Side Streams Throughout the Food Supply Chain in Västra Götaland

A Study of Reported Data, Interviews with Food Producers and a Simplified LCA Case Study

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Abstract

The importance of resource efficiency in the food supply chain is clear, since this sector is one of the biggest contributors to the negative environmental impacts globally.

This thesis project aimed to examine food side streams throughout the food supply chain in Västra Götaland, to map out how much has already been covered statistically and what gaps there are in the data for future research to cover. It also aimed to investigate how the food processing industry in Västra Götaland consider their side streams, how they deal with them, what hinders they are facing and how they could be supported to be able to manage the side stream in a more sustainable way. This was made through a webform and telephone interviews. Lastly the aim was to perform a simplified life cycle assessment (LCA) case study with a side stream of potatoes from a snack producer, comparing the global warming potential for cogeneration of the potatoes, producing combined power and heating, and anaerobic digestion of the potatoes, producing biogas and digestate.

The conclusions for the mapping of the side streams in the food supply chain in the region were that there were major gaps in the data material covering the primary production and the food processing sector, especially regarding non-waste side streams. The side streams from the consumer sector were best covered.

The conclusions for the interviews with the companies within food processing industry were that all participants worked with their side streams in some way, and that incitements behind different ways to handle their side streams were financial aspects and environmental aspects. They were hindered by for example not having the correct equipment, money for investments, or that they find legislation regarding responsibility and quality requirements and having to be registered as feed producers too complicated.

The conclusion for the LCA case study was that from a global warming potential perspective, it is better to produce biogas and digestate from the side stream potatoes than producing combined power and heating.

For future research it is recommended to regularly perform similar coverage of the side streams in the food supply chain in Västra Götaland, and to interview companies within the food processing industry at regular basis, to keep track of changes and encourage improvement.

Sammanfattning

Vikten av resurseffektivitet i livsmedelskedjan är tydlig, eftersom denna sektor är en av de största bidragarna till negativ klimatpåverkan globalt.

Målet med den här uppsatsen var att utforska sidoströmmar av mat inom livsmedelskedjan i Västra Götaland, för att kartlägga hur mycket som redan är täckt i statistiken och vilka luckor i datamaterialet som finns för framtida forskning att täcka. Dessutom var målet att undersöka hur livsmedelsproducerande företag i Västra Götaland ser på sina sidoströmmar, hur de hanterar dem, vilka hinder de ser och hur de bäst kan stöttas för att de ska kunna hantera sina sidoströmmar på ett mer hållbart sätt. Detta gjordes genom en webb-enkät och telefonintervjuer. Slutligen ämnade uppsatsen utföra en förenklad livscykelanalys (LCA) i en fallstudie över en sidoström av potatis från en snacksproducent, med en jämförelse av den global uppvärmningspotential för att producera antingen kraftvärme eller biogas och rötrest från potatisarna.

Slutsatsen från kartläggningen av sidoströmmar i regionen var att det fanns stora luckor i datamaterialet för primärproduktion och livsmedelsproducenter, speciellt gällande sidoströmmar som inte är avfall. Sidoströmmar från konsumentsektorn var bäst kartlagda.

Slutsatserna från intervjuerna med företag inom livsmedelsproduktionssektorn var att samtliga av de deltagande företagen arbetade med sina sidoströmmar på något vis, och att incitamenten bakom olika sätt att hantera sidoströmmar var ekonomiska aspekter och miljömässiga aspekter. De hindras till exempel av att inte ha korrekt utrustning, pengar för att kunna investera, eller att de upplever att lagstiftningen gällande ansvar och kvalitetskrav och att behöva vara registrerad som foderproducent som för komplicerat.

Slutsatsen för LCA fallstudien var att från perspektivet global uppvärmningspotential så är det bättre att producera biogas och rötrest från potatissidoströmmen än att producera kraftvärme.

För framtida forskning är det rekommenderat att regelbundet utföra liknande kartläggningar av sidoströmmarna i livsmedelskedjan i Västra Götaland, och att intervjua företagen inom livsmedelsproduktion med jämna mellanrum, för att hålla koll på förändringar och uppmuntra förbättringar.

Acknowledgments

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Further, I would like to send gratitude to the company representatives that filled in my webform and participated in the interviews: Eric Ljungström from Gunnar Dafgård AB, Magnus Larsson from Arla Foods Götene, Eva-Marie Åsberg from Pågen AB, Christer Rosén from Källbergs Industri AB, Carsten Jörgensen from Atria Sweden, Ingela Fondin from Estrella AB, Krister Lundström from Triumf Glass AB, Angela Oberdorfer from Bars Production, Josefin Jönsson from KLS Ugglarps, Maria Larsson from HK Scan Sweden AB and Mikael Dugge Engström from Dugges Bryggeri AB. Special thank you to Ingela Fondin, Estrella AB, for providing me with an interesting case for the LCA case study. Thank you also to Ola Karlsson from Foderlotsen AB, Anna-Karin Modin-Edman from Arla Foods AB, and everyone else that I have met or been in contact with during this thesis project, for answering my questions and meeting my speculations with knowledge. Without your help this thesis report would be but an empty shell.

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To write a master's thesis during a global pandemic meant that I spent the majority of the spring at home in my two-room apartment. Therefore, I would like to thank all my friends that I have made throughout my five years here at LTH. Without our occasional gaming nights, barbecues, picnics or just text messages and phone calls to check in on each other I would have most likely gone mad during these weeks of self-isolation.

Lastly, I would like to send gratitude towards my beloved family. To my boyfriend Manfred for spending endless hours listening to me ranting about my thesis project, for never doubting me even when I doubt myself and for pointing out the singing birds when I don't see them. To my parents for always showing interest and enthusiasm regarding my studies, no matter how much you understand or how interested you actually are. To my sisters, Ida and Malin, for being my role models and superheroes. When I worried about not having an as meaningful education as you do, you both expressed that you would like to have a "normal" job, where you can wear normal clothes, go to meetings and drink caffè latte, instead of wearing hospital scrubs (*read: pyjamas*) and attending to the never-ending stream of patients. Thank you for always reminding me of what is important in life and giving me words of encouragement!

"Exactly!" said Deep Thought. "So once you do know what the question actually is, you'll know what the answer means."
- Douglas Adams, The Hitchhiker's Guide to the Galaxy

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1 Introduction

The food supply chain is one of the largest contributors to the negative environmental impacts globally (FAO, 2019). It is therefore important that the resources in the food supply chain are used as efficiently as possible, as to minimize this impact. Today, about one third of all food that is produced does not end up being consumed, meaning that the amount of resources used to produce that food was unnecessary (FAO, 2015). One of the global goals for Sustainable Development in the 2030 Agenda, set by the United Nations Development program, is to halve the global food waste by 2030. The Swedish government have set up national goals and action plans to meet the global goals, and a big part of the Swedish food production is located in Västra Götaland making that into an important focus area.

For this master's thesis project, the focus was on the side streams from the food supply chain in Västra Götaland. To be able to improve the use of resources in the food supply chain in Västra Götaland, it is important to know how the situation looks today and what potential for improvement there is. A hypothesis going into this thesis project was that a lot of data regarding food loss and waste is already known from previous studies, but that the data for the entire food supply chain has not been put together. It is also of importance to identify the hinders that the food processing industry is facing because through knowing their driving forces and limitations, one could build a representative picture of the situation today and see the potential for future improvements.

1.1 Objectives

The objectives of this thesis were to

(i) Map out the side streams across the food supply chain in Västra Götaland by putting together official statistics and studies.

(ii) Interview food producers in Västra Götaland about which limitations and potentials they see with managing their side streams, to see how to best support the food production industry in managing their side streams in a sustainable way.

(iii) Assess the potential change in greenhouse gas emissions from different management options for side stream potatoes from a snack producer in Västra Götaland.

This means that the thesis project aimed to investigate side streams on three levels in Västra Götaland with increasing definition; side streams in the entire food supply chain, side streams in the food processing sector and finally one side stream at one specific food producer.

1.2 Delimitations

Only side streams in the food supply chain was investigated, and only data for Västra Götaland was included in the study. Important to note here is that Västra Götaland is a geographical area with open borders, meaning that the region is not a closed system and there is no tracking of what goes in and what goes out. It is likely that both unprocessed food, processed food, biogas substrate and side streams to animal feed are being shipped both in and out of the region, as is illustrated in Figure 1.

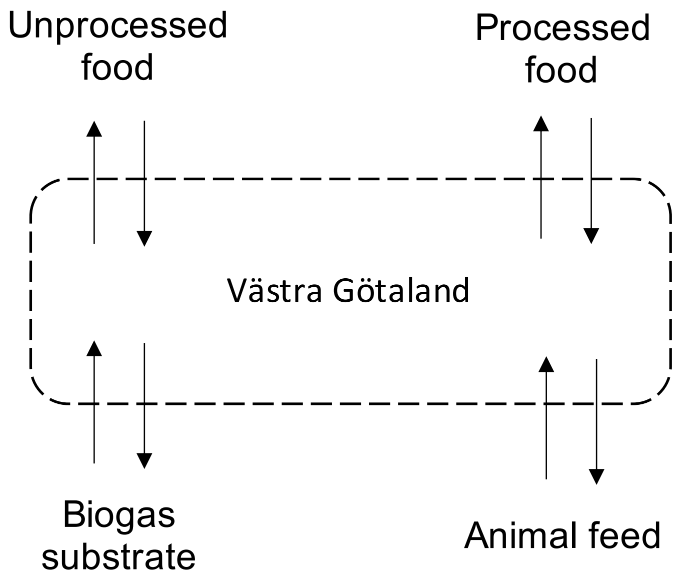


Figure 1: Västra Götaland is not a closed system, and this figure illustrates that material can pass both in and out of the region. The mentioned material groups are only examples, the shipping of material over the border is not limited to only them.

The tracking of this is outside the scope of this thesis, but it might be worth noting that for example all the potential biogas substrate in Västra Götaland might not be treated there, and vice versa all the produced biogas in Västra Götaland might not come from substrate from the region.

The focus was on the resources leaving the food supply chain, and not on the resources entering. The definitions for food and side streams are described in section 2.2 and the food supply chain is described in section 2.3. Anything outside these definitions were considered out of scope for this thesis report. This thesis project did not include gathering or calculating new data, but instead to map and compile existing data, and by that discover potential data gaps. The project focus was on occurrence and management of the existing side streams, preventative measures to reduce side streams were not assessed.

For the interviews in section 4, only companies in the food processing industry in Västra Götaland were included. The names of the companies were removed for anonymity reasons. In the LCA case study in section 5, the focus lay on the global warming potential alone and only regional solutions that were realistic for the snack producer were investigated.

2 Background

This section provides a background about the region Västra Götaland, the definitions used in the thesis report, the food supply chain, the environmental impact of food and food loss and waste and the food recovery hierarchy.

2.1 Västra Götaland

Västra Götaland is a geographical territory in south west of Sweden, with about 1.7 million inhabitants in 2018 (SCB, 2019). The area is approximately 300 km long and 250 km wide, and situated between the lakes Vänern, Vättern and the Atlantic Ocean. There are 49 municipalities in the area and the largest city is Göteborg (Västra Götalandsregionen, 2018).

Västra Götalandsregionen have set their own environmental goals and action plans to reach them, and they call this *Klimat 2030 - Västra Götaland ställer om*. The goal is to be completely fossil free in 2030, and the four focus areas to reach this goal was set to (i) sustainable transports, (ii) climate-smart and healthy food, (iii) renewable and resource efficient products and services, and (iv) healthy and climate-smart homes and buildings. The second focus area is especially connected to this thesis project, since it involves being more resource efficient within the food supply chain, by reducing the food loss and waste (Länsstyrelsen Västra Götalands län & Västra Götalandsregionen, 2017).

2.2 Defining food and side streams

This thesis project is about food, food loss and waste, and side streams from the food supply chain. FAO and WHO (2013) defines food in their *Codex Alimentarius* as follows:

> *"Food means any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of 'food' but does not include cosmetics or tobacco or substances used only as drugs."*

Of the food there are edible and inedible parts, where the inedible parts are for example bones and peels. What is considered to be edible versus inedible varies over time and between different cultures.

Food loss and waste (FLW) are terms commonly used in different reports and official publications regarding similar subjects as this report, but there is not one single definition for what FLW includes. FAO (2019) have the following definitions in their publication *The state of food and agriculture 2019*:

> **Food loss** is the lost amount of quantity or quality in the food, which is reduced early in the food supply chain, before the food reaching retailers and consumers.
>
> **Food waste** is the lost amount of quantity or quality in the food, which is reduced late in the food supply chain, at retailers and consumers.

In the FAO definition, any food that is diverted from the food supply chain to become feed or come to use in other industrial ways are not included in FLW since this is an economically productive way for the food to retain some of its original value. Food that goes to for example landfills, composting or anaerobic digestion is however considered FLW since these are waste treatment processes (FAO, 2019).

To keep track of FLW the FAO has created the **Food Loss Index (FLI)** and the **Food Waste Index (FWI)**. Similar to food loss and food waste, the FLI covers the losses early in the food supply chain and FWI covers the waste late in the food supply chain.

The indexes only include quantitative losses and are based on percentages instead of tonnes, since the production and population changes over time which then would affect the amounts of FLW (FAO, 2019).

One problematic aspect regarding using these definitions in this thesis project is that the Swedish terms 'matavfall' and 'matsvinn' both could be directly translated to food waste. However, neither of the definitions for food loss or food waste are the same as the definition for 'matsvinn' which includes only the edible parts of the food waste. These terms also have a rather negative sound to them, meaning that food producers might not want to be related with it.

For this thesis, the term 'side streams' has been chosen with the following description, inspired by Lindbom et. al (2013):

> **Side streams** includes all the food that throughout the food supply chain for various reasons ended up being used for something other than it was intended for.

This includes FLW as defined above, but also the residual food that for example is caused by overproduction, that pass the best before-date or that goes to feed. Although it is important to note that only the substances that has once been defined as food is included, but both the edible and inedible parts.

2.3 The food supply chain

The side streams throughout the food supply chain were mapped in this thesis project. The food supply chain includes all the steps that a food substance goes through from the field and farm all the way to the consumer. It can be divided into the following segments, as shown in Figure 2, with definitions based on FAO (2019); Primary production, Processing, Retailers and Consumers.

Figure 2: The food supply chain, based on FAO (2019).

> **Primary production** is the very first segment in the food supply chain and takes place on the farm. It includes steps such as agricultural production, harvest and slaughter, post-harvest, -slaughter and -catch operations, and also some primary processing such as deshelling and drying.
>
> **Processing** is where the food is refined and transformed into its final form through for example pasteurization, cooking and fermentation.
>
> **Retailers** distributes the foods to consumers.
>
> **Consumers** include both public consumption (i.e. restaurants, public services) and household consumption.

The consumers are the last step of the food supply chain, which then ends when the food is consumed or in other way removed from the chain as a side stream.

2.4 The environmental impact of food

The food supply chain leaves a massive environmental footprint, causing around 30% of total anthropogenic greenhouse gas emissions and is contributing to both acidification, freshwater scarcity, biodiversity loss and eutrophication. Deforestation is a major problem due to the increasing land use for food production (Aleksandrowicz, et al., 2016) (Poore & Nemecek, 2018).

Previously only the nutritional aspects of the food were considered when making official diet recommendations, but with the new focus on sustainability it has become more relevant to also include the environmental impacts in the recommendations. The Nordic Nutrition Recommendations 2012 includes an entire chapter about sustainable food consumption and environmental issues regarding food (Nordic Council of Ministers, 2014). In the western countries, overconsumption of food is common due to the availability and economic situation where most people are able to buy more food than they actually need. This results in health issues, over production and waste (Röös, et al., 2015).

When all of the food produced in the food supply chain is not consumed in the end, their environmental footprint is very inconvenient. About one third of the globally produced food for human consumption ends up as waste, which corresponds to 8% of the total anthropogenic greenhouse gas emissions and in 2012 the wasted food meant economical losses of a total market value of 936 billion USD (FAO, 2015). The average amount of food waste in Swedish households in 2018 was estimated to 95 kg per person and of this about 45 kg was considered unnecessary waste due to it being thrown away even though it was edible (Andersson & Stålhandske, 2020).

Of the sustainable development goals for sustainable development, which is a part of the 2030 Agenda set by the United Nations Development program in 2015, goal number 12 can be directly connected to the food supply chain and this thesis; Responsible consumption and production. The goal is divided into several milestones, and milestone 12.3 is to halve the global food waste at the retail and consumer levels and reduce the losses along the entire food supply chain including the post-harvest losses by 2030 (UNDP, 2020).

A specific part of the environmental footprint is the climate footprint. Different food products have different climate footprints, depending on where and how they are produced. A climate footprint is expressed as the kg of CO_2-equivalents that the food product has emitted throughout its entire lifecycle, which includes several stages in the food supply chain. To produce vegetables in artificially heated greenhouses is for example more energy demanding in comparison to having them grow outside in the sun, meaning that two very similar vegetables can have completely different climate footprints because of how they are produced (FAO, 2015).

2.5 Food waste drivers

Canali et al. (2017) divides the food waste drivers into groups based on three contexts; Technological, Institutional and Social. The technological food waste drivers they identified were for example the unpredictability of supply and demand volumes which leads to over production, perishability of food staples, damages during transport and cold chain inefficiencies. The institutional food waste drivers were further divided into Business management and economy and Legislation and policy. An example on food waste drivers identified in the business management and economy subgroup are retailers' expectations on a high proportion of the shelf-life remaining at delivery date, meaning that even though the food has not passed the best-before-date it cannot be delivered. Identified food waste drivers within the subgroup legislation and policy were for example the high expectations on the standards on fruits and vegetables, as well as different policies and legislations that restrict the usage of residual food for new purposes. The food waste drivers within the social context were for example small households, the presence of children and a higher income level.

It was also identified that lack of information and knowledge, about for example date labels, the correct usage of fridges and food handling in general, is a major food waste driver in that context (Canali, et al., 2017).

When looking at the amounts of food loss and waste in different sectors in the food supply chain it is important to note that how the food is handled in the beginning of the chain might affect the quality and cause higher amounts of waste in a different sector. Everything is connected and cannot be viewed separately. In retail, the most common reason for waste is that products turn bad before they are sold or because they get close to or pass their best-before or use-by date. The underlying cause might be poor quality, that the goods are damaged when delivered, or that the demand did not meet the expectations meaning that the retailer bought in more than they managed to sell. It is not uncommon that the unsold products are returned to the producers, meaning that the waste does not appear in the retail step in the food supply chain but rather in the processing step (Westöö & Jensen, 2018).

