Food waste as a resource for bio-based chemicals and materials in Sweden

Johan Torén, Katarina Lorentzon, Olivia Cintas

RISE Report 2019:108
Food waste as a resource for bio-based chemicals and materials in Sweden

Johan Torén, Katarina Lorentzon, Olivia Cintas
Introduction

Waste, also food waste, abound. From an environmental point of view food waste should first and foremost be avoided. However, the waste that inevitably is produced along the food production chain should be utilized to the best of our ability. One option is to produce biobased chemicals and materials from the waste through biological processes. This study looks into what food waste resources are available for such production, industrial fermentation, in Sweden, from waste emanating in primary production all the way through to final consumption. In addition, drivers for waste generation, influencing institution and waste market characteristics are assessed.

The authors gratefully acknowledge the Swedish Research Council Formas for financial support of this project (Project no. 211-2013-70).

Key words: food waste, biological resources, waste valorisation, biobased material, biobased chemicals

RISE Research Institutes of Sweden AB
RISE Report 2019:108
ISBN: 978-91-89049-60-4
Göteborg
## Content

**Summary** .................................................................................................................. 3

1 **Food waste as a resource** ....................................................................................... 6  
   1.1 Feedstock requirements for valorization ............................................................... 7  
   1.2 Food waste definitions ............................................................................................ 7  
   1.3 Drivers of food waste generation ........................................................................... 8

2 **Amounts and characteristics of food waste in Sweden** ........................................ 9  
   2.1 Primary production ............................................................................................... 10  
      2.1.1 Animal production ......................................................................................... 10  
      2.1.2 Fisheries and aquaculture ............................................................................. 11  
      2.1.3 Crop production and horticulture .................................................................. 12  
      2.1.4 Drivers for food waste generation in primary production and primary processing .................................................................................................................. 19

   2.2 Food industry ......................................................................................................... 20  
      2.2.1 Dairies ........................................................................................................... 20  
      2.2.2 Slaughter houses ........................................................................................... 21  
      2.2.3 Grain processing and bakeries ....................................................................... 23  
      2.2.4 Sugar processing ............................................................................................ 24  
      2.2.5 Potato processing .......................................................................................... 24  
      2.2.6 Breweries ....................................................................................................... 24  
      2.2.7 Distilleries ...................................................................................................... 24  
      2.2.8 Drivers for food waste generation in the food industry .................................. 25

   2.3 Distribution and retail ........................................................................................... 25  
      2.3.1 Drivers for food waste generation in distribution and retail ......................... 26

   2.4 Consumer food waste (restaurants, catering and households) ......................... 26  
      2.4.1 Drivers for consumer food waste ..................................................................... 28

3 **Reducing food waste** ............................................................................................... 28  
   3.1 Institutions influencing the amounts of food waste ............................................. 29

4 **Amounts and characteristics of food waste relevant for biobased chemical production** .................................................................................................................................. 31

5 **Waste treatment market characteristics** ................................................................ 32  
   5.1 Waste hierarchy .................................................................................................... 33  
   5.2 Emergence of the current waste management regime ........................................ 34  
      5.2.1 Platform chemicals ....................................................................................... 37

6 **Conclusions** ............................................................................................................ 38

7 **References** .............................................................................................................. 41
Summary

Waste is to an increasing extent no longer only a problem to be dealt with but a valuable resource to be circulated back into society in the forms of new products or energy. Waste of biological origin emanating in the food sector has a number of interesting characteristics in that they are suitable for biological processing into building blocks for biobased chemicals. This study is an attempt to answer the following question:

*Is food waste physically available and practically applicable for use as feedstock for the production of bio-chemicals through industrial fermentation in Sweden?*

We have assessed waste in the following categories: primary production, food industry, retail and distribution and consumer food waste, including restaurants, catering and households. A study by the Swedish EPA quantified the amount of food waste from different sectors of the food chain, this is summarized in the figure below.

![Figure 1: Food waste in Sweden 2012 (Naturvårdsverket, 2013)](image)

The figure includes a question mark for primary production. In the current study, we have estimated the theoretical amount of waste from crop production (chaff, tops, leaves, post-harvest losses) to about 9 000 000 tons. Note that there are no estimates of avoidable amounts for food industry waste.

