.

9.1.1. Feed and Farming

The feed and farming are processes that have significant impact on the environment and if certain mitigation measures would be implemented they could decrease this impact. The large amount of methane exhaust during the enteric fermentation of the cattle lifespan but also methane exhaust from the manure process have a significant impact during the beef production system (see the network diagrams in appendix 1). The longer lifespan that cattle has the more methane will be exhausted, both from fermentation and manure and the more impacts on the environment.

By stimulating the growth of cattle, less methane will be exhausted and the environmental impacts will be decreased. Growth can be stimulated through different measures such as choosing a certain breed of cattle, quality of the feed that is given to cattle and cattle health (Sonesson U. , 2009).

The total climate impact that a suckler cattle has depends not only on the cattle itself but also on how many calves that it can give birth to during its lifespan. The healthier the cattle is the more calves it can give birth to and the less the environmental impact will be. By keeping the cattle happy and healthy, more calves can be born which yields a more efficient system.

The digestibility but also the taste of forage is an important parameter to consider if reduced methane exhaust is desired. If the feed consists of high quality, which often means higher digestibility with a higher fat content then the methane exhaust will decrease. To measure the digestibility in forage different laboratory tests can be conducted. Tests such as NIRS (Near Infrared Refelctive Spectroscopy) can measure both the digestibility and the nutrition value that exists in forage (Krizsan & Nyholm, 2012). Increasing the digestibility and nutrition value in forage would yield animal health, the environment and increase the efficiency of beef production systems in both Sweden and Ireland. Earlier study has shown that by increasing the fat content in the diet for dairy cattles with 2%, resulted in methane emission reductions by 17% (Weidema, 2008).

By providing farmers with information and tools on ways to measure the digestibility and fat content in feed, they could also find the “optimal” feed composition and contribute to reduced greenhouse gases. Healthy animals with low disease rates that have a high calf birth rate and eat on high digested, high fat content feed are ways to decrease the methane exhaust and decrease the environmental impacts during beef production.

9.1.2. Manure process

Nitrous oxide and methane is leached from the manure process which has a large impact not only on acidification, and eutrophication but also on climate change. Nitrous oxide although not showing a significant impact in the network analyses (see Appendix 1) have a high global warming potential and this needs to be considered since it will affect acidification and eutrophication. By improving the quality of the feed as has been suggested for reducing the methane, also the nitrogen content in the manure will be reduced and thus a reduction of both nitrous oxide and ammonia (Weidema, 2008).

Ammonia emissions contribute to acidification and can be partly reduced by adding acid and reducing pH in liquid manure. The technical aspects of handling manure, depending on what it look like, could also reduce the emissions of nitrous oxides and ammonia. To decrease the spread of liquid manure adequate channels must be constructed and a cooling system should be implemented (Weidema, 2008).

Covering the manure could also be a good way to mitigate both emissions of methane and other nitrogen compounds such as nitrous oxide. By covering the manure the nitrogen content could be kept in the manure and used as fertilizer for the feed crops. Earlier studies has shown that without any cover methane emissions are 12,4 kg CH_4 /cattle&year and with a plastic cover they are reduced to 8,3 kg CH_4 /cattle&year.

Depending on the quality and type of manure, it could be used for biogas production. In order to reduce methane emissions, the Swedish government recently introduced economic incentives for turning manure into biogas. A yearly 30 million SEK from 2016 to 2019 is given as support to farms that sign up for turning their manure into biogas (Logardt, 2015).

10. Sensitivity analysis

There are several potential sources of uncertainties when conducting a LCA. It is described in ISO14040 how to proceed with an uncertainty analysis, and where issues might occur. There might be uncertainties in the data sources due to random or systematic errors, assumptions made or the clustering of sources as well as values. The sensitivity analysis could be used to detect the most important parameters, and where to direct further quality research. If the uncertainties are detected it could also help in the earlier stages of data collection, to set the boundaries and aid in decision-making. It is important to remember that decision-making entails recognizing the limitations existing in knowledge obtained, and therefore it might be difficult to put one option in favor of another. However, LCA analysis is still a very useful tool for understanding comprehensive systems, and its environmental and health impacts and to try and base a decision upon (Curran, 2015).