2.6 The food recovery hierarchy

There are many similar frameworks for the preferred order to manage food loss and waste. FAO (2013) talks about The Food Recovery Pyramid, meanwhile EPA (2019) describes The Food Recovery Hierarchy, and Papargyropoulou et al. (2014) instead calls it The Food Waste Hierarchy. Jordbruksverket (2020) includes a version of the frameworks modified for the Swedish systems. All the different frameworks are overlapping and Figure 3 is a compiled version of all the above-mentioned versions.

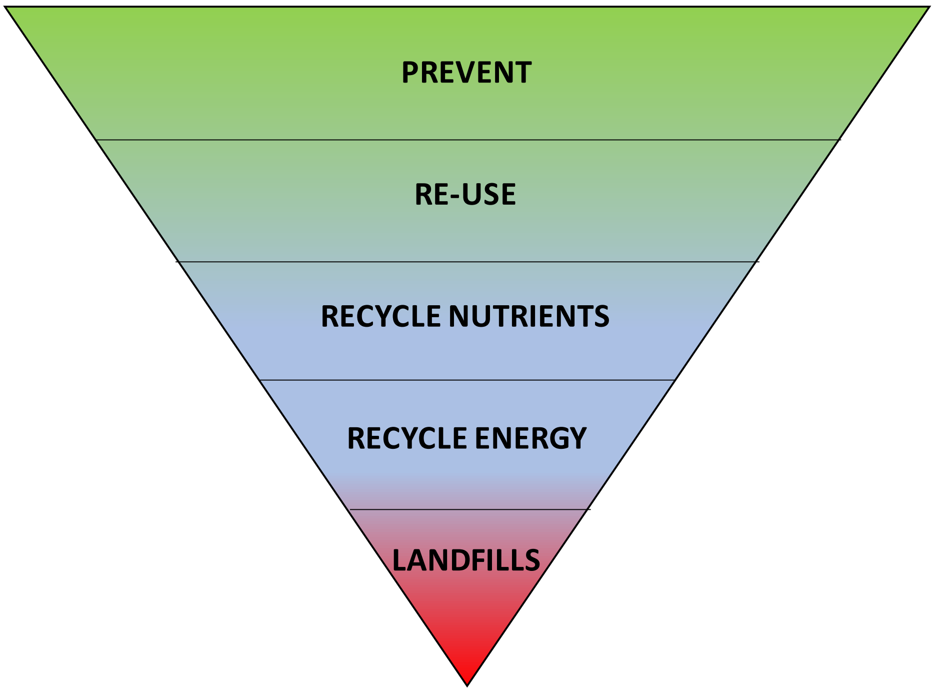


Figure 3: The food recovery hierarchy, loosely based on FAO (2013), EPA (2019) and Papargyropoulou et al. (2014) and the modification to the Swedish waste system from Jordbruksverket (2020) .

The best action is of course to prevent food loss and waste from occurring. Measures should be taken to reducing the over production and consumption which results in surplus foods, and to reduce avoidable food waste in the food supply chain. The next step is to re-use the food, but still keeping it within the human food chain by for example donating to food banks and redistribution networks. If the food is not fit for human consumption it can be diverted to animal feed, but this should be considered as less preferred. Further down in the hierarchy comes the option to recycle the food through industrial uses which recovers energy and/or nutrients from the waste.

An example is anaerobic digestion which creates biogas and composting which creates a nutrient-rich soil (Papargyropoulou, et al., 2014) (FAO, 2013) (EPA, 2019). Food products can also be used as substrate in the production of biofuels, such as ethanol, hydrogenated vegetable oil (HVO) and fatty acid methyl esters (FAME). From the biofuel production a byproduct might be animal feed (Jordbruksverket, 2020).

In Sweden, incineration is a common waste treatment where the mixed waste is burnt to recover energy, most often through cogeneration of heat and power. This might be the most available way for actors such as supermarkets whom are not automatically included in the municipal waste monopoly for handling of food waste (Eriksson, et al., 2015). The last resort, which is not an option for food in the Swedish system, is to dispose of the food on landfills. This has a really negative environmental impact caused by the emissions of methane gas as well as pollution of both soil and water (Papargyropoulou, et al., 2014).

It is important to note that the food recovery hierarchy might look different depending on the properties of the food product and the infrastructure in the area where it occurs. According to Eriksson, et al., (2015) the food waste has to be put in a local context considering the local infrastructure. There are also cases where it is better to use the food loss and waste as substrate for biogas, for example if it is unable to meet the requirements for animal feed (Jordbruksverket, 2020).

The following three categories, re-use for human consumption, recycle as animal feed and anaerobic digestion, are the focus for the interview part of this thesis project since they were considered to be common in the Swedish system of handling food side streams. They are therefore explained a little further in the following sections.

2.6.1 Re-use for human consumption

Re-using food for human consumption can be done in different ways depending on how the side stream looks and where in the food supply chain the food is lost or wasted. Some side streams in the food processing industry might be possible to direct back into the process lines to produce a new product. Already processed and packaged food products in finished goods inventories or at retailers could in many cases be donated to redistribution networks or food banks. Lagerberg Fogelberg, et al. (2011) lifts examples from Swedish retailers, one of them is a food store where the sorted out food items that are still good to eat are put in a special refrigerator where a charity organization can collect them.

In the EU guidelines for food donations it is stated that all food for human consumption has to fulfill the food hygiene requirements set by the EU. All actors involved in producing and distributing the food are responsible for ensuring a safe product. The liability is often something that hinders food producers and retailers from wanting to redistribute their product, since it might bring bad reputation to their brand if something went wrong (Europeiska kommissionen, 2017).

2.6.2 Recycle as animal feed

With the legislation today it is very regulated which human foods can be led to feed. The legislations consider both feed for animals in food production and other animals such as pets and animals in fur production. The strict regulations are due to health risks since food waste can contain viruses and bacteria and has to be nutritious and cannot not contain anything toxic or health damaging to the animal. No product that has turned bad can be sold as feed, meaning that they have to be stored properly. Studies show that if the feed has high levels of toxins, there will likely also be toxins in the food products later in the food supply chain. This means that the feed legislation is important to protect both animal health and human health.

A food producer that sends side streams to feed has to be registered as a feed producer as well and is responsible to make sure that the product meets the requirements in the legislation. The legislations regarding feed in Sweden are regulated both nationally and by the EU (Jordbruksverket, 2020).

In addition to the need to follow legislations, a feed producer needs to have a consistent and reliable stream of potential feed to be able to supply the animal production. Another difficulty is the packaging material that has to be removed from for example fruits and greens before they can become feed. This further complicates the process and adds costs. It is easier to use plant-based food as feed since side streams that contains animal products are much more regulated for hygienic reasons and to avoid cannibalism. Meat products are only allowed to be given to pets, animals in fur production and in the zoo (Jordbruksverket, 2020).

2.6.3 Anaerobic digestion

From anaerobic digestion of organic material, the products are biogas and digestate. The first step when the organic material, or the substrate, arrives to the biogas plant is a hygienisation step, where the substrate is heated to 70°C which kills of any harmful bacteria that might be present. After this, the organic material is transported into the digester where it is digested by different microorganisms without the presence of oxygen for at least 20 days. The temperature in this step might be either 37°C (mesophilic) or 55°C (thermophilic). The microorganisms produce biogas, which mainly consists of methane and carbon dioxide (Energigas Sverige, 2018). Co-digestion means anaerobic digestion of a mixture of many different substrates, for example food waste mixed with manure and energy crops, which leads to an increased methane content in the produced biogas (Energigas Sverige, 2017).

The digestate is the residue that was not turned into gas. This still contains all the nutrients from the original substrates but in a more available form which makes it perfect as fertilizer. To make sure that the digestate is of high quality and to prevent spreading of diseases there is a certification system in Sweden, owned by Avfall Sverige, which tracks the origin of the digestate and also makes sure that it does not contain any metal (Avfall Sverige, 2020).

3 Mapping of side streams from the food supply chain in Västra Götaland

3.1 Method

The mapping of the side streams in the food supply chain were divided after the different segments as described in section 2.3. An overview illustration of the workflow is shown in Figure 4.

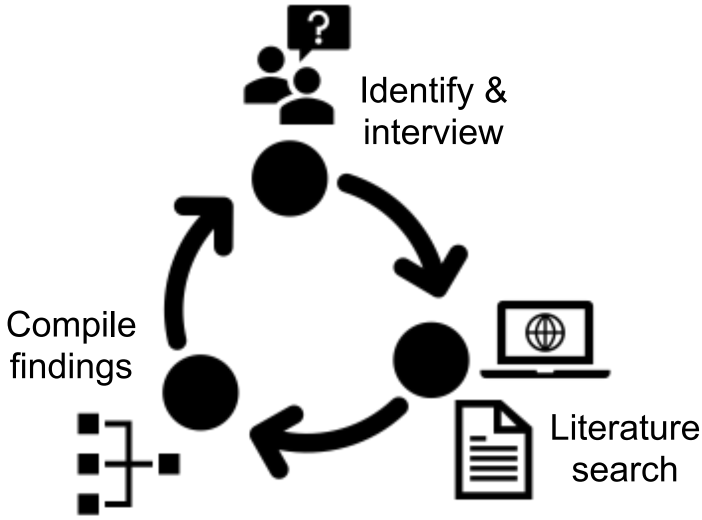


Figure 4: Workflow when mapping the side streams in the food supply chain.

The workflow for the mapping of the side streams were in many ways iterative. The first step was to define the different side streams and to identify researchers and authorities who could be involved or have information. This was made with help from supervisors and through a literature search on the subject in general. The next step was to contact and interview the researchers to receive their knowledge about the subject. Through these contacts additional reports and other information were received, leading on to the third step where a larger literature search was made, as well as checking official data bases. The found data was put together, and by doing that it became clear which gaps where still left to be filled which led up to new interviews, more reports, more data and so on.

3.2 Results

The resulting map of the side streams from the food supply chain in Västra Götaland was divided after the different sectors in the food supply chain. Since anaerobic digestion and cogeneration were found to be common ways to handle the food side streams which are considered waste, statistics for anaerobic digestion and cogeneration in Västra Götaland was also included.

3.2.1 Side streams from primary production

For a better understanding of the side streams, there is a need to understand the production. In Västra Götaland there is in total about 460 thousand hectares of arable land (Jordbruksverket, 2019), and Table 1 describes the usage of the land area in terms of what crops are grown.

Table 1: Usage of land area in Västra Götaland. Data for 2019 from Jordbruksverket (2019).

Crop	Area (hectares)
Cereals	200 156
Hay and pasture	188 355
Peas and beans	12 085
Oil bearing crops	14 064
Green fodder and corn	9 483
Potatoes (food and starch)	2 183
Garden crops	605
Fallow	28 372
Other	3 559
Total arable land	**458 863**

As seen in Table 1 the most abundant crop is cereals, followed by hay and pasture. Landquist and Nordborg (2019) presents the consumption and production of food and feed in Västra Götaland. From their report the amounts of unrefined food products that were produced in 2016 are presented in Table 2.

Table 2: Production of some unrefined food products in Västra Götaland. Data for 2016 from Landquist and Nordborg (2019).

Commodity group	Food	Production in Västra Götaland (tons/year)
(i) Animal products	Raw milk	501 154
	Beef[1]	22 269
	Pork[1]	49 712
	Lamb[1]	737
	Chicken	19 505
	Eggs	11 655
(ii) Fish products	Fish (wild)[2]	19 797
	Fish (farmed)	2 782
(iii) Cereals and pulses	Wheat (incl. feed)	457 111
	Rye	21 402
	Oat (incl. feed)	324 735
	Barley (incl. feed)	208 924
(iv) Roots, tubers & oil-bearing crops	Potatoes	74 651
(v) Fruits and vegetables	Carrot[3]	280
	Kales[3]	6 281
	Onion[3]	10
	Leek[3]	255
	Lettuce[3,4]	12
	Tomato[3]	655
	Cucumber[3]	512
	Apples	900
	Pears	200

1. Calculated from national data for Sweden, using the total number of animals of each species in Västra Götaland and how big percentage of the total production in Sweden that corresponds to. Note also the assumption that each animal gives the same amount of meat per animal as the average Swedish animal of that species.
2. Captured in Skagerrak, Vänern and Vättern.
3. Data from 2017.
4. Only lettuce grown in greenhouses, not on free land.

The unrefined food products are either refined by food industries within Västra Götaland or transported out of the region to other industries. Since there is no hard border around the region there is no control of what is transported where as long as it does not leave Sweden. According to Kalmendal (n.d.), Västra Götaland is the region with the largest amount of beef cattle, dairy cows, sheep and chickens in Sweden.

When it comes to the side streams from primary production no comprehensive statistics for Västra Götaland could be found. On a national level the amount of food loss from the primary production has been estimated in a study to 300 000 tons per year, where 98 000 tons per year is after slaughter and harvest. The losses can often be utilized within the farms as feed or as soil improvement as they are plowed back down in the fields. These amounts are then not included in any reported data. Therefore, there are no definite numbers for the losses in the primary production, since these side streams are not necessarily measured (Jordbruksverket, 2020).

There are ways to calculate estimations of the side streams from standard ratios and known data on the land use or number of animals. To perform these calculations were considered out of scope for this thesis, but it is worth noting that the standard ratios and the land usage data for Västra Götaland is published annually and therefore it would be possible to estimate the side streams from primary production in the region.

The one source that was found regarding the side streams from the primary production was that the self-sufficiency on cereals within Västra Götaland in 2016 were over 100% on both barley, oat and wheat, meaning that the production of cereals exceeded the consumption (including both human consumption and feed). Of the total produced amount of the three cereals in Västra Götaland, 58% of the wheat, 83% of the barley and 84% of the oat where used as animal feed (Landquist & Nordborg, 2019).

3.2.2 Side streams from the processing sector

There are approximately 400 companies within the food processing sector in Västra Götaland (Landquist & Nordborg, 2019). About 25% of the Swedish smaller and middle sized food industries are located in Västra Götaland, and every fifth person working in the food processing sector in Sweden works in this region (Kalmendal, n.d.).

Nationally the food producers in Sweden generated 870 000 tons of waste in total during 2016. The statistics only covers the side streams that can be considered as waste, meaning that side streams that go to for example feed are not included. Of the recorded waste, 234 000 tons are mixed waste and with animal origin, and 215 000 tons are plant based (Jordbruksverket, 2020). No specific data for Västra Götaland was found.

The national data for the waste streams from food processing industry is calculated by Statistics Sweden, SCB, using environmental reports where the companies themselves are reporting their environmental impacts and among that the amount of waste from their factories which should include side streams of food. To produce national statistics some representative companies are picked out, and their data is scaled up to represent the entire country. It would therefore be a statistically uncertain method to scale the national data back down to represent a region. SCB were not able to share their data for the sake of this thesis, due to confidentiality (Sörme, 2020). The environmental reports are public documents administered by Länsstyrelsen, and accessible through Svenska Miljörapporteringsportalen which is a web application owned by Naturvårdsverket. At the time this thesis was written, it was not possible to get access to the web application due to security issues in the system. Länsstyrelsen in Västra Götaland was contacted regarding regional data for the food industry, but no such data has been compiled.

No published statistics could be found about how much animal feed comes from residues from the food processing industries in Västra Götaland. However, according to Ola Karlsson at Foderlotsen AB, about 200 000 tons of biological material from the food industry in Västra Götaland goes to animal feed every year.

The material comes mainly from the spirits industry (stillage) which covers approximately 60%, the dairy industry (cheese whey and milk) which covers approximately 25% and the cereal industry (residues from starch and gluten extraction) which covers approximately 10%. Bakeries (bread and dough) covers approximately 4% and other industries such as potato processing industries and beer producers the remaining 1% (Karlsson, 2020).

The losses of fruits and vegetables that for different reasons appears in the step between processing industry and retailers can be calculated with certain calculation factors from Statistics Sweden, SCB, for the different products. These factors are based on approximations and not on measurements, meaning that any calculations using these factors should be considered with caution (Landquist & Nordborg, 2019). No such calculations were performed in this thesis, since it was considered to be out of scope.

3.2.3 Side streams from the retail sector

Depending on which municipality one looks at, the waste from retailers are sometimes handled by the municipality meaning that their food waste is included in Table 3 where consumer food waste is presented. Grahn, et al. (2020) used calculation factors from Andersson & Stålhandske (2020) to make an estimation for the retail sector in Västra Götaland, which landed on a total amount of 17 million tons of food waste per year.

Statistics for other side streams, which were not handled as waste, could not be found. As mentioned in the background, there are food producers that retrieves their products from the retailers to handle it themselves. Pågen is an example of a food producer in Västra Götaland who retrieves their unsold bread from the retailers when they deliver fresh bread. They state on the company's own website that the unsold breads go to bioethanol and animal feed together with the losses in the bakery production (Pågen, n.d.). Statistics for how large volumes the processing industry retrieves from the retail sector was not found, and the same goes for statistics regarding how much food that is redistributed for human consumption or sent to animal feed directly from the retailers.

3.2.4 Side streams from consumers

The consumer segment includes both public consumption, such as restaurants and public services, and household consumption. Since food waste from consumers are mostly handled by municipalities it is very well documented. Avfall Sverige is a Swedish association for waste management and recycling, consisting of 400 members in the Swedish waste management and recycling sectors. In their statistic tool Avfall Web, administrators from municipalities and waste management plants can report their data. From that, Avfall Sverige can compile regional and national statistics over the waste management in Sweden (Avfall Sverige, 2020).

Most of the municipalities in Västra Götaland gather food waste from households in either separate garbage containers or containers with compartments. Borås was the only municipality with optical sorting, meaning that they use different colored bags to separate the waste in a later step. 16 of the 49 municipalities reported to not have any separate gathering of food waste in 2018 (Westin, 2019). In Table 3 the mean value for the food waste from consumers in Västra Götaland in 2018 is presented, as well as how it was handled.

Table 3: The management of consumer food waste in Västra Götaland in 2018. Note that each value is the mean for Västra Götaland, based on data for each municipality. Data from Avfall Sverige (Westin, 2019)

				Share of food waste to…		
	Food waste (kg/person)[1]	Food waste to central anaerobic digestion (kg/person)[2]	Food waste to central composting (kg/person)[3]	…biological recycling incl. home compost[4]	…anaerobic fermentation and central compost[5]	…anaerobic digestion[6]
Mean value for Västra Götaland	36	30	0	44%	32%	20%

1. From households, restaurants, shops, offices and institutions. Home composting and food waste to sewage treatment not included.
2. Both biogas plants and sewage treatment plants.
3. Not including garden waste.
4. Including both central composting, home composting and anaerobic digestion. No difference if energy or nutrients are utilized.
5. In anaerobic fermentation and central composting only nutrients are utilized.
6. In anaerobic digestion both energy and nutrients are utilized.