Today, there is no clear-cut delimitation between food waste and food by-products – the classification is to a large extent a matter of supply, demand, quality and price. Despite a general awareness and a range of policy ambitions, the prognosis is that the amount of food waste will continue to increase due to increased consumption. Having said this, the question about required characteristics of the food waste for the valorization targeted in this project has been approached and answered as follows:
• Animal by-products are largely restricted for valorization either by legislation, which most often requires incineration, or by competition from biogas production, where the rather wet and often biologically unstable, microbiologically active material is fit for purpose.

• Waste from harvested crop production rich in fibers, sugar and/or starch is often valued as animal feed, but also for anaerobic digestion. However, material with low dry matter content and/or high content of cellulose is less valuable from both perspectives, since these uses often are associated with important costs for transport or pre-treatment per output.

• Waste from un-harvested crop production is left in the field mainly for commercial reasons (potential income less than costs associated with harvest) or for maintaining soil carbon (applicable to straw, though effects are contested), and represent potentially interesting material.

• Industrial food waste is relatively homogenous and uncontaminated, interesting for both biogas production and (for vegetable and dairy fractions) animal feed, but would, more profitable than these applications, be potentially interesting for valorization, especially when it comes to food waste in the more “inevitable” part of the food waste spectrum, where the potential for further reduction is limited.

• Food waste from retail and consumers, especially households, represents considerable, but geographically scattered, amounts. Furthermore, source separated food waste from these parts of the food chain is generally inhomogeneous and contaminated by other waste fractions. To make use of these materials in more sophisticated and sensitive processes important efforts would need to be mobilized, both to reduce contamination and for pre-treatment. Moreover, policy making is targeting household consumer waste reduction, since the incentives for reduction, considering today’s food prices share of disposable income, is less pronounced in this part of the chain than within other parts. In addition, the municipal responsibility for household waste and the current surplus capacities in incineration and biogas facilities in Sweden suggest that valorization of consumer food waste is less interesting than food waste from other parts of the food chain.

The statements listed above are supported by (Sanchez-Vazquez, et al., 2013), who conclude that if sufficiently uncontaminated the waste from agriculture, postharvest, processing and distribution, can be used in secondary processes such as polymer production, while consumer waste generally can be assumed too contaminated for secondary processes, except gasification.

A very simplified version of the conclusions on availability can be summarized in two bullet points:

• The nearer primary production, the more homogenous, well defined waste streams and the higher the competition with other purposes – positive price and free market.

• The nearer consumers, the more inhomogeneous, variable, contaminated, impure and degraded waste streams and the lesser the competition with other purposes - negative price and municipal monopoly.
While we hereby have made a delimitation of potentially interesting waste streams, the question about actually interesting waste streams, that also can be found in sufficient amounts, cannot be answered without prior pinpointing of a specific production process.

The economic availability of feedstock is governed by a multitude of factors, many of them political in nature. Policies and visions on national and regional levels support increasing source separation of food waste for extended biogas production and there are quite important efforts in research and development to make biogas production and upgrading more efficient and competitive. Furthermore, there are demand side policies for biofuels which are lacking as of yet in the field of biochemicals. Given these conditions, it is not likely that a development where food waste streams are used as feedstock for biochemicals will come about without incentives, support and policy changes. Even if this utilization leads to steps in a positive direction in the waste hierarchy.
1 Food waste as a resource

Food waste has gained increased interest as feedstock for various kinds of fuels, chemicals and materials see e.g. (Sanchez-Vazquez, et al., 2013) (Kosseva & Webb, 2013) (Galanakis, 2015). In this report we will look closer into both the amounts and characteristics of food waste in Sweden as well as contemporary and expected waste management strategies for this resource. The analysis aims to examine if and, in that case, what food waste is physically and practically applicable for use as feedstock for bio-based chemicals, corresponding to the following research question:

Is food waste physically available and practically applicable for use as feedstock for the production of bio-chemicals through industrial fermentation in Sweden?

This question can be illustrated by Figure 2, where the cross-section of three sets of materials represents the portion of food waste that is both available, also in a longer time perspective, and potentially suitable for industrial fermentation processes.