Sensitivity analysis during this study has been used to change some of the parameters and see how the environmental impacts would change compared to the original parameters. By studying previous reports and through discussion in the group it was concluded that cattle both in Ireland and in Sweden could graze more days outside (increase the amount of grass and silage) and have a decrease in the amount of force feed that they eat. These were the parameters that were changed (see appendix 3 for the changes made) in order to see what the new scenario would look like.

10.1. Results

The results show that by increasing the days of grazing and decreasing the amount of force feed in both systems the impact from the agricultural land occupation was increased with 10% for both Sweden and Ireland. This is due to the increased days of grazing that cattle would need in order to consume more amounts of grass and silage. The natural land occupation has decreased in both countries because of the reduced required amounts of force feed.

The impacts on freshwater and marine eutrophication have decreased substantially in both Ireland and Sweden with a 45% decrease for marine eutrophication in Ireland and 38% for Sweden. This is due the less need of fertilizers that contain both phosphorous and nitrogen that are the main contributors to eutrophication when growing crops that are needed for force feed.

The impact on climate change in both Sweden and Ireland has decreased by changing the parameters although being a very small decrease (3% in Ireland and 0,4% in Sweden). The different impact categories and how they have changed with the new parameters can be seen in appendix 3.

The results imply that if the amount of grass and silage would be increased by having the cattle graze more days outside at the same time as reducing the amount of force feed, a positive outcome would be yielded with regards to a reduced environmental impact in many impact categories.

11. Discussion

Conducting a life cycle assessment can be strenuous and time consuming. LCA is a method that gives a good overview of a system, but it is not completely comprehensive. In this report the entire beef production processes in Sweden and Ireland have been assessed. The inventory was put together with data from a certain number of farms found in other LCAs read during the literature review. There are also studies that focus on "typical farms" with general data based on national statistics (Sonesson & Wallman, 2008).

One problem when collecting average data is the quality of the data. In this report, a lot of assumptions were made, see section 5.1 Data Collection. It has been challenging to access the same type of data for the two systems to allow adequate comparison. In some cases the data is based on a certain type of cattle and not an average value for all cattle types. The manure is based on a certain type of manure and there has been estimations in terms of feed intake of the cattle. These assumptions will have an impact on the results. There are a lot of uncertainties about how the production takes place in the two different countries. In this study, delimitations in the processes have been made since it was estimated that the two systems were similar. One delimitation was the process in the slaughterhouse and the other one was the impact when delivered to the consumer. This might have affected the results if there was a difference in the systems that was not acknowledged. In order to increase the comparability between different LCAs, it is important to maintain the same high quality data and the same methods for characterization. When several studies are conducted in the same field, data can be used several times and the time dedicated for data collection and data analysis will decrease (Mårtensson, 2009).

A conclusion from the literature review is that one kilogram of meat, in this case dressed beef, is a common functional unit when performing LCAs on meat. This unit is not comprehensive since it does not include the contents of nutrition, which can be considered a fundamental function of food. Other functions are also important, such as taste and price which are not included in the functional unit.

As stated before, it is not possible to compare different LCAs if the goal and scope, system boundaries and functional unit differ. However, it can be interesting to see what other LCAs on beef have concluded and if the results of this study is in line with previous LCA studies. There are a number of scientific articles about the climate impact of beef production as well as a number of reports on the same topic. There are large variations in the results of these studies that can be explained by methodological choices as well as system boundaries and how the allocation problems have been dealt with. Another important factor is how the production of beef has been carried out. The spam from the emissions of greenhouse gases can be estimated between 22-40 kg of carbon dioxide equivalents per kilogram of beef (Sonesson & Wallman, 2008). In this report the climate impact has been estimated to 67.3 kg CO2 Eq/kg of dressed weight in the Swedish case and 45.6 kg CO2 Eq/kg of dressed weight in the Irish case. The results of this study are much higher than the values found in literature from previous LCAs.