As seen in Table 3, the mean amount of food waste per person on the consumer level is 36 kg, and most of it goes to central anaerobic digestion producing biogas. Note that this includes the streams from both public and household consumption (Westin, 2019). Grahn, et al. (2020) used the data for each municipality from Avfall Sverige, and the number of inhabitants there, to calculate the total amount of food waste from households in the entire region of Västra Götaland. This resulted in about 140 million tons of food waste from households per year. They also calculated an estimate of 12 million tons per year from large-scale catering establishments and the same amount per year from restaurants, based on the factors from Andersson & Stålhandske (2020).

There is no central composting for food waste in Västra Götaland (Westin, 2019). Nationally in Sweden, 4 kg food waste per person was composted in household composts in 2016 (Westöö & Jensen, 2018). Assuming that this is applicable also for Västra Götaland this would mean in total approximately 6800 tons of food waste to household composts per year in the region.

3.2.5 Anaerobic digestion in Västra Götaland

Västra Götaland together with Skåne are the regions in Sweden with the biggest potential for production of biogas from biomass such as side streams from the food supply chain, residues from agriculture and energy crops. There are ongoing projects to further develop the production of biogas in Västra Götaland, and the goal set in 2010 was to produce 2.4 TWh/year in 2020 (Västra Götalandsregionen, 2019). There are in total six co-digestion plants in Västra Götaland, and there are also two wastewater treatment plants in the region that handles food waste through anaerobic digestion, as shown in Table 4 (Avfall Sverige, 2019).

Table 4: Plants for anaerobic digestion in Västra Götaland from the statistics by Avfall Sverige (2019) and the amounts of digested waste in 2018. The table also includes the energy production from the co-digestion plants and whether they are certified digestate producers.

Type of plant	Location	Digested food waste in 2018 (tons)[1]	Total digested waste in 2018 (tons)[2]	Energy production (GWh/year)[3]	Certified digestate producer[4]
Co-digestion plants	Lidköping	0	98 170	>50	Yes
	Borås	17 160	27 360	10-50	Yes
	Skövde	2 110	38 020	10-50	Yes
	Vårgårda	1 510	72 100	10-50	Yes
	Mariestad	0	78 660	10-50	-
	Falköping	4 770	7 250	2-10	-
Wastewater treatment plants	Alingsås	8 450			
	Göteborg	8 920			

1. Data from Avfall Sverige (2019). Food waste is here described as household waste and thereby comparable waste from households, restaurants, food retailers, schools and similar businesses. Waste from food processing industry is not included.
2. Data from Avfall Sverige (2019). The co-digestion plants handle other waste as substrates in addition to food waste, what kinds were not specified.
3. (Energigas Sverige, n.d.)
4. (RISE Research Institutes of Sweden, n.d.)

The biggest co-digestion plant in Västra Götaland is located in Lidköping. This plant produced over 50 GWh/year, while the plants in Borås, Skövde, Vårgårda and Mariestad all produce 10-50 GWh/year. The smallest plant is in Falköping, which produces 2-10 GWh/year (Energigas Sverige, n.d.). Worth noting is that neither of the co-digestion plants in Lidköping and Mariestad had food waste as substrate in 2018. The plant that handles the biggest amount of food waste is the plant in Borås, and after that comes the two wastewater treatment plants in Alingsås and Göteborg, followed by Falköping, Skövde and lastly the plant in Vårgårda (Avfall Sverige, 2019). Four of the co-digestion plants are also certified digestate producers (RISE Research Institutes of Sweden, n.d.).

3.2.6 Waste incineration in Västra Götaland

As mentioned by Eriksson, et al. (2015), waste incineration is in many cases the most available way for actors outside of the municipal waste management system. This is also the most common way to handle mixed waste, which to some extent consists of food. In Table 5 the four cogeneration plants in Västra Götaland where household waste is incinerated are listed.

Table 5: Cogeneration plants handling household waste in Västra Götaland, the amounts of waste they handled and their energy production in 2018 (Avfall Sverige, 2019).

		Handled waste in 2018		Energy production in 2018	
Cogeneration plants	**Location**	Total waste (tons)	Household waste (tons)[1]	Heat (MWh)	Electricity (MWh)
Sävenäs avfallskraftvärmeverk	Göteborg	538 150	220 570	1 506 350	204 590
PC filen	Lidköping	122 680	27 640	350 420	22 590
Lillesjö avfallskraftvärmeverk	Uddevalla	115 510	49 940	293 580	69 620
Ryaverket	Borås	104 040	23 150	222 100	50 000

1. Includes only Swedish household waste, while the total waste also includes imported waste.

The biggest cogeneration plant in Västra Götaland is Sävenäs avfallskraftvärmeverk in Göteborg, which incinerated 538 150 tons of waste in 2018, whereof 220 570 tons were household waste. The plants in Lidköping, Uddevalla and Borås are smaller and incinerated 20-50 tons of household waste in 2018.

3.3 Discussion

In general, for the entire food supply chain, it was easiest to find statistics regarding the side streams that is considered as waste and are anaerobically digested or incinerated. For the consumer sector it is reasonable since re-using and recycling the food for new purposes when it has already reached the consumers would be complicated to regulate. The consumer sector is also easier to control since the waste streams is handled by the municipalities, meanwhile the waste streams from the primary production and the food processing sector is not as controlled and the statistics thereby rely on the companies themselves reporting their data. Since the data regarding the primary production relies on statistical calculations from different factors, it means that there might be a lot of food which is lost without it being included in the statistics.

For the side streams which are not considered waste, meaning the food which can be re-used for human consumption or recycled as animal feed, the statistics are very brief. Since the food in these cases is not considered waste but rather a byproduct or loss, the companies and retailers do not have to report anything about these side streams to the authorities. No statistics at all were found for side streams which are re-used for human consumption. This might be because the foods are either re-used in the company's own production meaning that it never leaves the facility and is therefore not tracked, or if the food is redistributed to food banks it means financial losses which the companies or retailers are not content with and which also can vary over time and be hard to keep track of.

The cereals from the primary production which are used as animal feed is most likely grown for that purpose, meaning that it is questionable if it can be considered a side stream even though it could have been used for human consumption. Had it been used for human consumption the animal feed would have to consist of something else which might be a less sustainable option.

In many cases it seemed to be possible to calculate the side streams from statistical factors and other data that was already known. These calculations would naturally not be as good as actually measuring, but for the cases where the actualities are completely unknown it would be of interest to have at least some kind of estimation.

4 Interviews with food processing industry in Västra Götaland

The interview part of the thesis was directed at companies in the processing sector in the food supply chain, here mentioned as the food industry.

To get a first picture of which questions would be good to ask, a pre-interview was held with a Senior Sustainability Manager from the food industry. Based on this conversation, the interview focus was decided to be on potential, possibilities and innovation to make sure to have a positive view that could be of interest for the participating companies (Modin Edman, 2020). The interview was also decided to be divided in two parts; first the participants filled in a web form and then followed a telephone interview if there was an interest. To steer clear from things that could be sensitive, no specific questions about amounts or percentages of total production were asked. This was not either considered within the scope of the interview, even though it might have been an interesting aspect.

The selection of companies was done by searching the web for food companies in Västra Götaland. To get in contact with them both contact information previously used in other projects within RISE and found on the companies' own websites were used. A first contact was made by sending an email with an explanation of the project and purpose and a link to the web form described in section 4.1. In total, 20 companies were contacted by email. 11 companies filled in the web form and of these 5 companies participated in the telephone interview, described in section 4.2.

The overall questions that the interview part of the thesis aimed to answer was;

(i) How are the side streams from the food industry handled?
(ii) Why does the food industry handle side streams the way they do?
(iii) What does the food industry need to be able to change how they handle their side streams?

4.1 Web form

4.1.1 Method

The webform can be found in Appendix A: Webform. It was written in Swedish due to only targeting Swedish companies and it consisted of four parts. At the end of part 2-4 the participants were given the opportunity to leave extra comments. The first part contained information about the project, and asked the participants to fill in name, title, company name and telephone number if they wanted to participate in the follow up interview by telephone (which is described in section 4.2). The only obligatory question in the entire form was to fill in their email address, which they then automatically got a copy of their answers to when they submitted the form.

Part two was about the management of side streams, and asked the participants to rate on a scale from 1-5 how actively their company is working with their side streams in the aspects follow up, measuring, minimizing, sustainability, etc. It then showed a figure describing the food recovery hierarchy, similar to Figure 3, and asked the participants to rate on a scale from 1-5 to what extent their side streams are re used for human consumption, goes to animal feed and goes to biogas. The participants were then given a short description of avoidable and unavoidable side streams and asked to rate from 1-5 if their side streams were mostly unavoidable (1) or avoidable (5), or a little of both.

Part three was about possibilities and limitations. The participants were asked to rate from 1-5 how big the potential is for improving how the company is working with side streams today. They were then asked to pick the big limitations when it comes to handling the side streams, given the suggestions economy, legislation, infrastructure, technology and that the handling is outside the company's core business. It was also possible to add own alternatives on this question.

The participants were then asked if there were any examples of side streams within the company that they would like to handle in a different way but that is hindered by any limitations.

The last part was a description of the purpose of the LCA case study, and a question asking if the company was interested in participating. This is further continued in section 5.

4.1.2 Results

In total, 11 companies out of the 20 that were contacted directly through email answered the webform. The companies represent 7 different branches of the food industry, as seen in Table 6.

Table 6: Number or participating companies in the webform and their branch of industry.

Branch of industry	**Number of companies participating**
Ready-made meals/Bakery	1
Bakery	1
Dairy	1
Egg	1
Meat	3
Snacks & Confectionery	3
Brewery	1

Most of the branches were represented by only one company, with the exception of meat industry and snacks and confectionary industry which was represented by three companies each. The companies are of different sizes, from smaller industries, to medium-sized and larger.

Further, the 11 companies represent only about 3% of the total number of around 400 food companies in the region (Landquist & Nordborg, 2019). Therefore, it was reasoned that the results could not be considered representative for the entire food industry in Västra Götaland. The differences between the branches of industries were not investigated either since there were so few in each category. With that said, it could still give an indication on how the food industry might be reasoning regarding their side streams and how they could be met by and what they need from legislators, authorities, researchers, innovators and such to improve how they work with the side streams.

4.1.2.1 Management of side streams

The first question was regarding how actively the company works with their side streams. The results from this question are shown in Figure 5.

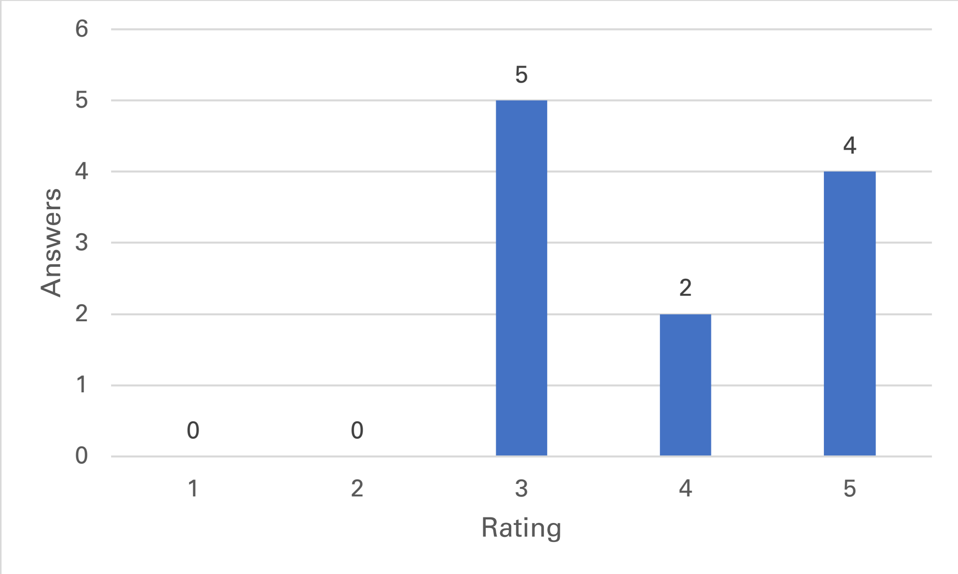


Figure 5: The answers to the question 'how actively does the company work with side streams?'. 1=not active and 5=very active. The y-axis tells how many answers each rating, on the x-axis, received.

As seen in Figure 5, no company answered that they are not actively working with their side streams. The most common answer was the middle, which can be considered as moderately active. The conclusion is that all the answering companies does work in some way with their side streams, but from this webform it is unknown in which ways. The specific ways the companies were working with the side streams were further explored in the telephone interview in section 4.2.

When it comes to the handling of side streams, the answers varied quite a lot. This is reasonable since the participants have very different types of productions and side streams that can be handled in very different ways. The mean values of the answers are shown in Figure 6.

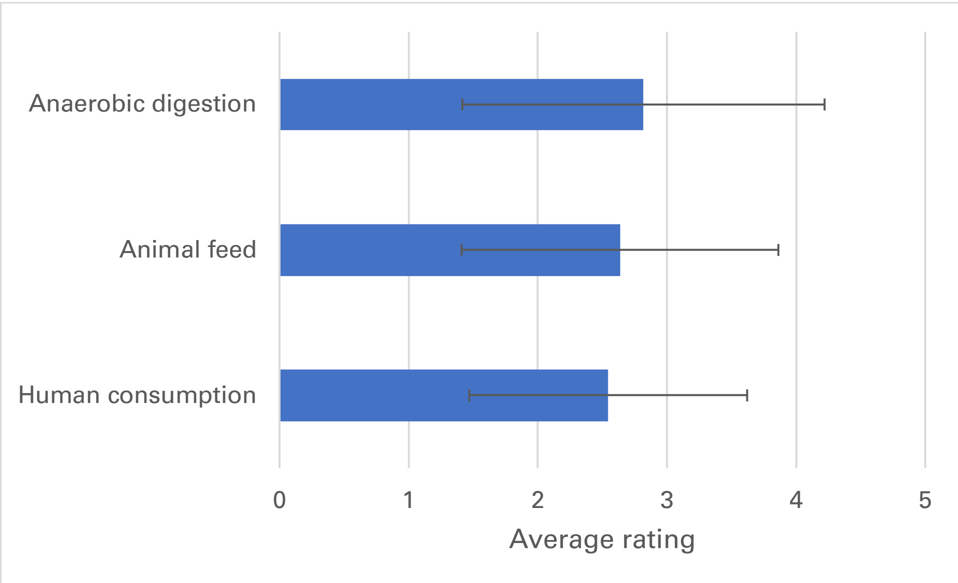


Figure 6: The mean values and standard deviations of the answers from the ratings of to how big extent the companies' side streams goes to anaerobic digestion, animal feed or are recycled for human consumption. 1= not at all, 5= big extent.

As seen in Figure 6 the mean value for biogas was slightly higher than recycling for human consumption and animal feed. From doing a one-way ANOVA test, it was investigated whether the variance within the answers in each rating category (anaerobic digestion, animal feed or human consumption) were bigger than the variance between the rating categories.

The null hypothesis is that the means of the three are the same, and the ANOVA test showed that the null hypothesis cannot be rejected which says that there is no significant difference between the categories. In other words, none of the categories can be said to have a higher rating than the others.

The next question was regarding avoidable and unavoidable side streams. The description of this was that a unavoidable side stream consists of for example bones and peels which has to be removed in the process, while an avoidable side stream consists of food which for some reason cannot be sold or delivered, and it also includes wastage due to for example over production or production errors. Naturally, the unavoidable side streams are hard to minimize since they are part of the process while avoidable side streams would most likely involve a potential for improvement. The companies rated from 1 (mainly avoidable) to 5 (mainly unavoidable), and the responses are shown in Figure 7.

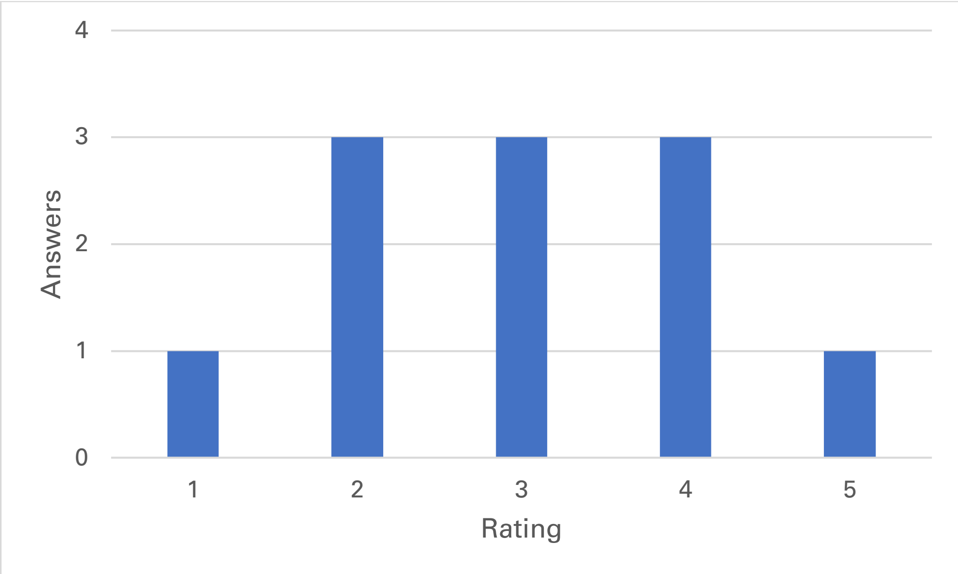


Figure 7: How the companies rated if they had mainly avoidable or unavoidable side streams. 1=Mainly avoidable and 5=Mainly unavoidable. The y-axis tells how many answers each rating, on the x-axis, received.

As seen in Figure 7, the responses regarding avoidable and unavoidable side streams are distributed so that each rating have at least one answer. Only two companies answered on the extremes, 1 and 5 respectively, and the rest of the companies answered somewhere in between claiming that they have side streams worth mentioning of both the avoidable and unavoidable kind. As have already been discussed with the case of how the companies have very different productions and handling of their side streams it is also reasonable that it looks very different between the companies when it comes to how avoidable their side streams are.

4.1.2.2 Possibilities and limitations

The companies own perception on their potential for improvement on how they handle their side streams is relevant to know, since this could perhaps also be considered as a measure of how willing they are to make changes. Figure 8 shows how the companies rated their potential for improvement, when it comes to handling their side streams.