*see definition in section 1.2 below

**Figure 2 Cross-section of three set of materials representing streams of interest for this study**

Food waste from products intended for human consumption are most probably also good substrate for bacteria, which in bioreactors can produce the building blocks for e.g. plastics, paints, and fine chemicals. Ultimately, this could lead to a new chemicals industry in Sweden with food waste as raw material. Many of these new products can be assumed to benefit from integrated production in biorefineries, which can also improve energy efficiency by internal energy integration.

In order to understand both physical and practical prospects of using food waste streams for the production of chemicals and materials, this report aims to answer the sub-questions:

- What kind of food waste exists today?
- Will there be enough food waste of the right quality to allow for a future industrial production (amounts and characteristics)?
Is it likely that this feedstock would be applicable for use as feedstock in an emerging industry for bio-based chemicals?

The report starts by compiling a “wish list” of characteristics of waste streams to be used as feedstock for valorization and by defining food waste in the context of this study. Then, it continues by a brief but broad inventory of food waste streams in Sweden, which finishes in a concluding short-list of potentially interesting waste streams that to a greater or lesser extent answer the requirements in the “wish list”. Thereafter, an overview of current and future management practices is made, followed by overall conclusions on whether Swedish food waste is physically and practically applicable for use as feedstock for the production of bio-chemicals through industrial fermentation.

1.1 Feedstock requirements for valorization

One prerequisite for industrial and large scale valorization of food waste through microbial fermentation by the use of e-coli is feedstock corresponding to certain characteristics:

- High dry matter content – to enable long-term storage in ambient conditions
- High carbon and nitrogen content – to minimise cost and environmental impact caused by transporting water and other unnecessary, or even harmful, substances
- High content of carbon in sugars – to minimise pretreatment
- Few but large sources – to minimise cost and environmental impact from collection
- Homogenous, well defined streams without contaminants – to provide stable and predictable processing conditions for fermentation with high yield
- Commercially and legally available streams – to enable other outcomes than waste management or feeding animals to a reasonable cost

These requirements are met by very few waste streams – trade-offs will of course be called for when finally suggesting a short-list of potentially interesting waste streams.

1.2 Food waste definitions

Currently, there are many different definitions of “food waste” globally. To be able to compare and monitor trends in food waste estimates, the European project FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies, FP7, Grant agreement 311972) was attributed the task to develop a definition that, over time, will enable harmonized quantification of food waste. According to the definition, that was published in July 2014, food waste is “any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including - composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)”. Hence, food waste is defined by the final destination of all food, and inedible parts of food, removed from the food supply chain; any food, and inedible parts of food, sent to animal feed, bio-material processing or other industrial uses are termed ‘valorisation and conversion’ and are
distinct from ‘food waste’. The definition covers both food and drink waste, thus both solid and liquid disposal routes. Where possible, the edible and inedible (see below) fraction should be separately analysed or estimated. The definition is based on e.g a criteria document and an extensive literature together with the knowledge and experience of the project consortium (FUSIONS, 2014a).

In Sweden, a cross-sectorial group for coordinated action towards less food waste, SaMMa, proposes a somewhat different definition: Food waste is all biologically degradable waste that arises in handling of food and that could be used as food, including liquid waste. In addition, bones, peels etc are also included; although these categories are not food, they are intimately connected to it (Jansen & van Gulik, 2014). This definition was endorsed by the federation Swedish Waste Management in their comments to the Commission’s proposal amending several directives on waste (European Commission, 2014). It is also the definition that was used by the consortium of research institutions and Sweden statistics in their latest survey on food waste, carried out on behalf of the Swedish EPA.

In Global Food Losses and Food Waste - extent, causes and prevention (FAO, 2011), the authors use the term ‘food losses or waste’, referring to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption.

Furthermore, food waste can be classified in different fractions based on potential. The Swedish EPA uses the terms avoidable and inevitable food waste (Naturvårdsverket, 2013). The classification is quite self-explanatory, inevitable food waste being inedible parts (peals, bones etc) and other food stuff, while avoidable food waste on the other hand is edible food turned into waste through mismanagement or technology failure in any part of the food chain (surplus or malfunctioning production, inappropriate storage or transportation, lacking or undeveloped purchasing routines, exceeded expiration dates etc). The European research project Fusions, on the other hand, employs the terms food, which is waste that has or had the potential to be eaten, and inedible parts of food (FUSIONS, 2014a). Both these classifications are imperfect since the distinction between the two fractions to a large extent is a matter of consumer preferences; peels, offal, blood etc could be edible/avoidable for someone and inedible/inevitable for another.