It is important to underline that there has not been any allocation performed in this study. The way to deal with allocation can have a large impact on the final results. In this study, allocation has not been performed in SimaPro. Instead a model to deal with allocation based on economic calculations has been performed. In many previous studies economical allocation has been adopted, where the beef gets 90% of the burden in terms of environmental impact and the co products, such as the skin get 10% of the impact (Cederberg C., 2004). Allocation problems due to milk production are not discussed in the reports reviewed in this study.

In this LCA the environmental impacts have not been weighted. If weighting would have been undertaken, the environmental impact regarding climate change would have been given a significant high value in this report. Climate change is one of the most alarming environmental impacts and the authors of this report consider it more severe than the other impacts that were of great matter in the results, such as land use, eutrophication and acidification.

The two systems can be compared in terms of efficiency where you look at how intensive or how extensive they are. An intensive meat production would try to maximise the output on the smallest area of land possible, in order to meet the growing demand of produce. These types of intensive strategies could have negative environmental effects leading to depletion of natural resources and concentrated pollution of land. A more extensive approach on agriculture might mean less efficient production but the stress on the land is minor, allowing it to recover more easily (Conestoga-Rovers & Associates, 2010).

This report includes a section about social aspects and animal welfare. This is usually not taken into account in a LCA but it is nevertheless something important to consider. This LCA shows that Irish beef has a smaller environmental impact than Swedish beef, mainly because of the smaller lifespan of the cattle. However, the literature study shows that the production of beef from Ireland is not as regulated as the Swedish meat production in terms of animal welfare.

The results of this report are line with previous studies regarding the significant impacts, although the actual values do not correspond. Several aspects within this report are based on assumptions, allocation has been overlooked and more processes in the production chain could have been taken into account. For future studies, it would be advised to focus on a comparative study of two specific systems with the collection of first source accurate data, avoiding allocation.

12. Conclusion

By conducting this comparative attributional life cycle assessment, the following conclusions have been made:

- The Swedish beef production system has a higher environmental impact in all the chosen impact categories including: climate change, eutrophication, acidification and land use & land change.
- Feed has been identified as a hotspot in all impact categories besides climate change where farming has the most significant impact due to the emissions of methane.
- Contrary to popular belief, the transport of the meat from Ireland to Sweden has very little impact compared to the production of feed and the farming process.
- Further data collection and analysis must be conducted in order to have a better comparative study for both systems and present better decision-making advice for the consumer.