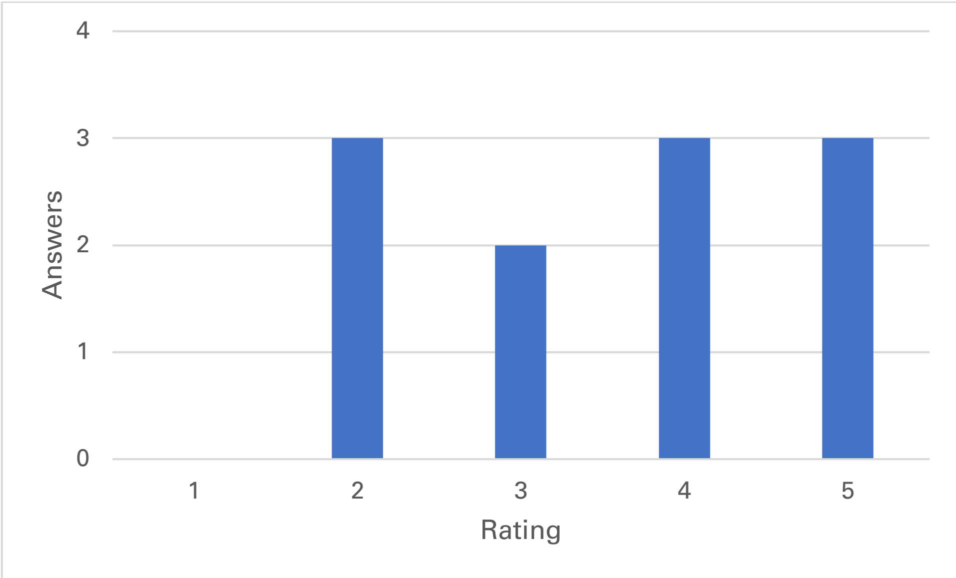


Figure 8: How the companies rated their potential for improvement on handling their side streams. 1 = no potential and 5 = very big potential. The y-axis tells how many answers each rating, on the x-axis, received.

A conclusion from Figure 8 is similar to that of Figure 5, that there is no company that answered that they have no potential for improvement. Otherwise the answers were quite evenly distributed from 2 (little potential) to 5 (very big potential).

A comparison was made between the ratings of the companies' experienced potential for improvement and if they have mainly avoidable or unavoidable side streams. The idea was to see whether there was a connection between the two ratings. As already mentioned, it should be easier to minimize the avoidable side streams than the unavoidable side streams since they are a part of the process. The companies were given numbers, 1-11, where company 1 had experienced the lowest potential for improvement and company 11 had experienced the highest potential for improvement. The comparison between the ratings is shown in Figure 9.

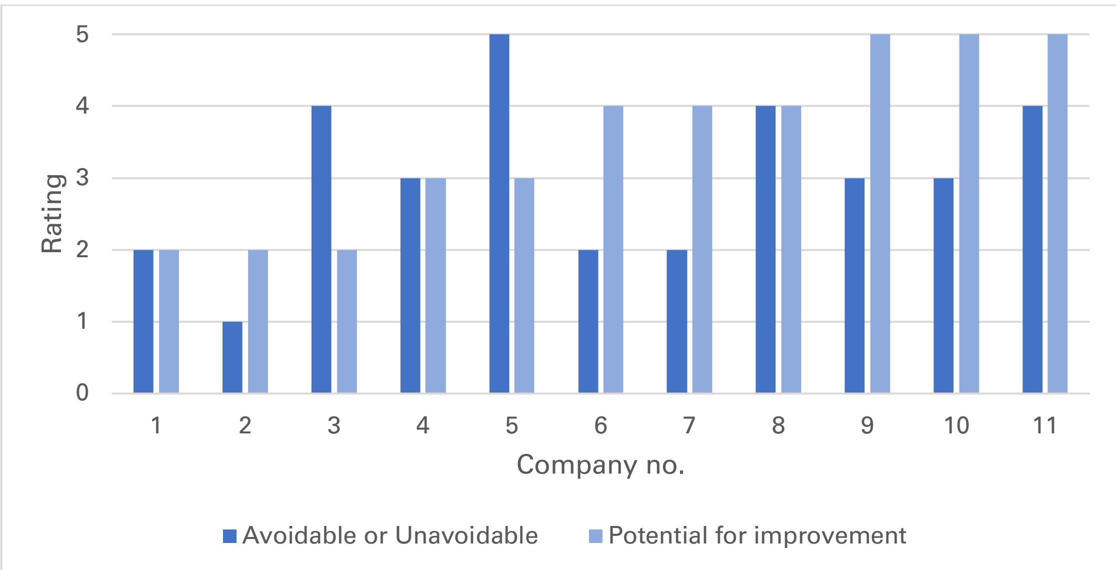


Figure 9: How each company, number 1-11, rated if they had mainly avoidable or unavoidable side streams (1=Mainly avoidable and 5=Mainly unavoidable), in comparison to their experienced potential for improvement (1 = no potential and 5 = very big potential).

As seen in Figure 9, there is no clear pattern for all the companies between their rating of avoidable or unavoidable side streams and their experienced potential for improvement. A reasonable assumption would be that the companies with high potential for improvement would also have mainly avoidable side streams, but no such connection could be seen. This is not unreasonable since there are other things that the companies might be able to improve than minimizing their avoidable side streams, for example how the side streams they have are managed. This was also proven in the telephone interviews, as described in section 4.2, where specific improvements were further discussed with the participants.

The next question in the webform was regarding which limitations the companies saw were hindering how they manage their side streams. They were allowed to choose how many or how few alternatives that they wanted, and also add more alternatives. The results for the already provided alternatives are shown in Figure 10.

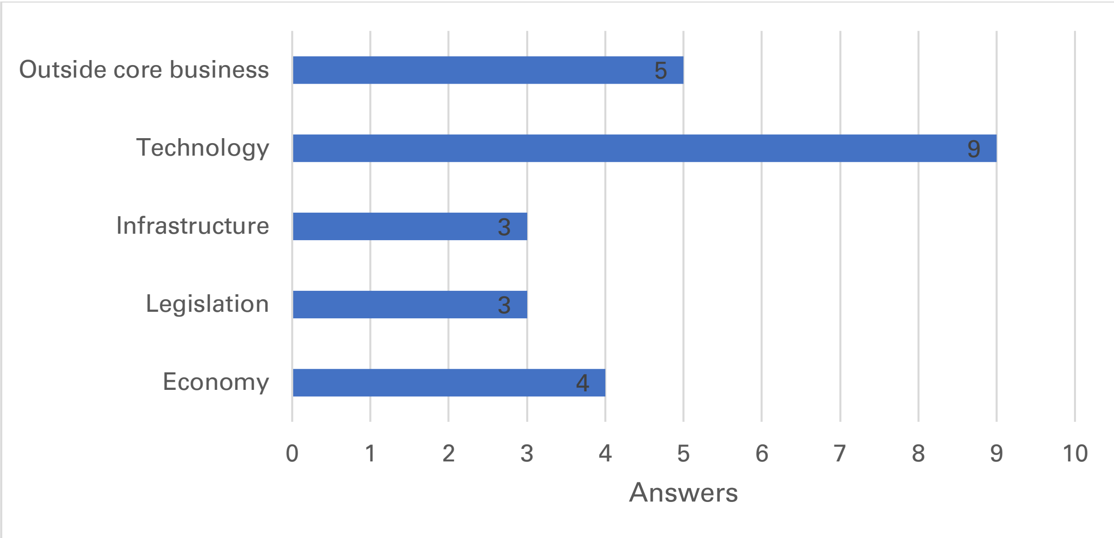


Figure 10: The limitations that the companies see hinders them when handling their side streams.

The most commonly picked alternative, which was picked by almost all the companies, were technology. This alternative was thought about as not having the correct equipment to be able to manage their side streams in a good way, or that with the production line as it is built today the company are unable to make major changes. Note that this description was not included in the webform, meaning that the companies might have interpreted the alternative differently.

The next most commonly picked alternative was that the management is outside the company's core business, meaning that it is not in the main interest of the company's business to handle the side streams. This alternative was picked by 5 companies. Economy were exemplified in the webform as personnel costs and premises costs, considering that management of side streams might need working hours and extra space. This alternative was chosen by 4 companies. Infrastructure and legislation were the least chosen alternatives, picked by 3 companies each. Infrastructure was exemplified with the availability of a biogas plant, and legislation could for example be the need to be registered as a feed producer to be able to have a side stream going to animal feed.

The answers from the webform did not provide any information about why the companies chose the specific limitations that they did, but this was further explored in the telephone interviews in section 4.2, where the companies were to pick out and motivate one alternative as their biggest limitation.

Other limitations that the companies themselves provided were the need for capital for investments, for example to do research into how a side stream could be used or for investing in new equipment. Another was that to be able to make a new product from a side stream there needs to be a market for that specific product, otherwise it will not be profitable.

4.2 Telephone interview

4.2.1 Method

Five of the participants of the web form were contacted again by email to book time for a telephone interview. The participating companies are presented in Table 7.

Table 7: The companies participating in the telephone interview.

Company	Production	Size	Customers
Company A – "Ready meal company"	Ready meals, bread, raw materials for caterers	~ 1500 employees	Consumers and business
Company B – "Egg company"	Egg products	70-80 employees	Business
Company C – "Snacks company"	Snacks, mainly potato chips	~ 200 employees Produced 14 000 tons of potato chips in 2019	Consumers
Company D – "Brewery"	Beer	12 employees Produced 870 000 liters of beer in 2019	Consumers
Company E – "Protein bar company"	Protein bars, no production in their own brand	~40 employees Produce 15-16 million protein bars /year	Consumers

The participants were asked to have their answers from the web form in front of them during the interview. They were informed about that the interview would be recorded to make sure that the discussion would make for a reliable source that would not rely on memory. Any missing information about the company that could not be found on the website was also asked for.

In general, the companies' answers from the web form were discussed more in depth during the interview. The discussions were all based on the same follow up questions. When discussing part two of the web form, about management of side streams, the participants were asked to give examples on side streams that are reused for human consumption, goes to animal feed and goes to biogas. They were also asked to explain what motivates or hinders them from sending their side streams to the three different alternatives. Lastly, they were asked to give examples of their avoidable and unavoidable side streams.

In part three, about possibilities and limitations, the participants were asked to motivate their rating on how big the potential is for improving how the company is working with side streams today. If they had ranked their potential as big, they were asked if they had a goal to work towards, and if they had ranked it as small, they were asked if they had fulfilled a certain goal already.

They were then asked to pick one of the limitations for handling the waste streams that they had chosen, which they would think would make the biggest difference for the company if it was removed and motivate their answer. Depending on if they had given an example on a possible side stream that the company would like to divert to a different management alternative, they were asked to elaborate this answer.

4.2.2 Results

4.2.2.1 Management of side streams

Company A produce a wide range of products from many different food raw materials, meaning that they have a variety of side streams. Company B base all of their products on raw eggs, leaving them with their main side stream which is eggshells mixed with what they call the 'technical egg mass', consisting of eggshell membrane and residues of egg white. The main side streams from Company C that were brought up were snacks, frying oil and raw potatoes. Company D have two side streams from the beer production; brewers spent grain and yeast. Company E produce no products in their own brand, they produce exclusively for other brands. Their side streams consist mainly of dough for protein bars.

The companies' rating on how actively they work with their side streams are shown in Table 8.

Table 8: The interview participants' answers from the web form regarding how actively they work with their side streams.

	Company A "Ready meal company"	**Company B ”Egg company”**	**Company C ”Snacks company”**	**Company D ”Brewery”**	**Company E ”Protein bar company”**
How actively does the company work with their side streams?	4 – Actively	3 – Moderately active	5 – Very active	3 – Moderately active	3 – Moderately active

As seen in Table 8 all five companies that were interviewed work moderately to very active with their side streams. A big driving force for all companies for wanting to work with side streams is environmental reasons, to make sure that the company takes its' responsibility in those issues. Economy was brought up as another driving force when it comes to why it is important to work actively with management of side streams. It is economically beneficial to minimize the loss of resources. Another thing all companies touched upon was that the residues from the production has a value. There is a cost involved for the company to send the side streams to incineration or landfills, while there in some cases might be a potential income from selling it as for example biogas substrate or as animal feed. This motivates making more sustainable choices. For Company D the side stream of brewers spent grain is wet, and very heavy. If they had the option to dry the brewers spent grain it might be that they could sell it, but as for now they pay to get the brewers spent grain transported away from their production site.

Three ways to manage side streams were explored in the webform; recycling for human consumption, animal feed or biogas production. The companies' answers are shown in Table 9.

Table 9: The interview participants' answers from the webform regarding handling of their side streams.

To what extent does the side streams go to…	**Company A "Ready meal company"**	**Company B "Egg company"**	**Company C "Snacks company"**	**Company D "Brewery"**	**Company E "Protein bar company"**
Human consumption	3 – some extent	1 – not at all	1 – not at all	1 – not at all	2 – little extent
Animal feed	4 – big extent	3 – some extent	1 – not at all	4 – big extent	1 – not at all
Anaerobic digestion	4 – big extent	1 – not at all	5 – very big extent	1 – not at all	1 – not at all

Only two of the companies answered that they do re-use side streams for human consumption. Company A have side streams that are recycled as products for human consumption, since they send bread residues to beer production. Company E can sometimes rework their side stream from the protein bar production to a new special edition product, but since they do not produce anything in their own brand, they need to have a customer that is interested in that specific product.

The remaining companies were asked what hinders them from re-using their side streams for human consumption. Company B could potentially extract calcium from the eggshells for human consumption, but to make such a product profitable there has to be a need for alternatives to the already existing calcium products and supplements on the market. The egg white in the technical egg mass is perfectly fine nutrition wise and could be used for human consumption, but this is hindered by legislation due to microbial issues when the egg white is in contact with the eggshell. Company C have recently installed equipment to separate starch from their wastewater, but it cannot be guaranteed that the starch is free from chemical residues and can therefore not be reused in food production. The fine starch is instead sent to processing industry. Company D could potentially dry their brewers spent grain and sell it for human consumption, since it is a product with high protein content. The drying process would be very energy intensive and today they do not have the equipment for that.

Three of the companies could give examples of side streams for animal feed. Company A sends only plant-based side streams to animal feed and due to ethical reasons, they do not send anything to mink feed. Residual bread dough goes to pig feed. Bread that has passed the best-before date is unpacked by an external company and sent to production of biofuels, where the residues goes to pig feed as well. Company B use a centrifuge to separate the eggshells from the technical egg mass, and the latter goes to animal feed. Company D express that they rather see that their side stream becomes food for someone than biogas, and they therefore collaborate with a cattle farmer sharing the cost for transporting the brewers spent grain from the production site to the farm. The remaining two companies both brought up legislation and the need to be registered as a feed producer as an issue that hinders them from sending their side streams for animal feed. Company C also brought up the responsibility issue, that they need to be able to guarantee that the side stream is free from other non-food residues.

Company A mix all the residues that cannot be used for anything else with water into a slurry, which then goes to anaerobic digestion producing biogas. For Company C, anaerobic digestion is the main way to handle their side streams. They send peels, potato residues and starch to this cause. Company B have considered sending side streams for anaerobic digestion, but there has not been enough money or interest to continue down that road. Company E claim that the biogas plants cannot handle their side streams from the protein bar production, meaning that anaerobic digestion is not an option for them. Company D consider, as already mentioned, animal feed to be a better option than biogas.

Both Company C and Company E also have side streams going to cogeneration plants where the side streams are incinerated, producing combined power and heating. For Company E this is the main management of their side streams. Other examples of alternative handling of side streams that were mentioned in the interviews were ethanol production and soil improvement.

Avoidable side streams are side streams where there is clear potential for improvement. Unavoidable side streams are much harder to improve since they are likely connected to things like usage of certain equipment, the quality of the product or the raw material. Table 10 displays how the companies rated their side streams.

Table 10: The interview participants' answers from the webform regarding avoidable and unavoidable side streams.

	Company A "Ready meal company"	**Company B "Egg company"**	**Company C "Snacks company"**	**Company D "Brewery"**	**Company E "Protein bar company"**
Are the side streams mostly unavoidable or avoidable?	3 – same amounts of both	2 – mostly unavoidable	4 – mostly avoidable	2 – mostly unavoidable	5 – mostly avoidable

Both Company D and Company B have mostly unavoidable side streams. Company E on the other hand declare that they have mostly avoidable side streams. Their side streams appear mainly due to mistakes in the production, due to raw material passing best before date or due to products stop being in a brand's product line. Company A estimate that they have the same amount of avoidable and unavoidable side streams. The unavoidable side streams are for example bones and salmonella infected meat, which are discarded. Another unavoidable side stream is the cleaning water from cleaning the sauce cookers and other cooking equipment, which contains food residues. This water is sent to external water treatment plants. Company C have a side stream of snacks that does not reach the packaging within a certain time limit and are therefore discarded. They have recently changed their way of working in the production to avoid long stops and reduce this side stream, and they continuously report the 'edible waste' to their owners.

4.2.2.2 Possibilities and limitations

The next question was about the companies' potential for improvement. It was noted in the results from the webform in section 4.1 that there was no clear connection between the experience potential for improvement and having avoidable or unavoidable side streams. The companies' answers are shown in Table 11.

Table 11: The interview participants' answers from the webform regarding their potential for improvement.

	Company A "Ready meal company"	**Company B "Egg company"**	**Company C "Snacks company"**	**Company D "Brewery"**	**Company E "Protein bar company"**
How big is the potential for improvement?	5 – very big potential	4 – big potential	5 – very big potential	2 – little potential	3 – some potential

As seen in Table 11, three of the companies claimed in the webform to have a big or very big potential for improvement while two claims to have some or little potential. None claimed to have no potential for improvement. From the interviews it also became clear that all companies had thoughts about improvement they would like to do regarding their management of side streams.

The companies that answered that they had big or very big potential for improvement, which was company A, B and C, all had visions or goals for how this could be done. Company A lifts the possibility to mix the slurry for biogas with the water from cleaning the cooking equipment instead of with clean water, to also use the food residues in the water and thereby increase the total carbon content in the slurry. Company B would like to see different usage of their side streams, to utilize for example the amino acids and calcium for human consumption and possibly use the eggshell membranes for dermatological uses. To further reduce the avoidable side streams at Company B, the egg cracking equipment could possibly be improved to reduce the amount of egg white stuck to the eggshells. Company C are already working to improve their production flow to reduce the amount of discarded snacks, as already mentioned. The side stream of raw potatoes that are lost or discarded due to quality issues is today sent to cogeneration of power and heating, which was further explored in section 5 in the LCA case study.

Meanwhile the companies that answered that they have little or some potential had already tried different possibilities, or experienced that the limitations were bigger than the potentials. Company D have investigated many alternative ways for managing their side streams, for example drying the brewers spent grain. Due to doing these investigations and finding no fitting solutions they consider that they have little potential for improvement. Company E have recently set up environmental goals for their protein bar production, including reduction of waste and losses, and they have created action plans to make sure to reach these goals.