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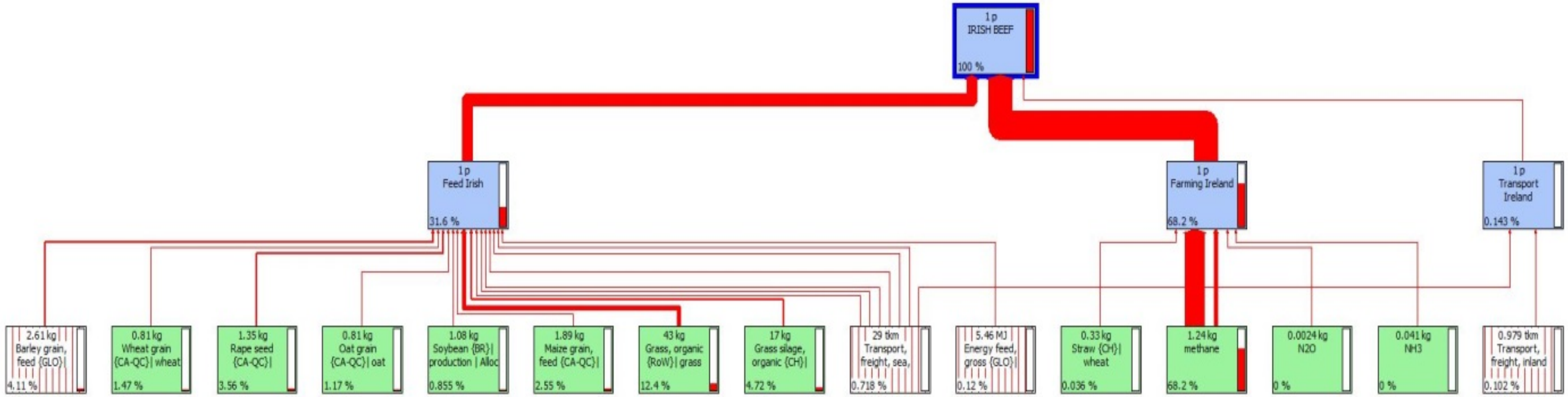
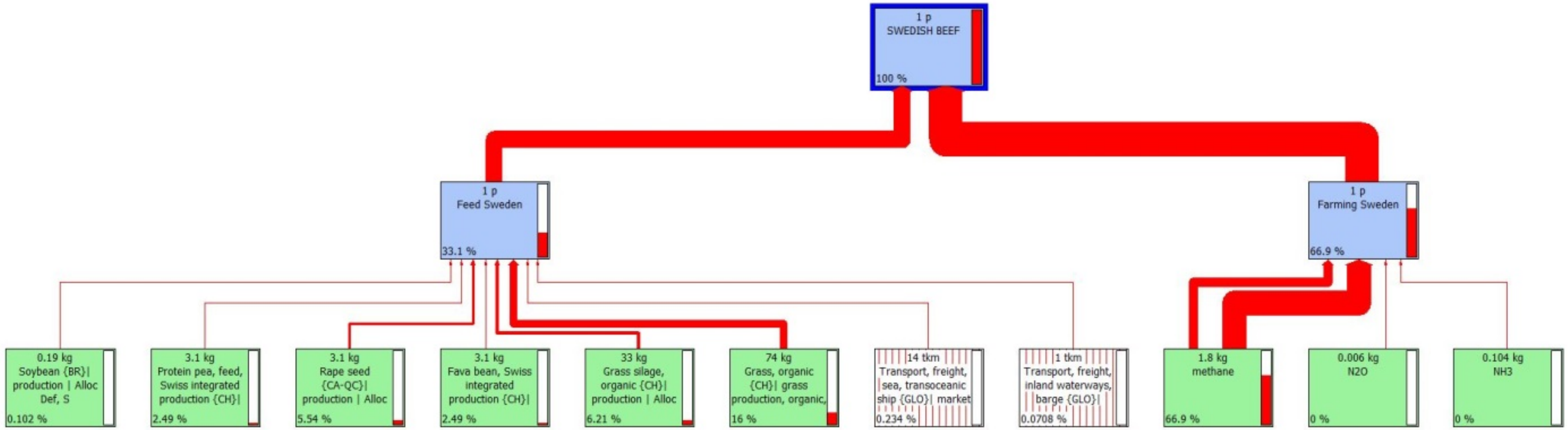
Appendix 1: Network diagrams for Ireland and Sweden

Network, cut off 0% Ireland



Network, cut off 0 % Sweden



Appendix 2: Description of potential allocation

If a process in a system has more than one output, it can be useful to deal with the allocation. When the process is divided into parts it is easier to see their specific impacts. When a system is "multi-functional" there are different ways to proceed with the allocation such as avoidance, allocate in- and outputs between useful coproducts and if physical relations cannot be made, allocation could be done by using other relations (Curran, Life Cycle Assessment Student Handbook, 2015).

In this report a potential allocation was conducted manually, without using any software, based on economic value. The economic approach was favoured before one of protein content because of the difficulty to perform the latter.

In the **Error! Reference source not found.** below it is estimated that each cattle will produce the same average weight of beef regardless of the time it lives. The average weight of a cattle is estimated to be 290kg for the Irish and 288kg for the Swedish cattle. For this calculation the dairy cattle are not separated from the life stock as being 50% of the cattle in Ireland, but it is assumed that all cattle produces 50% of milk and 100% of beef.

The number of dairy cattle varies between the two countries and so does the average life span. The milk production is first calculated from an average production per month, and then added up to the total amount of months the cattle lives. When the value of the milk is weighted it means that only 50% of the cattle in Ireland will produce this amount of milk and 65% of the cattle in Sweden. In the end the total price for the milk from one average cattle is compared to the price for the meat from one cattle.

Allocation table:

	Ireland	Sweden	Both
Dairy cattle [%]	50	65	
Average weight of beef from one cattle [kg]	290	288	
Life span [month]	18	45	
Milk produced [l/month]			750
Milk produced [kg]	13500	33750	
Market value milk [sek]			9
Market value beef [sek]			200
Price for beef per animal [sek]	58000	57600	
Price for milk per animal [sek]	121500	303750	
Weighted [sek]	60750	197438	
Share of beef [%]	95	29	
Share of milk [%]	5	71	

Appendix 3: Sensitivity analysis

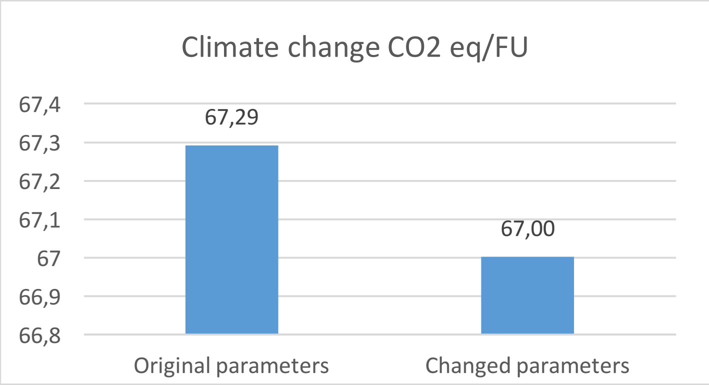
The tables below show the new inputs made in the sensitivity analysis. The lifespan of the cattle is estimated to be 18 months in Ireland and 45 months in Sweden.

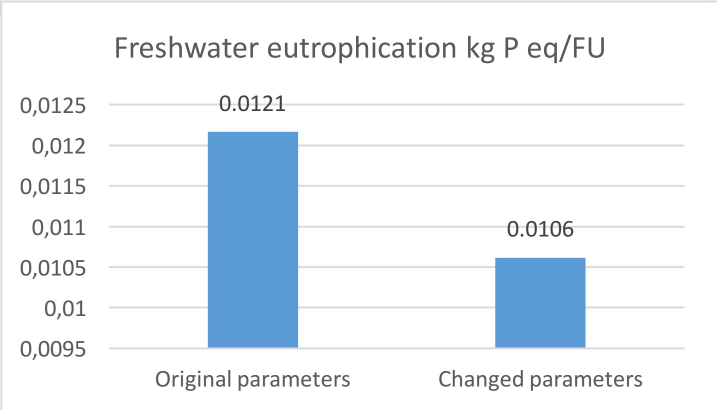
Decreased amount of force feed by 1/3, increased amount of grass and silage		
	Ireland per FU in kg	***Assumption***
Barley	0.87	Initial value divided by 3
Wheat	0.27	
Molasse	0.15	
Rape seed	0.45	
Oats	0.27	
Soy	0.36	
Maize	0.63	
Silage	22.1	Initial value times 1.3
Grass	55.9	Initial value times 1.3
Transport	-	Unchanged