To be able to improve, the companies have to work around the limitations that they are facing. In the webform the companies got to pick out an unlimited number of limitations, and for the interview they were asked to pick out the one which would make the biggest difference for the handling of side streams if it was removed. Their answers are shown in Table 12.

Table 12: The interview participants' answers regarding which limitation that they had answered in the webform would make the biggest difference for the handling of side streams if it was removed.

	Company A "Ready meal company"	**Company B "Egg company"**	**Company C "Snacks company"**	**Company D "Brewery"**	**Company E "Protein bar company"**
Which limitation would make the biggest difference if it was removed?	Infrastructure – the availability of biogas production sites and the internal infrastructure on the site	Capital for investments[1] – costs for research, development of new products and investments in equipment	Legislation – to make it possible to send side streams to animal feed Infrastructure – secure the possibilities to treat side streams in a sustainable way	Technology – to be able to handle the brewers spent grain and the yeast	The handling lies outside of the company's core business[2] – since the production is subcontracting, the side streams cannot easily be used for other products

1. Note that this was an option that Company B came up with.
2. Note that this was also the only limitation that Company E chose in the webform.

Company A points out infrastructure as the limitation that would make the biggest difference for the managing of their side streams if it was removed. Today their side streams have to have high enough total carbon content to be worth sending to anaerobic digestion, since they experience that it is hard to find biogas plants nearby. The internal infrastructure on their own production site is another limitation, since the recycling station is located in the middle of their production site. This means that if they for example wants to use the cleaning water for mixing the slurry, they need a lot of pipes.

Company B pointed out capital for investments, which was an option that was added to the webform, as the limitation that would make a big difference for them if it was removed. If for example the government could step in with money for research, development and equipment it would be possible for them to invest in new possible uses of their side streams. Company C pointed out two limitations; legislation and infrastructure. If the legislation for animal feed would change it might be possible for them to send side streams to that purpose, which would be more sustainable than for example sending their discarded potatoes to cogeneration. The limitation of infrastructure is similar to the limitation that Company A points out, that it is hard to find biogas plants nearby that can handle their side streams.

Company D could manage their side streams differently if they for example had equipment for drying the brewers spent grain, which would make it more microbiologically stable and enable them to sell the brewers spent grain as a biproduct rather than pay for it to be transported away. Company E picked only the limitation that the handling of side streams lies outside of the company's core business in the webform. This is connected to the fact that they produce only on demand, for customers that have certain products in their range and that order certain amounts. For a company that does not produce anything in their own brand, they cannot easily use the side stream from one product any other way.

4.3 Discussion

In general, from the webform and the telephone interviews, the overall questions stated in the beginning of section 4 could be somewhat answered. It would have been a better result with more participants, but the result can, combined with the mapping of the side streams from the food processing sector in section 3.2.2, at least give an indication.

The first question that the interview section aimed to answer was regarding how the side streams from the food processing industry in Västra Götaland are handled, and the webform shows that the side streams are handled in many different ways, depending on what type of side stream it is. One of the biggest aspects for why companies handle their side streams in a certain way seems to be financial reasons, that everything comes with a prize and that it has to be worth it financially for the company.

The last question was regarding what the food industry needs to be able to change how they handle their side streams. The most chosen limitation alternative in the webform was technology, which could indicate that what the companies need is financial support to be able to invest in new equipment. Another commonly picked alternative was that it is outside the company's core business, which perhaps could be interpreted as for example not wanting to be registered as a feed producer as well as a food producer. When the companies participating in the telephone interview got to pick one limitation which would make the biggest difference if it was removed, the availability of biogas plants were lifted as well as the legislation. In general, it seems like the food processing industry in many cases finds it complicated to handle their side stream in a sustainable way. The higher up in the food recovery hierarchy one looks, the more requirements are set on the side streams quality, and the more responsibility lies on the food producer to meet the requirements. It is therefore often easier to consider the side stream as waste or as not suitable for consumption by humans or animals.

As seen in Figure 5, all the participating companies in the webform work moderately to very actively with their side streams. It is not unlikely that if all 400 food producers in Västra Götaland had answered the webform, that figure would look very different. Just above half of the 20 targeted companies answered the webform, and it is a possibility that they participated because they are proud of how they work while the remaining nine companies did not want to show that they do not work with their side streams. The email and the webform were deliberately phrased to not use negative words as 'waste' or 'losses', and to not ask the companies for specific amounts or other things that might be uncomfortable for them. Even then, it is possible that it was considered too intrusive by some companies.

5 Simplified LCA case study on side stream potatoes

5.1 Background

Life cycle assessment (LCA) is a quantitative tool for calculating and evaluating the environmental impact of different systems. ISO 14040 describes the principles and framework to be used to conduct an LCA, and ISO 14044 describes the requirements that should be applied. For this thesis, a simplified version of an LCA is performed. It could be described as an environmental system analysis which is based on the ISO-standards and following the same steps as is included in a full LCA.

From doing an LCA one gets a complete picture of the environmental impact of a product, with consideration of what resource streams there are going in and out of the system which makes it possible to see what could be reduced to minimize the impact. The LCA work is divided into four phases; Defining the goal and scope, inventory analysis, impact assessment and interpretation of the results. The workflow is iterative rather than linear, as shown in Figure 11.

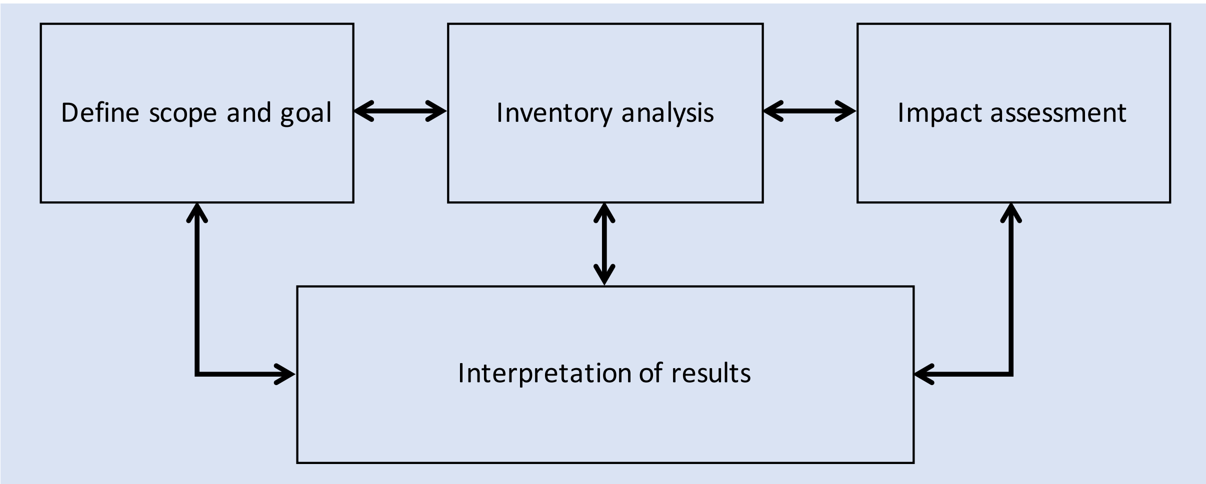


Figure 11: Iterative workflow in Life Cycle Assessment (LCA), as described in ISO 14040.

The goal and scope can vary depending on the subject and intention of the LCA study. In the inventory analysis phase the data for inputs and outputs of the system are studied, considering the goal and scope. In the impact assessment phase, the results from the inventory analysis are put together with information that brings understanding of the environmental significance of the gathered data in relation to the functional unit. The last step is to interpret the results from the previous steps by summarizing them and draw conclusions and make recommendations with regards to the goal and scope of the study. Just as Figure 11 indicates, there might be a need to move iteratively in the workflow and for example change the goal and scope depending on the results from the other phases of the LCA.

Depending on the scope the environmental impact of the system can be studied through various impact categories, such as global warming, eutrophication and acidification of soil and water. Economic and social aspects are typically not included in the scope for an LCA study.

5.1.1 Goal and purpose

The goal of this study was to perform an LCA case study to compare the global warming potential (GWP) of two different ways to handle side stream potatoes from a potato chips production located in Västra Götaland. The two options were with cogeneration and anaerobic digestion. The purpose was to give an indication whether it is best from a climate perspective to produce biogas and digestate or combined power and heating from side stream potatoes.

The side stream potatoes which were studied in this case study are sorted out from the potato chips production in three different steps; in the unloading of the potatoes arriving to the factory, when in storage and during the washing step. This is shown in Figure 12, which also shows the other side streams from the chips production.

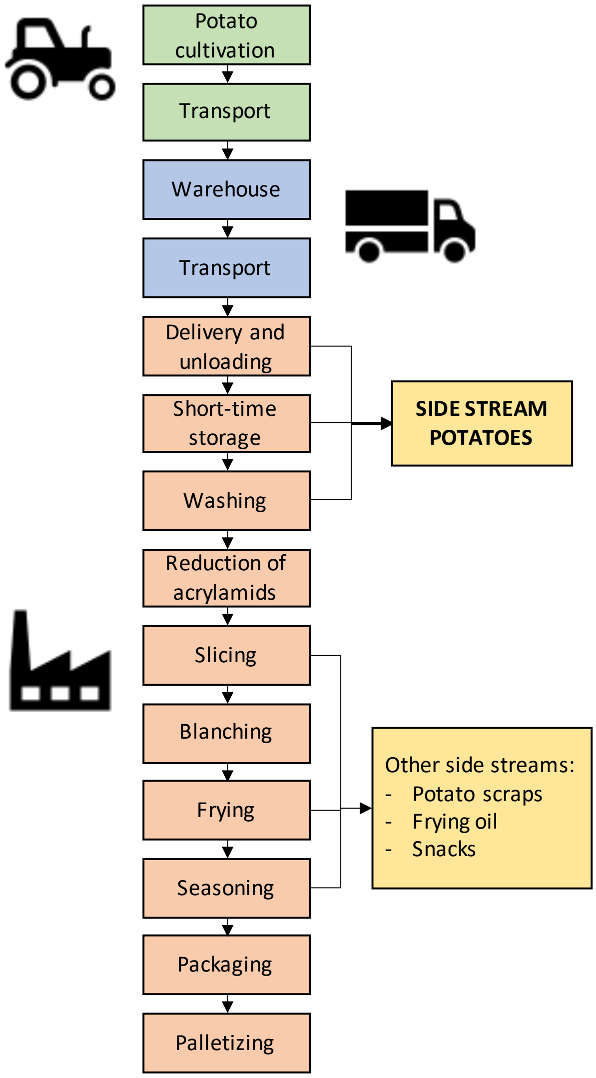


Figure 12: Simplified process chart over potato chips production, based on interview with Fondin (2020).

The side stream of potatoes is separated from the chips production for different reasons. In the unloading step there might be potatoes that ends up on the floor due to mishaps, and these potatoes cannot be returned to the production. In the short-time storage room and the washing step, potatoes are sorted out because they have sprouts and blemishes or are the wrong size (too big or too small). All the potatoes from the different process steps are put in the same container outdoors and are then transported away. The side stream potatoes are intact and very hard. Other side streams are potato scraps (peels and end pieces), used frying oil and snacks. The management of these side streams are not considered in this case study. (Fondin, 2020).

Today the potatoes go to a cogeneration plant and to create combined power and heating. This costs the snack producer 600 SEK/ton of side stream potatoes. During 2019 the amount of side stream potatoes from the potato chips production were 509 tons in total, meaning an annual cost of 305 500 SEK for handling this side stream (Fondin, 2020). The snack producer therefore has a financial incitement to find a better way to handle the side stream potatoes.

Cogeneration is also the one of the lowest sections of the food recovery hierarchy, where only the energy is recovered and no nutrients, meaning that the hypothesis was that it would be of environmental interest to redirect the side stream.

5.1.2 Scope

The scope of the study involves the global warming potential of two scenarios; A: cogeneration and B: anaerobic digestion. It reaches from having the side stream potatoes at the snack producer's factory gates, until using the biogas, having the digestate, or distributing the power and heating. The initial climate impact for the potatoes are allocated to only burden the main product, potato chips, since the side stream potatoes are of no economic value. The included scenarios are shown in Figure 13.

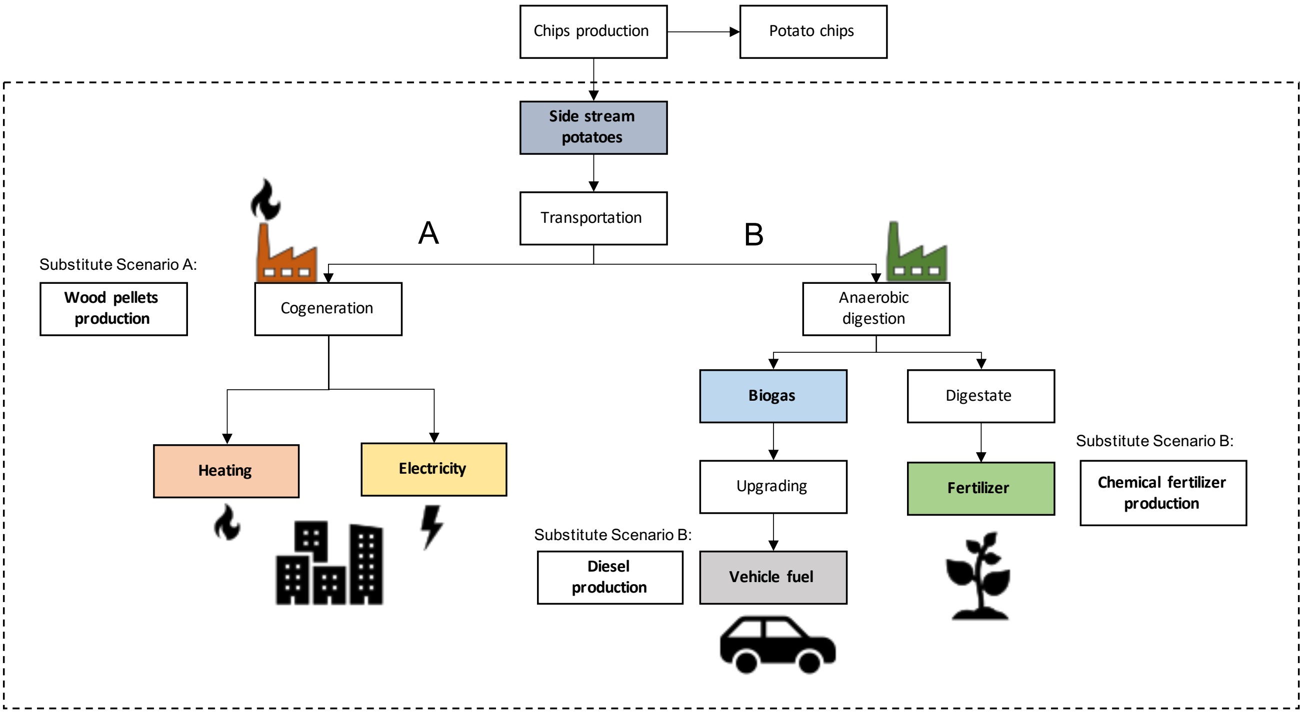


Figure 13: The scenarios which is included in the study. The dashed line marks the system boundary. The two scenarios are Scenario A: Cogeneration, producing combined power and heating, which substitutes cogeneration from wooden pellets, and Scenario B: Anaerobic digestion, producing methane gas which substitutes diesel as vehicle fuel and digestate which substitutes chemical fertilizer.

The scope for scenario A: cogeneration includes transport from the snack producer to the cogeneration plant located 9 km away, burning the potatoes and with energy recovery including the energy in the flue gases through flue gas condensation. This scenario does not consider usage of the power and heating. This scenario was assumed to substitute the production, distribution and burning of wood pellets.

The scope for scenario B: anaerobic digestion includes transport from the snack producer to the biogas plant located 20 km away, pre-treatment of the potatoes, hygienisation, anaerobic digestion, dewatering of the digestate, upgrading of the biogas to methane gas as vehicle fuel and usage of the methane gas in a car. This scenario was assumed to substitute the production and usage of diesel as vehicle fuel, and the production of chemical fertilizer.

The emissions caused by transporting potatoes from the snack producer to the cogeneration plant were included. Both scenarios are further described in section 5.1.4.

5.1.3 Functional unit

The functional unit (FU) is the unit which all calculations are related to, to make the results from the two scenarios comparable. For this study, the functional unit is 1 ton of side stream potatoes, and the results will be presented as CO_2-equivalents per FU.

5.1.4 System boundaries

In scenario A: Cogeneration, the side stream potatoes are transported to the nearest cogeneration plant located about 9 km away. This is the plant to which the snack producer sends the side stream potatoes today. The process from side stream potatoes to heat and electricity is described in Figure 14.

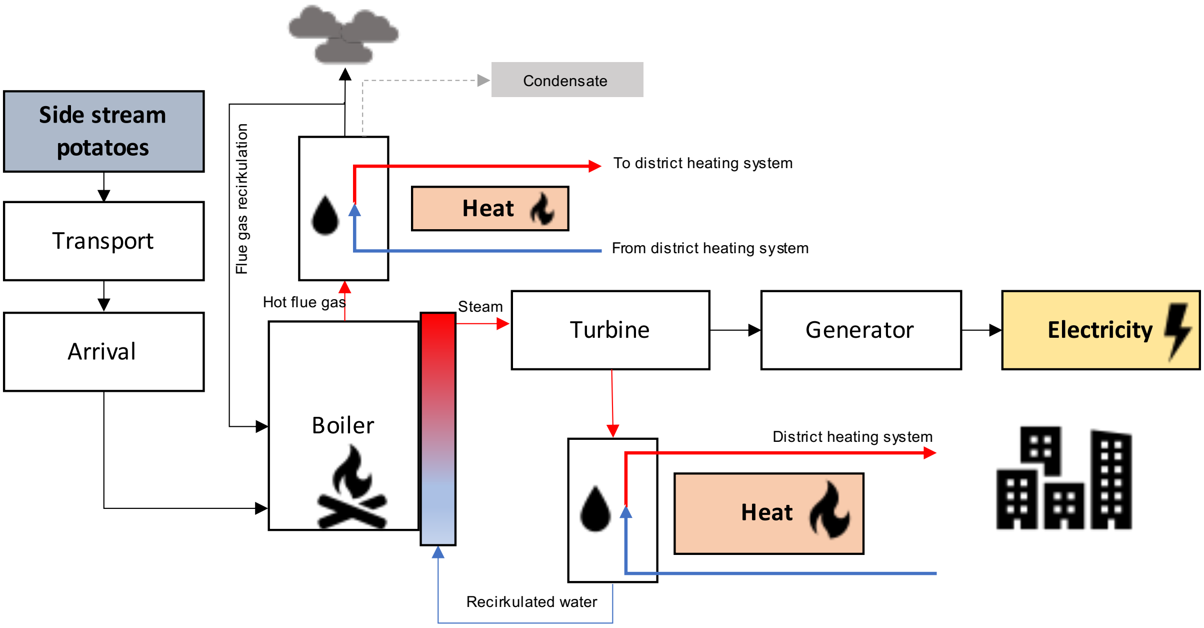


Figure 14: The incineration of side stream potatoes at the cogeneration plant, producing heat and electricity. Based on Energiföretagen (2019) and Naturvårdsverket (2005).