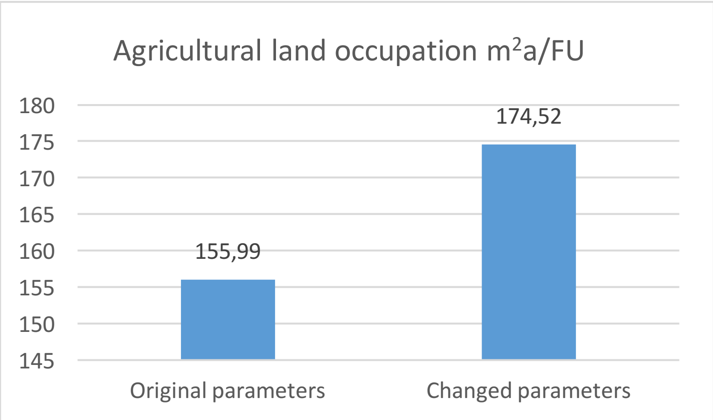
Decreased amount of force feed by 1/3, increased amount of grass and silage		
	Sweden per FU in kg	***Assumption***
Soy	0.06	Initial value divided by 3
Broad bean	1.03	
Pea	1.03	
Rape seed	1.03	
Sillage	42.9	Initial value times 1.3
Grass	96.2	Initial value times 1.3
Transport	-	Unchanged