The potatoes are incinerated in the boiler which heats water and the water drives a turbine which generates electricity. The hot water then goes through a condenser where it meets cold water from the district heating system, which is then heated and sent back out in the system. The now cold water in the condenser is recirculated into the boiler again (Energiföretagen, 2019). The hot flue gas from the boiler, containing quite a lot of moisture depending on the fuel, goes through a flue gas condenser, where it also meets water from the district heating system and thereby even more energy from the process can be retrieved (Naturvårdsverket, 2005). Distribution of electricity and heat is not included in the system.

In scenario A, the side stream potatoes were assumed to substitute wood pellets as energy fuel. Wood pellets are produced from residues from sawmills and other wood industries. In Sweden, wood pellets are commonly used as fuel in cogeneration plants. The material is dried and milled, and then pressed to a rod shape with a diameter of 6-12 mm. The moisture content in the finished wood pellets is around 8-10%, and the energy content is above 16,9 MJ/kg (Lehtikangas, 1999).

In scenario B: Anaerobic digestion the side stream potatoes are transported 20km to the nearest biogas plant that handles food waste. The process from side stream potatoes to biogas and digestate is described in Figure 15.

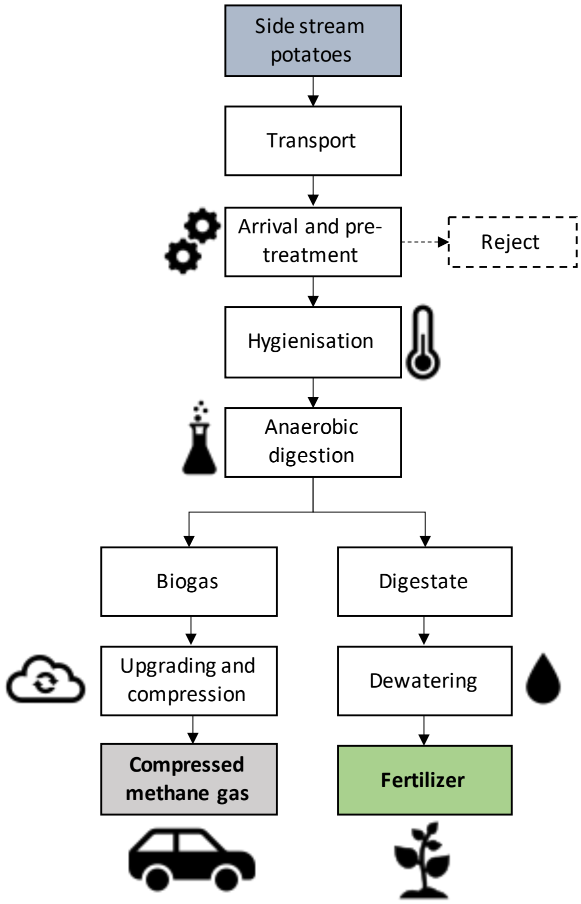


Figure 15: The anaerobic digestion of side stream potatoes, producing biogas as vehicle fuel and digestate as fertilizer based on Energigas Sverige (2018).

At arrival, the potatoes are pretreated by grinding and mixing with water, creating a slurry that can be pumped. If there are unwanted items among the substrate they are sorted out as reject that is often sent to incineration. In this study it was assumed that no potatoes were rejected. The slurry goes through a hygienisation step where it is heated to 70°C for 1 hour to kill of any unwanted bacteria that might be present in the substrate. After that, the slurry is pumped into the anaerobic digestion tank, where it is digested by anaerobic bacteria under mesophilic conditions. The products from the anaerobic digestion is biogas and digestate. The biogas is upgraded and compressed to be able to work as vehicle fuel. In this process the gas is purified from the unwanted gas molecules such as carbon dioxide through water scrubbing and the compressed methane gas consists of 97% methane. The digestate has a high water content and is dewatered before having the finished fertilizer (Energigas Sverige, 2018). The usage of the vehicle fuel is included in the study, but not the distribution to fuel stations. The distribution and spreading of the fertilizer are not included in the study.

In scenario B, the methane gas and digestate produced from side stream potatoes were assumed to substitute diesel as vehicle fuel and chemical fertilizer. Diesel consists of a mixture of hydrocarbons such as aromatics and paraffins, and additives to make it a better fuel (Gode, et al., 2011). The chemical fertilizer was assumed to be 100% nitrogen fertilizer, to make it an easier comparison to the nitrogen content in the digestate.

5.1.5 Data quality

The data used in the study should be published as recently as possible, to represent the current situation. Since the case study was located geographically in Västra Götaland, with side stream potatoes from a certain snack producer, the data should represent the area and technology as best as possible.

The data was gathered from scientific reports and official statistics and databases. Specific sources are further described in the inventory analysis. To get the emissions data for the transports, the tool NTMcalc from the Network for Transport Measures was used.

As much as possible, the data used to model the scenarios should be regarding potatoes. The side stream potatoes were assumed to have properties comparable to regular potatoes for human consumption. Where no such data could be found, assumptions were made from as similar fuels or substrates as possible. No data could be found for the energy content in the dry matter of potatoes, the efficiencies for the cogeneration plant and the emissions data for the cogeneration plant with potatoes as fuel. For the energy content, assumptions based on the energy content in the dry matter of other crops were used, from Lehtikangas (1999) and (Spörndly, et al., 2019). For the efficiencies, assumptions were made based on Olegård (2015) which is a Bachelor's thesis report from Karlstad University where they investigated the efficiencies in the incineration and flue gas condensation at Varberg Energy biomass-fired heating plant using wooden fuels with different dry matter content. The emissions data for the cogeneration plant were assumed to be close enough using woodchips with a moisture content of 40% as fuel, where data could be found from Gode, et al. (2011).

5.2 Inventory

For the sake of this LCA study it was assumed that the weekly amount of side stream potatoes were 10 tons based on the annual amount, and that they are shipped away with diesel trucks once every week. To put things in perspective, the energy consumption for the potato chips production during 2019 was 5 285 MWh from electricity and 49 329 MWh from natural gas and biogas

5.2.1 Scenario A: Cogeneration

The energy content in the side stream potatoes were assumed to be 10 MJ/kg dry substance, based on the energy content in other crops mentioned by Spörndly et al. (2019) and in wood mentioned by Lehtikangas (1999). The efficiencies in the boiler and flue gas condenser were based on the study by Olegård (2015). They determined that the efficiency of the boiler is lower with high water content in the fuel, which therefore were assumed to be 65%. Meanwhile they determined that the efficiency of the flue gas condenser was higher with high water content, which therefore were assumed to be 30%. Note that both efficiencies are based on the energy content in the side stream potatoes.

The data inventory of scenario A is shown Appendix B: Data inventory for LCA case study. The total amount of combined power and heating cogenerated from one ton of side stream potato at a cogeneration plant was calculated to be 2380 MJ. Of this, 542 MJ is electricity. In one year, 509 tons of side stream potatoes are discarded from the snack producer, meaning that in one year the side stream potatoes could produce 77 MWh of electricity per year which is about 1% of the total annual electricity demand for the potato chips production.

5.2.2 Scenario B: Anaerobic digestion

The volatile solids percentage is a measure for organic material in the substrate, and it is only this part of the dry substance that can be digested through anaerobic digestion and thus become biogas. Therefore a high percentage of volatile solids per dry substance almost always means a high biogas yield, with the exception of for example plastic and lignin that has a high volatile solids percentage but cannot be digested (Carlsson & Uldal, 2009).

There is always a small leakage of biogas from biogas plants. For the impact assessment it was assumed that the biogas leakage is pure methane gas and that the leakage happens before upgrading to vehicle fuel.

Due to assuming that no potatoes were rejected, it could be further assumed that the digestate yield were one ton of digestate per ton side stream potatoes. The nitrogen content in the digestate was of interest for the comparison with chemical fertilizer in the impact assessment.

The data inventory of scenario B is shown in Appendix B: Data inventory for LCA case study. The calculations show that one ton of side stream potato generates upgraded biogas with an energy content of 3500 MJ, and digestate as fertilizer with a nitrogen content of 3.75 kg. The emission data for the impact assessment of the biogas plant digesting side stream potatoes could not be found, and therefore the emissions were based on the energy demand for digesting similar substrates to potatoes, as described by Lindkvist, et al. (2019) and Berglund & Börjesson (2006). In total it was calculated that the energy demand for the biogas plant in scenario B is 427 MJ per ton of side stream potatoes.

5.3 Results

The global warming potential for the two scenarios related to the functional unit is presented as kg CO_2-equivalents per ton of side stream potatoes. The conversion factors for different greenhouse gases to CO_2-equivalents are shown in Table 13.

Table 13: Conversion factors for carbon dioxide, carbon monoxide, methane and nitrous oxide to carbon dioxide equivalents (Myhre, et al., 2013).

Emissions to air	CO_2-equivalents (g^{-1})
CO_2	1
CO	2
CH_4	28
N_2O	265

It is important to note the difference between emissions of fossil carbon dioxide and biogenic carbon dioxide. Biogenic carbon dioxide comes from the incineration of biofuels such as wooden fuels and energy crops, while fossil carbon dioxide comes from the incineration of fossil fuels. The carbon in both fuels are bound from the atmosphere, but while fossil fuels are formed over millions of years, the biofuels are formed on a much shorter interval. This means that the biogenic carbon dioxide can be seen as part of the natural carbon cycle, and the emissions from biofuels can therefore be considered as carbon dioxide neutral (Naturvårdsverket, 2020). What this means for the impact assessment is that the usage of biogas as vehicle fuel and the cogeneration of power and heating from wooden fuels and potatoes is considered carbon dioxide neutral while diesel is a fossil fuel and the usage emit fossil carbon dioxide.

For the impact assessment, the total emissions of carbon dioxide equivalents from the different scenarios was calculated. These values were then compared with the emissions of carbon dioxide equivalents from the substitution scenarios; wooden pellets, diesel and chemical fertilizer.

5.3.1 Scenario A: Cogeneration

From the data inventory the amount of energy coming from cogeneration from side stream potatoes was known. The emissions data from Gode, et al. (2011) are based on gram emissions per mega joule, which therefore could be related to the functional unit through the calculated energy and the conversion factors in Table 13. As no data for cogeneration from potatoes could be found, it was assumed that it was the same as for cogeneration from woodchips with a moisture content of 40%.

Emission data for the production, distribution and usage of wooden pellets in a cogeneration plant were taken from Gode, et al. (2011). The calculations were made so that both fuels generated the same amount of energy as from 1 ton of side stream potatoes. For comparison, the energy from 1 ton of wooden pellets corresponds to 6.4 tons of side stream potatoes.

The impact assessment data for scenario A can be found in Appendix C: Emission data for LCA case study. Figure 16 shows the global warming potential, GWP, for the scenario where the GWP from incineration of wood pellets is shown as negative values and the GWP from incineration of the side stream potatoes are positive values.

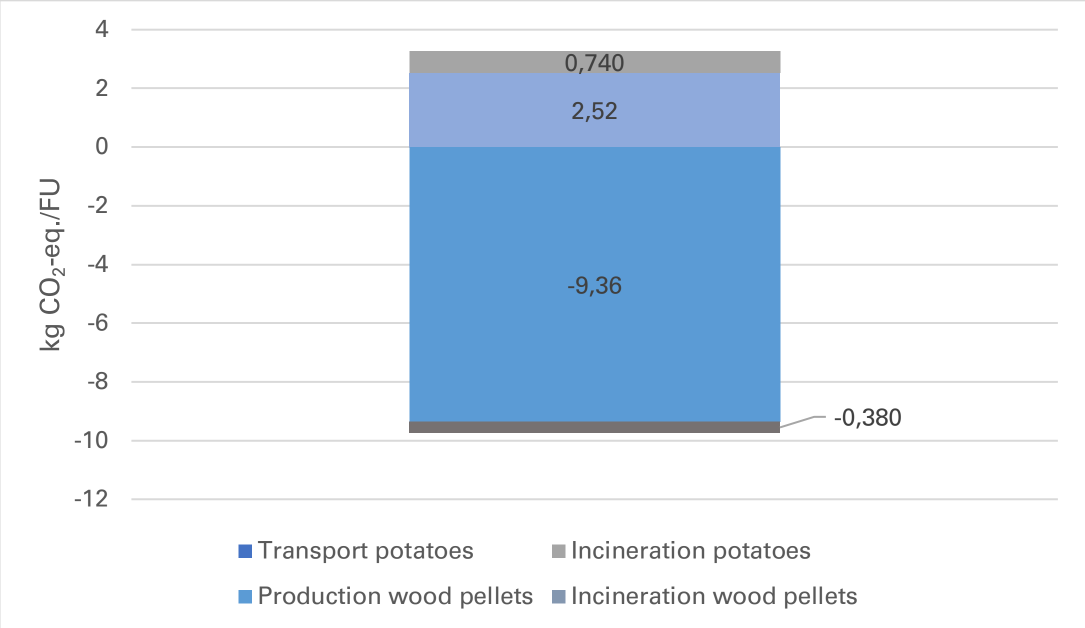


Figure 16: The global warming potential for scenario A: cogeneration, where incineration of side stream potatoes is substituting incineration of wood pellets.

As seen in Figure 16, the GWP from cogeneration from side stream potatoes was calculated to 3.26 kg CO_2-equivalents per functional unit, which is slightly lower than the GWP for when using wooden pellets as fuel for the same cause. When subtracting the substitutional process, the net GWP resulted in negative 6.48 kg CO_2-equivalents per functional unit.

5.3.2 Scenario B: Anaerobic digestion

As mentioned in the inventory analysis, the emission data for the anaerobic digestion of side stream potatoes were based on the energy demand for the biogas plant. It was assumed that the energy comes from the Swedish electricity mix, which mainly is produced through nuclear power and hydropower. The global warming potential, GWP, from this electricity mix is about 13g CO_2-equivalents per kWh (Energi- och klimatrådgivningen i Stockholmsregionen, 2018). The methane leakage from the biogas production were also included, and the emissions from usage of upgraded biogas as vehicle fuel in a private car were taken from Gode, et al (2011).

Emission data for the production, distribution and usage of diesel as vehicle fuel in a private car were taken from Gode, et al (2011). The comparison with chemical fertilizer were made with the corresponding amount of 100% nitrogen fertilizer that the nitrogen content in the digestate could substitute, and the emissions from the production were found from Börjesson & Berglund (2003).

The impact assessment for scenario B can be found in Appendix C: Emission data for LCA case study. Figure 17 shows the GWP for the scenario, where the GWP of the substitutions are shown as negative values and the GWP of the anaerobic digestion of side stream potatoes as positive values.

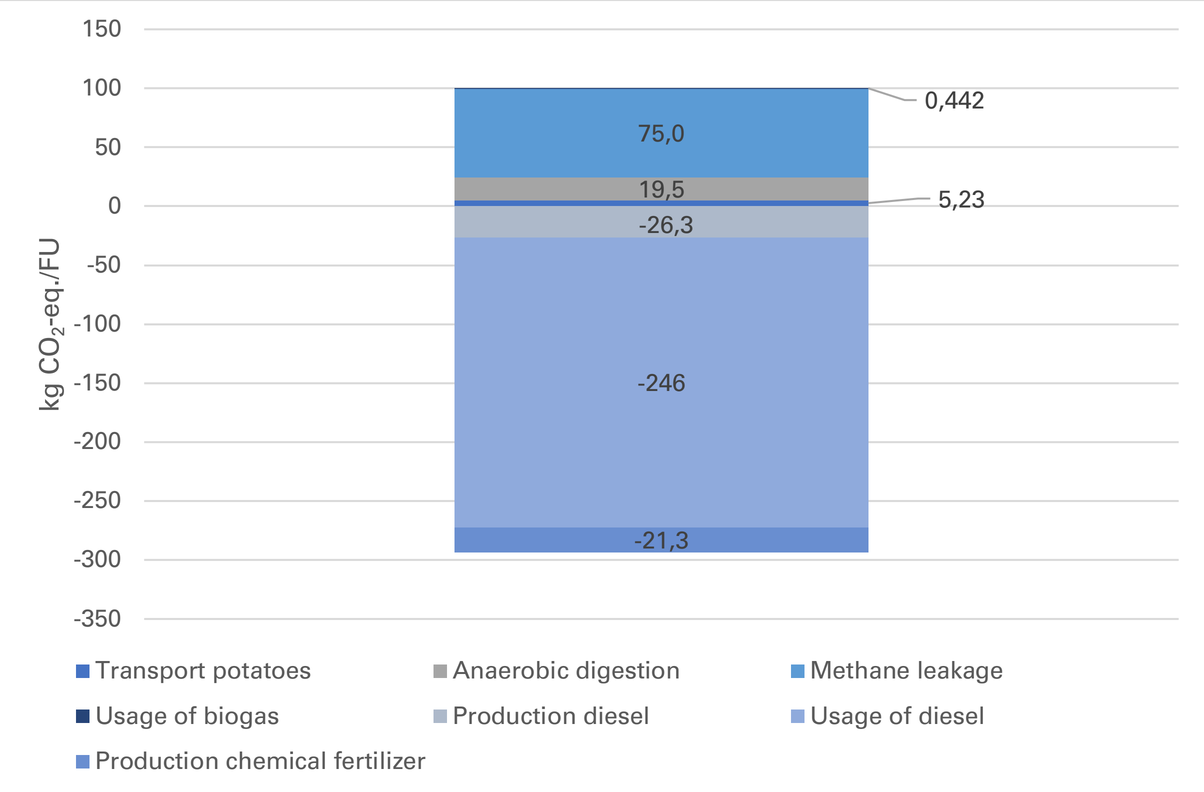


Figure 17: The global warming potential for scenario B: anaerobic digestion, where biogas and digestate from side stream potatoes are substituting diesel and chemical fertilizer.

As seen in Figure 17, the anaerobic digestion of side stream potatoes producing biogas as vehicle fuel and digestate as fertilizer has a lower GWP per ton of side stream potatoes than the combination of the production of chemical fertilizer and the production, distribution and usage of diesel. The GWP per ton of side stream potatoes for the biogas and digestate was calculated to 100 kg CO_2-equivalents per ton of side stream potatoes, while the total GWP per ton of side stream potatoes for the diesel and chemical fertilizer were calculated to 293 kg CO_2-equivalents per ton of side stream potatoes. When subtracting the substitutional processes, the net GWP resulted in negative 193 CO_2-equivalents per functional unit.

5.3.3 Comparison

As seen in Figure 16 and 17, the net value of the global warming potential is very negative for the substitution in Scenario B: Anaerobic digestion and just below zero for the substitution in Scenario A: Cogeneration. The negative values mean that the substitution gives a reduction in global warming potential, and the scenario with the biggest reduction is therefore the better option. This indicates that sending the side stream potatoes from the potato chips production for anaerobic digestion, producing biogas as vehicle fuel and digestate as fertilizer, is a better solution from a global warming potential aspect than sending the side stream as fuel for cogeneration of combined power and heating.

The difference between the two scenarios is 186 kg CO_2-equivalents per ton of side stream potatoes. This is equivalent to transporting the 10 tons of potatoes around 1600 km with a diesel fueled truck. With the already included 40km two-way trip to the biogas plant in the original scenario, this means that the potatoes in Scenario B can be transported to a biogas plant located about 800 km away from the snack producer before Scenario A has a lower climate impact than Scenario B. From the snack producer, this would mean that the potatoes could be shipped south as far as to northern Germany or shipped north to for example Östersund.

For distances longer than this it is also questionable if it is an environmentally defensible option to substitute diesel and chemical fertilizer with biogas and digestate from anaerobically digesting the side stream potatoes. And naturally a biogas plant close to the snack producer would be preferred both environmentally and financially with transport costs.

5.4 Discussion

Considering the assumptions made in the case study, especially regarding Scenario A: Cogeneration, the results should not be taken as facts but rather as indications. The assumptions were made to represent the case as well as possible, but no assumption is as good as the reality.

The cost for Scenario A: Cogeneration was known from the snack producer to be 600 SEK per ton potatoes, but the cost for Scenario B: Anaerobic digestion was not considered in this case study. Considering that the inventory analysis indicates that the amount of energy recovered from the potatoes through anaerobic digestion is higher than from cogeneration, and that the anaerobic digestion in addition to energy also recovers nutrients, it would not be unreasonable that this might be a cheaper alternative. The snack producer is already shipping other side streams for anaerobic digestion, meaning that it might be possible for them to join those shipments and therefore save the transport costs. This is supposing that the same biogas plant can handle the different kinds of side streams.

For the calculations in this case study, it was assumed that the side stream potatoes were digested or incinerated without being mixed with anything else. In reality it is more likely that the potatoes are mixed with other substrates or fuels, which would affect the efficiencies and yields.

An important aspect to remember in this case study is that the very best option, looking at the food recovery hierarchy in Figure 3, would be if the side stream of discarded potatoes did not exist at all or could be reduced. The negative GWP for Scenario B: Anaerobic digestion suggests that there is a reduction of global warming potential for every ton of side stream potato that substitutes diesel and chemical fertilizer, which could be interpreted as that more of the potatoes from the chips production should be sent for biogas production. It is then important to note that this result is connected to the goal and scope of this life cycle analysis, which is assuming that there is a set amount of side stream potatoes every year with zero climate impact, and did not consider what would happen if this amount was increased or reduced.

Another alternative scenario which were not considered in this case study were animal feed. This comes as a higher alternative in the food recovery hierarchy, meaning that it has potential to be an even better alternative than anaerobic digestion. No clear answer was found regarding the potato quality needed and what processing they would need to become animal feed. More research on this would be needed. There might be a fraction of the potatoes that would be possible to give as animal feed, but since the discarded potatoes are all stored in the same open container outdoors, no matter in what process step they were discarded, there would be a need to change the routines in the chips production first. Considering all this, the alternative to make animal feed from the side stream potatoes was not investigated further.

6 Conclusions

For the side streams throughout the food supply chain that are considered as waste, and treated with for example anaerobic digestion or cogeneration, there were quite a lot of data which is accessible through official statistics. This data mainly covered the consumer sector. A gap in the data was regarding the losses in primary production and to some extent food processing industry since the environmental reports from food producers could not be accessed.

It is almost always better from an environmental perspective if the side streams are considered as resources and used according to the higher levels in the food recovery hierarchy wherever it is possible. This is mainly possible in the earlier steps of the food supply chain, before reaching the consumer sector. Although, these side streams were not as well documented since the industry does not have to report any data regarding their byproducts, which for example animal feed could be considered as, or regarding side streams which is redirected for human consumption. It might be possible to find data regarding these side streams in the environmental reports from food producers.

The webform in section 4.1, filled in by food processing companies, showed no significant difference between to what extent their side streams are re-used for human consumption, recycled as animal feed or sent to anaerobic digestion. This was most likely due to few participating companies and that the participating companies had very different productions, which therefore generates very different side streams. This shows the importance of remembering that the food recovery hierarchy is only a model, and it has to be adjusted according to the circumstances with every single side stream. Depending on the geographical location and the composition and properties of the side stream, different solutions might be the most sustainable option.

The telephone interviews in section 4.2, with five of the webform participants, indicated that it was in general easier, both technology-wise and legislation-wise, to consider the side streams as waste rather than as a resource for animal feed or human consumption. A common perception was that it is complicated to be registered as a feed producer, and the responsibility that comes with it is unwanted. To support the companies, it might therefore be a possibility to inform about and simplify the requirements and legislation, to make it less complicated and thereby lower the hurdle. Investments in certain technology might be needed to take care of the side streams in a good way, and naturally that has to be worth it financially for the company. The same goes for the cost of any additional working hours and factory space which might be needed to handle the side streams in a different way than today. One of the companies participating in the telephone interview suggested that financial support for such investments could be a possible solution which encourages companies to reconsider their management of side streams for a more sustainable option.

Lastly, the LCA case study in section 5, with the side stream of potatoes from the snack producer, indicated that it would be a more sustainable solution to produce biogas as vehicle fuel and digestate as fertilizer through anaerobic digestion than producing combined power and heating through cogeneration. This would mean a redirection of the side stream from the current management, which was cogeneration, and the financial aspect of this was not included in the case study. From the calculated difference in global warming potential between the alternative scenarios and the substitution of diesel, chemical fertilizer and cogeneration from wooden pellets, it was estimated that the side stream potatoes could be transported about 800 km away from the snack producer before cogeneration becoming a better option than anaerobic digestion.

7 Future research

The side streams in the food supply chain should always be of interest to look at, both regionally in Västra Götaland, nationally in Sweden and globally. For future research regarding the side streams in Västra Götaland it is suggested to perform similar studies as this one regularly, to be able to follow the development and changes. To regularly interview the food processing industry, it would potentially be possible to see how for example changes in legislation or development of the infrastructure impact how the companies are able to work with their side streams. To contact the food processing industries at a regular interval might also make them more interested in improvement.

There were gaps in the data collection covering the side streams throughout the food supply chain in Västra Götaland. Some data might exist and just have to be compiled, while other data is unknown and would have to be calculated or gathered. A suggestion is to get access to the environmental reports from the food processing industry, where they might be reporting data on their side streams. The data should be accessible through either contacting the companies themselves, through Svenska Miljörapporteringsportalen (SMP) or from Länsstyrelsen in Västra Götaland.

Grahn, et al (2020) covered the biogas potential in Västra Götaland, and with that the potential from food waste. It would be interesting to see the potential for other, higher, levels in the food recovery hierarchy as well. The estimation from Foderlotsen AB, through Ola Karlsson (2020), regarding how much the food side streams are used as animal feed was the only coverage found on that level in the food recovery hierarchy. A similar study as the on performed by Grahn, et al (2020) could perhaps be performed regarding side streams in Västra Götaland which is recycled as animal feed or re-used for human consumption.

It would be interesting to have more participants in the webform and the telephone interviews, to get a more reliable result and more aspects regarding the possibilities and limitations that the food processing industry in Västra Götaland is facing. In this study only 11 companies filled in the webform, and 5 of those participated in the telephone interview. This was most likely due to that the webform was sent out days before the crisis caused by the Covid-19 global pandemic began for real in Sweden. If it could be scaled up to at least 50-100 participants in the webform it would represent a much larger portion of the total number of food processing companies in the region, and therefore give a more representative result.

The LCA case study on side stream potatoes started with potatoes at the factory gate with nullified environmental impact from their background. To get a different aspect, one could instead look at how the handling of side streams impact the total environmental impact from the potato chips production, including also the other side streams such as peels and frying oil. It might be that redirecting the side stream potatoes, which was suggested from the case study performed in this thesis project, is not the alteration which brings the biggest reduction of the total environmental impact from the potato chips production. The redirection of for example potato peels and potato residues to animal feed rather than anaerobic digestion might possibly reduce the environmental impact even more, and therefore be a scenario which would be more interesting to look at from a financial perspective rather than redirecting the side stream potatoes.

References

Aleksandrowicz, L. et al., 2016. The Impacts of Dietary Change on Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review. *PLoS ONE,* 11(11).

Andersson, T. & Stålhandske, S., 2020. *Matavfall i Sverige - Uppkomst och behandling 2018,* Stockholm: Naturvårdsverket.

Avfall Sverige, 2019. *Svensk avfallshantering 2018,* Malmö: Avfall Sverige.

Avfall Sverige, 2020. *Certifierad Återvinning.* [Online]
Available at: https://www.avfallsverige.se/kunskapsbanken/certifierad-atervinning/
[Accessed 06 March 2020].

Avfall Sverige, 2020. *Kommunernas bransch-organisation för avfallshantering.* [Online]
Available at: https://www.avfallsverige.se/
[Accessed 14 February 2020].

Börjesson, P. & Berglund, M., 2003. *Miljöanalys av biogassystem,* Lund: Lunds Tekniska Högskola, Institutionen för teknik och samhälle.

Berglund, M. & Börjesson, P., 2006. Assessment of energy performance in the life-cycle of biogas production. *Biomass and Bioenergy,* 30(1), pp. 254-266.

Canali, M. et al., 2017. Food Waste Drivers in Europe, from Identification to Possible Interventions. *Sustainability,* 9(37).

Carlsson, M. & Uldal, M., 2009. *Substrathandbok för biogasproduktion,* Malmö: Avfall Sverige Utveckling.

Energi- och klimatrådgivningen i Stockholmsregionen, 2018. *Miljöpåverkan från el.* [Online]
Available at: https://energiradgivningen.se/klimat/miljopaverkan-fran-el
[Accessed 05 May 2020].

Energiföretagen, 2019. *Kraftvärme.* [Online]
Available at: https://www.energiforetagen.se/energifakta/kraftvarme/
[Accessed 03 May 2020].

Energigas Sverige, 2017. *Produktion och distribution.* [Online]
Available at: https://www.energigas.se/fakta-om-gas/biogas/produktion-och-distribution/
[Accessed 25 May 2020].

Energigas Sverige, 2018. *Produktion och användning av biogas och rötrester år 2017,* Eskilstuna: Energimyndigheten.

Energigas Sverige, 2019. *Vad är energiinnehållet i naturgas, biogas och fordonsgas?.* [Online]
Available at: https://www.energigas.se/fakta-om-gas/biogas/faq-om-biogas/vad-aer-energiinnehaallet-i-naturgas-biogas-och-fordonsgas/
[Accessed 05 May 2020].

Energigas Sverige, n.d.. *Karta biogasanläggningar.* [Online]
Available at: https://www.energigas.se/fakta-om-gas/biogas/karta-biogasanlaeggningar/
[Accessed 06 March 2020].

EPA, 2019. *Food Recovery Hierarchy.* [Online]
Available at: https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy
[Accessed 14 February 2020].

Eriksson, M., Strid, I. & Hansson, P.-A., 2015. Carbon footprint of food waste management options in the waste hierarchy e a Swedish case study. *Journal of Cleaner Production,* Volume 93, pp. 115-125.

Europeiska kommissionen, 2017. EU:s riktlinjer för livsmedelsdonationer. *Europeiska unionens officiella tidning*, 25 October.

FAO, 2013. *Tool kit - Reducing the Food Wastage Footprint.* [Online]
Available at: http://www.fao.org/3/i3342e/i3342e.pdf
[Accessed 14 February 2020].

FAO, 2015. *Food wastage footprint & Climate Change,* Rom: FAO.

FAO, 2019. *The State of Food and Agriculture 2019 - Moving forward on food loss and waste reduction,* Rome: Licence: CC BY-NC-SA 3.0 IGO.

Fondin, I., 2020. *Head of Environmental and Energy issues, Estrella AB* [Interview] (16 April 2020).

Gode, J. et al., 2011. *Miljöfaktaboken 2011 - Uppskattade emissionsfaktorer för bränslen, el, värme och transporter,* Stockholm: Värmeforsk.

Grahn, D., Andersson, T. & Persson, E., 2020. *Potentialstudie för biogas i Västra Götaland,* Stockholm: IVL Svenska Miljöinstitutet.

Jordbruksverket, 2019. *Åkerarealens användning efter län/riket och gröda. År 1981-2019.* [Online]
Available at: http://statistik.sjv.se/
[Accessed 12 February 2020].

Jordbruksverket, 2020. *Ökad foderanvändning från matsvinn och restprodukter - Bättre resurseffektivitet för att uppnå miljö- och klimatmål,* s.l.: Jordbruksverket.

Kalmendal, R., n.d.. *Livsmedelssektorn i Västra Götaland Trender och fakta,* s.l.: Västra Götalandsregionen.

Karlsson, O., 2020. *E-mail correspondance, Foderlotsen AB* [Interview] (8 April 2020).

Länsstyrelsen Västra Götalands län & Västra Götalandsregionen, 2017. *Klimat 2030 Västra Götaland ställer om - Strategiska vägval.* [Online]
Available at: https://klimat2030.se/ladda-ner/
[Accessed 25 May 2020].

Lagerberg Fogelberg, C., Vågsholm, I. & Birgersson, A., 2011. *Från förlust till vinst – såhär minskar vi matsvinnet i butik,* Uppsala: SLU, Sveriges lantbruksuniversitet, Institutionen för biomedicin och veterinär folkhälsovetenskap.

Landquist, B. & Nordborg, M., 2019. *Produktion och konsumtion av livsmedel i Västra Götaland 2003 och 2016 - Detaljerad resultat- och metodikrapport,* Lund: RISE Research Institutes of Sweden AB.

Lehtikangas, P., 1999. *Lagringshandbok för trädbränslen,* Uppsala: Institutionen för virkeslära, SLU, Sveriges lantbruksuniversitet.

Lindbom, I., Gustavsson, J. & Sundström, B., 2013. *Minskat svinn i livsmedelskedjan - ett helhetsgrepp. Slutrapport,* Göteborg: SIK Institutet för livsmedel och bioteknik.

Lindkvist, E., Karlsson, M. & Ivner, J., 2019. System Analysis of Biogas Production—Part II Application in Food Industry Systems. *Energies,* 28 January, 12(3), p. 412.

Modin Edman, A.-K., 2020. *Senior Sustainability Manager, Arla Foods AB* [Interview] (20 February 2020).

Myhre, G. et al., 2013. Anthropogenic and Natural Radiative Forcing. In: T. Stocker, et al. eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, USA: Cambrudge University Press, pp. 659-740.

Naturvårdsverket, 2005. Förbränningsanläggningar för energiproduktion inklusive rökgaskondensering. *Naturvårdsverkets Branschfaktablad,* 1(2).

Naturvårdsverket, 2020. *Biogena koldioxidutsläpp och klimatpåverkan.* [Online]
Available at: https://www.naturvardsverket.se/Sa-mar-miljon/Klimat-och-luft/Klimat/Tre-satt-att-berakna-klimatpaverkande-utslapp/Biogena-koldioxidutslapp-och-klimatpaverkan/
[Accessed 20 May 2020].

Nordic Council of Ministers, 2014. *Nordic Nutrition Recommendations 2012.* 5 ed. s.l.:Nordic Council of Ministers.

Olegård, A., 2015. *Utredning av verkningsgrad på Varberg Energis bioeldade värmeverk - Optimering av fukthalt genom beräkningsmodell,* Karlstad: Karlstad university.

Pågen, n.d.. *Hållbarhet - nu och i framtiden.* [Online]
Available at: https://pagen.se/vi-bakar-med-karlek/vart-hallbarhetsarbete/
[Accessed 09 March 2020].

Papargyropoulou, E. et al., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, 1 August, pp. 106-115.

Poore, J. & Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. *Science,* Volume 360, pp. 987-992.

Röös, E., Karlsson, H., Witthöft, C. & Sundberg, C., 2015. Evaluating the sustainability of diets–combining environmental and nutritional aspects. *Environmental Science & Policy,* Volume 47, pp. 157-166.

RISE Research Institutes of Sweden, n.d.. *Biogödsel.* [Online]
Available at: http://publiccert.extweb.sp.se/sv/Product/List/915
[Accessed 06 March 2020].

Sörme, L., 2020. *E-mail correspondance, SCB* [Interview] (17 April 2020).

SCB, 2019. *Folkmängd i riket, län och kommuner 31 december 2018 och befolkningsförändringar 2018.* [Online]
Available at: https://www.scb.se/
[Accessed 29 January 2020].

Spörndly, R., Bergkvist, G., Nilsdotter-Linde, N. & Eriksson, T., 2019. *Ersättningsfoder till nötkreatur vid grovfoderbrist,* Uppsala: Sveriges lantbruksuniversitet, forskningsplattformen SLU Future Food.

UNDP, 2020. *Goal 12: Responsible consumption and production.* [Online]
Available at: https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-12-responsible-consumption-and-production.html
[Accessed 05 March 2020].

Västra Götalandsregionen, 2018. *About Region Västra Götaland.* [Online]
Available at: https://www.vgregion.se/en/about/
[Accessed 29 January 2020].

Västra Götalandsregionen, 2019. *Kraftsamling biogas 2017-2020.* [Online]
Available at: https://www.vgregion.se/regional-utveckling/verksamhetsomraden/miljo/kraftsamling-biogas/kraftsamling-biogas-2017-2020/
[Accessed 27 February 2020].

Westöö, A.-K. & Jensen, C., 2018. *Matavfall i Sverige Uppkomst och behandling 2016,* s.l.: Naturvårdsverket.

Westin, J., 2019. *Hushållsavfall i siffror - kommun- och länsstatistik 2018,* Malmö: Avfall Sverige.

WHO & FAO, 2013. *Codex Alimentarius Commission – Procedural Manua.* Twenty-first ed. Rome: Secretariat of the Joint FAO/WHO Food Standards Programme.

Appendix A: Webform

<u>Sida 1:</u>

Frågeformulär: Sidoströmmar i livsmedelsindustrin

Det här frågeformuläret är en del av ett examensarbete vid Lunds Tekniska Högskola, som görs i samarbete med RISE Research Institutes of Sweden.