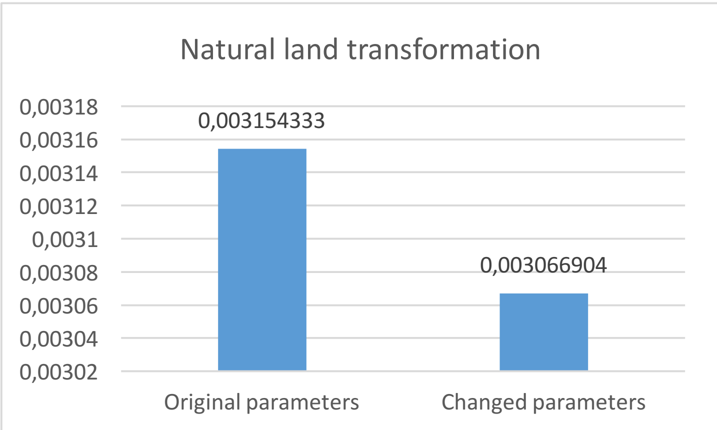
Results from the sensitivity analysis

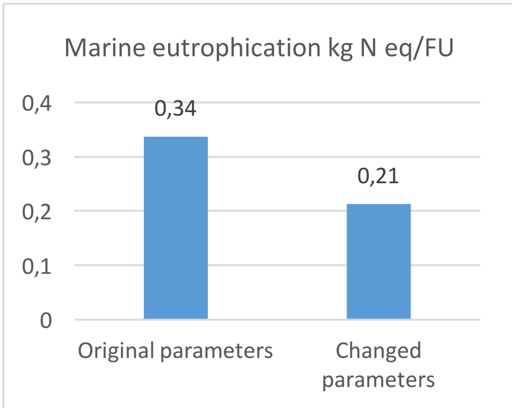
For Sweden



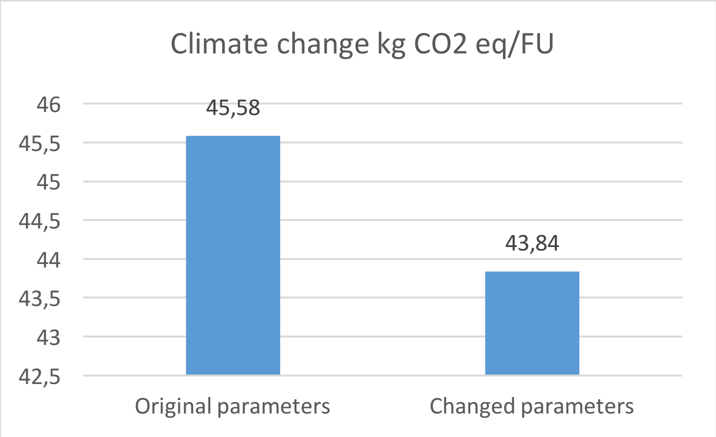


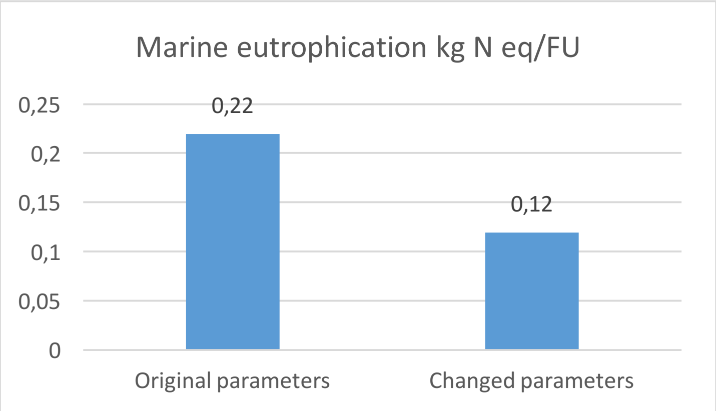


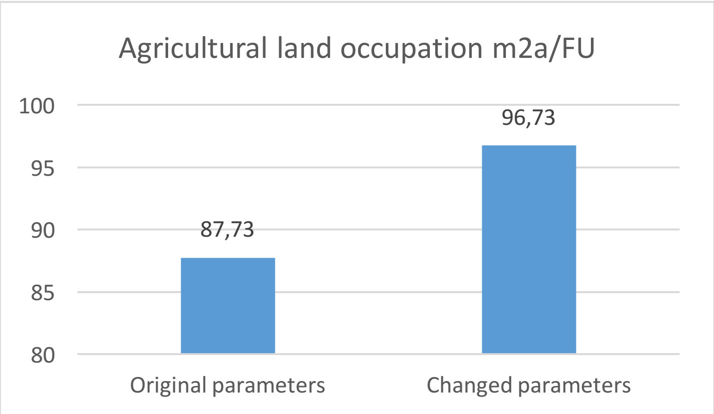


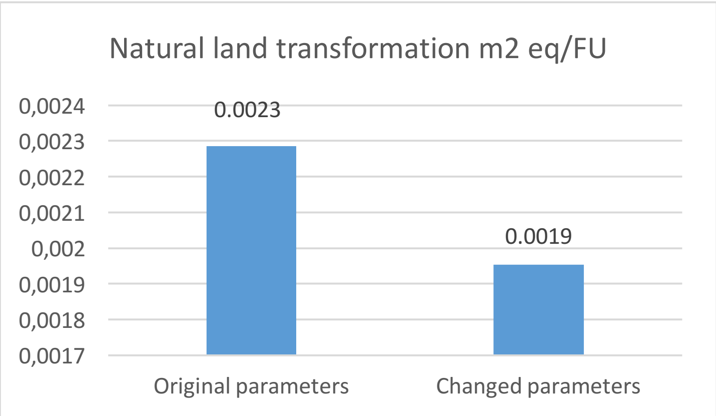


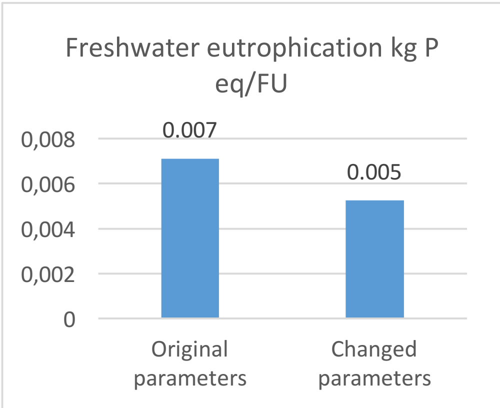
For Ireland


Climate change kg CO2 eq/FU
46
45,5
45
44,5
44
43,5
43
42,5
45,58
43,84
Original parameters
Changed parameters


Marine eutrophication kg N eq/FU
0,25
0,2
0,15
0,1
0,05
0
0,22
0,12
Original parameters
Changed parameters


Agricultural land occupation m2a/FU
100
95
90
85
80
96,73
87,73
Original parameters
Changed parameters


Natural land transformation m2 eq/FU
0,0024
0,0023
0,0022
0,0021
0,002
0,0019
0,0018
0,0017
0.0023
0.0019
Original parameters
Changed parameters


Freshwater eutrophication kg P eq/FU
0,008
0,006
0,004
0,002
0
0.007
0.005
Original parameters
Changed parameters