Syftet med examensarbetet är att bygga upp en helhetsbild över sidoströmmar i livsmedelskedjan i Västra Götaland – vad vet vi och vad vet vi inte?

I ett första steg har tidigare insamlade data och rapporter studerats för att se vad man redan vet, från primärproduktionen till hushållen. I detta andra steg ligger fokus på företag inom livsmedelsförädling och deras sidoströmmar, för att se vad där finns för potential. I tredje och sista steget kommer en LCA-fallstudie att genomföras på en sidoström hos ett företag, där hanteringen i dagsläget jämförs med någon alternativ hantering för att identifiera om det finns möjligheter till förbättring hållbarhetsmässigt.

Vid eventuella frågor kontakta:

Emma Kihlberg (student), email: xxx@student.lu.se, telnr: xxx-xxx xx xx

Karin Östergren (huvudhandledare), email: xxx@ri.se, telnr: xxx-xxx xx xx

Anna Ekman-Nilsson (bitr. handledare), email: xxx@ri.se, telnr: xxx-xxx xx xx

Din email-adress samlas in för att du ska få ditt formulärssvar skickat till dig på mail.

Syftet med formuläret

För att ge en rättvis bild av hur resurshanteringen fungerar i samhället idag är det viktigt att få input direkt från livsmedelsindustrin. Syftet med formuläret är att lyfta fram vad livsmedelsföretag ser för potential med de sidoströmmar de har från sin produktion. Vad görs idag och vad skulle kunna göras imorgon?

I detta första steg ber jag dig därför svara på frågorna i detta formulär efter bästa förmåga. Vid ett uppföljningssamtal kommer jag sedan att ställa några följdfrågor, och du har möjlighet att tillägga vidare information eller tankar.

För att ett examensarbete ska bli godkänt måste det kunna publiceras. Eventuella känsliga uppgifter kommer därför inte att tas med i rapporten. Ställ gärna frågor kring detta så arbetar vi fram en bra lösning som passar alla!

<u>Ditt namn och yrkesroll</u>

____

<u>Vilket företag representerar du?</u>

____

<u>Får vi kontakta dig för ett uppföljningssamtal? Om ja, fyll i telefonnummer nedan</u>

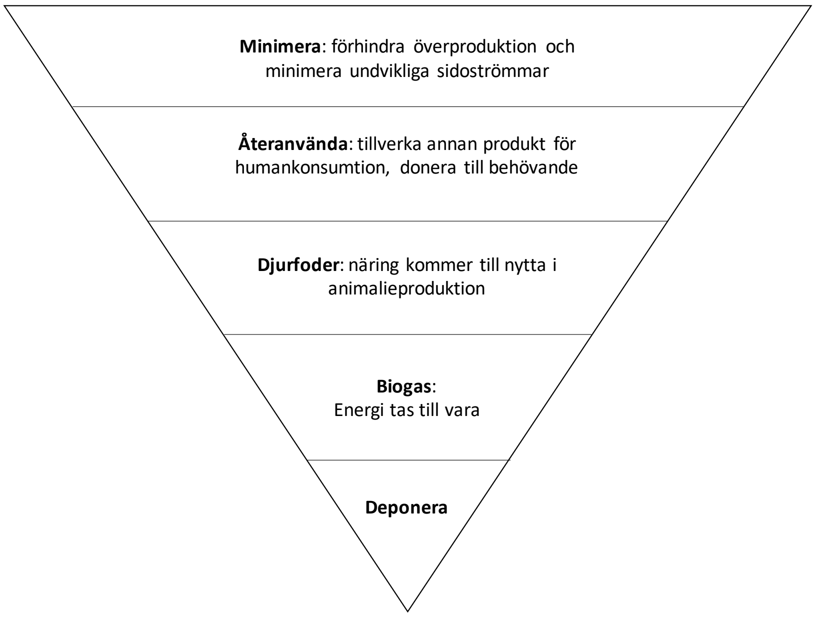
____

<u>Sida 2: Hantering av sidoströmmar</u>

<u>Hur aktivt jobbar företaget med sidoströmmar? (uppföljning, mätning, hållbar hantering, minskning etc)</u>

Inte aktivt *(1) (2) (3) (4) (5)* Mycket aktivt

Olika alternativ för hantering av sidoströmmar:



<u>I hur stor utsträckning går företagets sidoströmmar till återanvändning för humankonsumtion?</u>

Inte alls *(1) (2) (3) (4) (5)* Stor utsträckning

<u>I hur stor utsträckning går företagets sidoströmmar till djurfoder?</u>

Inte alls *(1) (2) (3) (4) (5)* Stor utsträckning

<u>I hur stor utsträckning går företagets sidoströmmar till biogas?</u>

Inte alls *(1) (2) (3) (4) (5)* Stor utsträckning

Oundvikliga och undvikliga sidoströmmar: En oundviklig sidoström är t.ex. ben och skal som tas bort i processen. En undviklig sidoström är mat som inte kunnat säljas/levereras av olika anledningar samt spill i produktionskedjan eller leveranskedjan, t.ex. kopplat till överproduktion och produktionsfel.

<u>Hur stor del av sidoströmmarna är oundvikliga respektive undvikliga?</u>

Till största del oundvikliga *(1) (2) (3) (4) (5)* Till största del undvikliga

<u>Kommentar kring hantering av sidoströmmar (frivilligt)</u>

Sida 3: Möjligheter och begränsningar

Hur stor förbättringspotential finns det i hur företaget hanterar sidoströmmarna idag?

Ingen förbättringspotential *(1) (2) (3) (4) (5)* Stor förbättringspotential

Vilka är de stora begränsningarna för företaget när det kommer till att ta hand om sidoströmmarna?

- ☐ Ekonomi (personalkostnader, lokalkostnader, etc)
- ☐ Lagstiftning
- ☐ Infrastruktur (tillgänglighet till biogasanläggningar, etc)
- ☐ Teknik/utrustning
- ☐ Hanteringen ligger utanför företagets kärnverksamhet
- ☐ Annat: _______________

Finns det något exempel inom företaget på en sidoström som man skulle vilja styra om från dagens hantering, men som hindras av någon begränsning?

____

Kommentar kring möjligheter och begränsningar (frivilligt)

____

Sida 4: LCA-fallstudie

Syfte LCA-fallstudie

Som ett sista steg i examensarbetet kommer en fallstudie med en förenklad livscykelanalys (LCA) att genomföras för en sidoström som har stor potential till alternativa användningsområden. Fokus för fallstudien är miljöpåverkan och resurseffektivitet. Företaget kommer att få bidra med information om sidoströmmen och senare ta del av resultaten.

Om ditt företag har intresse av att delta i en LCA-fallstudie kommer möjligheterna att diskuteras vidare vid uppföljningssamtalet.

Vore det av intresse för företaget att delta i en LCA-fallstudie?

- ☐ Ja
- ☐ Nej

Vill du tillägga någonting?

____

Appendix B: Data inventory for LCA case study

Table B1: Data inventory of scenario A: Cogeneration. Abbreviations used: ssp=side stream potato, fgc=flue gas condenser, ds=dry substance, b=boiler.

	Denotation	Equation	Value	Unit
Dry substance, ssp[1]	x_{ds}	$1 - \frac{m_{H_2O}}{m_{ssp}}$	25%	
Energy content, ssp[2]	E_{ssp}		2500	MJ/ton ssp
Efficiency, boiler[3]	η_b	$\frac{E_{b,out}}{E_{ssp}}$	65%	
Efficiency, fgc[3]	η_{fgc}	$\frac{E_{fgc,out}}{E_{ssp}}$	30%	
Total efficiency	η_{tot}	$\eta_b + \eta_{fgc}$	95%	
Energy out, boiler	$E_{b,out}$	$\eta_b * E_{ssp}$	1630	MJ/ton ssp
- Electricity[4]	$E_{b,el.}$	$\frac{1}{3} * E_{b,out}$	542	MJ/ton ssp
- Heat[4]	$E_{b,heat}$	$\frac{2}{3} * E_{b,out}$	1080	MJ/ton ssp
Energy out, fgc[5]	$E_{fgc,out}$	$\eta_{fgc} * E_{ssp}$	750	MJ/ton ssp
Total energy out	E_{out}	$E_{b,out} + E_{fgc,out}$	2380	MJ/ton ssp

1. (Carlsson & Uldal, 2009)
2. Assumption based on Lehtikangas (1999) and Spörndly et al. (2019)
3. Assumption based on Olegård (2015)
4. (Energiföretagen, 2019)
5. Observe that all the energy out from the flue gas condenser is heat for the district heating system

Table B2: Data inventory of scenario B: Anaerobic digestion. Abbreviations used: ssp=side stream potato, ds=dry substance, vs=volatile solids, al=after leakage, Nm³=normal cubic meter.

	Denotation	Equation	Value	Unit
Dry substance, ssp[1]	x_{ds}	$1 - \frac{m_{H_2O}}{m_{ssp}}$	25%	
Volatile solids[1]	$x_{vs/ds}$	$\frac{m_{vs}}{m_{ds}}$	95%	
	m_{vs}	$x_{vs/ds} * x_{ds} * m_{ssp}$	0.238	ton vs/ton ssp
Methane yield[1]	Y_{CH_4}	$\frac{V_{CH_4}}{m_{VS}}$	411	Nm³ CH_4/ton vs
Biogas yield[1]	Y_{biogas}	$\frac{V_{biogas}}{m_{ssp}}$	186	Nm³ biogas/ton ssp
Methane content in biogas from ssp[1]	x_{CH_4}	$\frac{V_{CH_4}}{V_{biogas}}$	53%	
Methane leakage[2]	x_{leak}	$\frac{V_{leak}}{V_{biogas}}$	2%	
Volume biogas after leakage	$V_{biogas,al}$	$V_{biogas} - V_{biogas} * x_{leak}$	182	Nm³/ton ssp
Volume upgraded biogas (97% CH_4)	$V_{97\%\ CH_4}$	$\frac{Y_{CH_4} * m_{vs}}{x_{CH_4}}$	101	Nm³/ton ssp
Energy content methane gas (100% CH_4)[3]	E_{CH_4}		9.97	kWh/Nm³
Energy content upgraded biogas	$E_{97\%\ CH_4}$	$E_{CH_4} * 0{,}97$	3504	MJ/ton ssp
Amount of N in digestate[1]	x_N		1,5%	
	m_N	$x_N * m_{ds}$	3.75	kg N/ton ssp

1. (Carlsson & Uldal, 2009)
2. (Gode, et al., 2011)
3. (Energigas Sverige, 2019)

Table B3: Energy demand for the biogas plant in scenario B.

Process step	**Energy demand (MJ/ton side stream potatoes)**
Pre-treatment[1]	30
Anaerobic digestion[1]	176
Upgrading of biogas[2]	134
Compression of biogas[2]	77.3
De-watering of digestate[1]	10
Total:	**427**

1. (Lindkvist, et al., 2019)
2. (Berglund & Börjesson, 2006)

Appendix C: Emission data for LCA case study

Table C1: Emission data for scenario A: Cogeneration from side stream potatoes (abbreviated as ssp).

Scenario A: Cogeneration from side stream potatoes	**Transport[1] (g/ton ssp)**	**Cogeneration[2] (g/ton ssp)**	
CO_2	2440	5.94	
CO	-	109	
CH_4	63.2	4.04	
N_2O	25	1.52	**Total:**
CO_2-equivalents	**108000**	**740**	**11.6 kg/ton ssp**

1. Assuming a two-way trip of in total 20 km, and that each shipment of side stream potatoes weighs 10 ton. Emissions data calculated using the tool NTMcalc.
2. Due to missing emissions data for cogeneration from potatoes, data for cogeneration from woodchips with a moisture content of 40% from Gode, et al. (2011) were used.
3. (Gode, et al., 2011)

Table C2: Emission data for cogeneration from wooden pellets, based on data from Gode, et al. (2011).

Cogeneration of wooden pellets	**Prod. & distr.[1] (g/ton ssp)**	**Cogeneration[1] (g/ton ssp)**	
CO_2	808	-	
CO	-	-	
CH_4	19	0.0713	
N_2O	2.85	1.43	**Total:**
CO_2-equivalents	**936**	**380**	**9.74 kg/ton ssp**

Table C3: Emission data for Scenario B: Anaerobic digestion.

Scenario B: Anaerobic digestion	**Transport[1] (g/ton ssp)**	**Anaerobic digestion[2] (g/ton ssp)**	**Methane leakage[3] (g/ton ssp)**	**Dewatering digestate[2] (g/ton ssp)**	**Usage in personal car[4] (g/ton ssp)**	
CO_2	505	-	-	-	-	
CO	-	-	-	-	424	
CH_4	4.68	-	2.68	-	18.1	
N_2O	0.196	-	-	-	-	**Total:**
CO_2-equivalents	**5048**	**1950**	**7500**	**468**	**44.2**	**100 kg/ton ssp**

1. Assuming a two-way trip of in total 40 km, and that each shipment of side stream potatoes weighs 10 ton. Emissions data calculated using the tool NTMcalc.
2. Based on the energy demand, and the GWP of Swedish electricity mix from Energi- och klimatrådgivningen i Stockholmsregionen (2018).
3. Assuming all the leakage (2%) is methane gas.
4. (Gode, et al., 2011)

Table C4: Emission data for diesel production, distribution and usage in personal car, based on Gode, et al. (2011).

Diesel	**Prod. & distr.[1] (kg/ton ssp)**	**Usage in personal car[1] (kg/ton ssp)**	
CO_2	22.1	244	
CO	-	-	
CH_4	0.115	0.00189	
N_2O	0.00364	0.007	**Total:**
CO_2-equivalents	**26.3**	**246**	**272 kg/ton ssp**

Table C5: Emission data for production of chemical fertilizer (100% nitrogen), based on Börjesson & Berglund (2003). Note that the amount of chemical fertilizer per ton of side stream potato (abbreviated ssp) were 0.00375 ton.

Chemical fertilizer, 100% Nitrogen	**Production (kg/ton ssp)**
CO_2	12.2
CO	0.0027
CH_4	0.326
N_2O	-
CO_2-equivalents	**21.3**

Appendix D: Populärvetenskaplig sammanfattning

Sidoströmmar från livsmedelskedjan i Västra Götaland

- En kartläggning av statistik, intervjuer med livsmedelsproducenter och förenklad LCA för svinnpotatis

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På vägen från jord till bord försvinner stora mängder mat av olika anledningar, till exempel produktionsfel, dålig kvalitet eller att den inte blir såld innan den är för gammal. Den når därmed aldrig fram för att hamna på tallriken och ätas upp. Det betyder att all den energi som krävts för att producera och transportera maten kan anses ha gått förlorad, och den miljöpåverkan som det inneburit var helt onödig.

För att minska den här onödiga miljöpåverkan pratar man om resurseffektivitet, vilket betyder att man helt enkelt försöker se till så att alla resurser som krävs för att producera maten, så som energi och råvaror, utnyttjas på bästa sätt istället för att slösas bort genom att det blir en massa svinn.

I den här uppsatsen, som skrevs i samarbete med RISE Research Institutes of Sweden, ligger fokus på resurseffektivitet i livsmedelskedjan i Västra Götaland. Benämningen 'sidoströmmar' användes istället för matsvinn för att inkludera all den mat som var tänkt att hamna på tallriken men som av någon anledning inte gjorde det. Det är viktigt att studera hur, var och varför sidoströmmar uppstår, och även vad som händer med dem, för att exempelvis beslutsfattare ska kunna basera sina beslut på hur verkligheten ser ut och för att veta hur man ska kunna stötta företag i att hantera sidoströmmar på ett hållbart sätt.

Det allra bästa är om man kan hindra sidoströmmarna från att alls uppstå, eller se till att de ändå på något sätt blir till mat för människor. Om det inte är möjligt kan man som nästa steg överväga att utnyttja näringen i maten som djurfoder, eller i ytterligare nästa steg att utnyttja energin i maten för att producera biogas eller el och värme till våra hem.

Den första delen av uppsatsen består av en kartläggning av sidoströmmarna från hela livsmedelskedjan i Västra Götaland, utifrån den statistik som finns. Kartläggningen skulle visa hur mycket man redan vet om vilka mängder mat det rör sig om och vad som händer med den. Det visade sig finnas en hel del officiell statistik, framförallt som täckte sidoströmmar från hushållen där det främst rör sig om matavfall till biogas. Det saknas mycket kunskap om sidoströmmarna från jordbruket och livsmedelsindustrin, framförallt kring det som inte hanteras som avfall.

I den andra delen av uppsatsen genomfördes intervjuer med livsmedelsproducenter för att ta reda på hur de jobbar med sina sidoströmmar. Intervjuerna genomfördes genom att en webbenkät skickades ut till representanter för företag i Västra Götaland och de som ville kunde sedan även delta i ett uppföljningssamtal via telefon. Totalt svarade 11 företag på enkäten, och 5 deltog i uppföljningssamtal. Företagen uttryckte att det är ekonomi och utrustning som till stor del styr hur de hanterar sina sidoströmmar idag, och även att de upplever lagstiftningen som krånglig när det till exempel gäller att skicka sidoströmmar till djurfoder. Det är därför enklare för dem att hantera sidoströmmarna som avfall och skicka dem för produktion av till exempel biogas eller el och värme.

I tredje och sista delen gjordes en jämförelse mellan klimatpåverkan från att antingen förbränna eller göra biogas av potatisar som kasserats hos en chipsproducent i Västra Götaland. Förbränningen ger el och fjärrvärme till bostäder, och det är vad som görs av potatisarna i dagsläget. Biogasen kan användas som fordonsbränsle och rötresten som blir över vid produktion av biogas kan användas som näring i odlingar. Metoden som användes för att beräkna klimatavtrycken var en förenklad livscykelanalys, där man räknade ut hur mycket växthusgasutsläpp de två alternativa hanteringarna motsvarade.

Genom att anta att förbränningen av potatis ersatte förbränning av träpellets, att biogasen ersatte diesel och att rötresten ersatte konstgödsel, gick det att komma fram till att det var ett bättre alternativ att göra biogas och rötrest av potatisarna än att göra el och värme av dem. Potatisarna kan transporteras till en biogasanläggning hela 80 mil bort från chipsproducentens fabrik innan det blir mer klimatsmart att förbränna dem.

Generella slutsatser för hela uppsatsen är att det finns ingen fullständig bild av alla sidoströmmar från livsmedelskedjan i Västra Götaland, utan det är någonting för framtida forskning att ta reda på. Det verkar dessutom finnas ett behov av att bli bättre på att informera om och göra lagstiftningen tydligare, för att underlätta för livsmedelsföretagare att bli mer hållbara. Det finns även en poäng för livsmedelsföretag att göra livscykelanalyser för sidoströmmar för att se hur stor klimatvinst en förändring kan innebära utifrån just deras förutsättningar.