In this project, food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered, disposed, valorised or converted, i.e. we do not take the final destination into account, since the purpose of the project is to assess the potential for valorisation of different kinds of food and inedible parts of food removed from the food chain.

1.3 Drivers of food waste generation

Apart from assessing quantities of food losses along the entire food chain, (FAO, 2011) identifies causes of food losses and possible ways of preventing them. It is found that the causes of food losses and waste in medium/high-income countries are mainly related to consumer behaviour and lack of coordination between different actors in the supply chain. In contrast, the causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. In broad terms, FAO states that food losses will be influenced by crop production choices and patterns, internal infrastructure and capacity, marketing chains and channels for distribution as well as consumer purchasing and food use practices.

© RISE Research Institutes of Sweden
The project FUSIONS mentioned above is a European project about working towards a more resource efficient Europe by significantly reducing food waste. The project has identified drivers for food waste generation and distinguishes five groups of food waste related to the following items:

A. the inherent characteristics of food products and the ways through which they have to be produced and consumed;
B. social factors and dynamics in population habits and lifestyles that are non-readily changeable;
C. individual behaviours and general expectations of consumers towards food that are non-readily changeable;
D. other priorities targeted by private and public stakeholders;
E. non-use or sub-optimal use of available technologies, organisational inefficiencies of supply chain operators, inefficient legislation, and bad behaviour of consumers for different reasons

It is also found that the possibility of intervening in the food system and reducing food waste increase from the top to the bottom of this list, and that although food wastage may be difficult to reduce to zero, there are a lot that can be done provided the solutions are adapted for each single activity and process of the supply chain.

In the following chapter, drivers within particular parts of the food chain are described in more detail.

2 Amounts and characteristics of food waste in Sweden

As previously mentioned, this paper aims to explore the prospects of developing *biochemicals through industrial fermentation* from food waste in Sweden. Hence, amounts and characteristics of food waste refer to the situation on Sweden.

In Figure 3 the amounts of food waste from food industry, retail and distribution and consumers (restaurants, catering and households) are shown based on data from (Naturvårdsverket, 2013). The total amount, 1 211 000 tons, corresponds to about 127 kg per person and year.

The amounts of food waste from primary production (agriculture and fishery) have not been assessed in (Naturvårdsverket, 2013), but they are addressed separately below.
2.1 Primary production

Waste in primary production and primary processing include losses in agricultural production, including animal by-products\(^1\), and fisheries. A classification of animal by-products is included in section Food industry below.

There is practically no coherent data of satisfying quality on food waste from Swedish primary production. To address the need for better data on waste and production losses from primary production, (Franke, et al., 2013) carried out a literature survey and assessed the quantities of waste and drivers for it. This assessment, together with other sources, are used below.

2.1.1 Animal production

Jordbruksverket (Jordbruksverket, 2014c) describes and quantifies losses in the production chain for Swedish beef from farm to slaughter, including stillborn calves, calf mortality, deaths among older animals, rejects in inspections before and after slaughter, and food quality meat by-products at slaughterhouses. It was found that losses represented 9% of slaughtered weight in 2012. Male calves from dairy breed with low rate of growth are sometimes put down at birth, since they are not competitive in beef production (Franke, et al., 2013). However, most of the weight lost (85%) is calves older than 6 months that are put down or die of natural causes. Dairy cows that die or are being

---

\(^1\) However, in this report, manure is not included.
put down also represent a significant proportion of total mortality in beef livestock. Rejection at slaughter is relatively low (Jordbruksverket, 2014c).

In kilos, the main losses in Swedish pig production are sows that die or are put down (15 % of standing stock) and slaughter pigs ready for slaughter (1.8 % of slaughter pigs). However, in number of animals, piglets represent the highest mortality (20.4 %) (Göransson, et al., 2014).

Very few horses go to slaughter. The major part of the horses are put down to be buried, cremated or for energy production. Some of these would not be fit for slaughter, since they have been treated with medicines that are not allowed in production of meat for human consumption (Franke, et al., 2013). Data on waste from sheep, lamb and goat production in (Franke, et al., 2013) is very limited.

About 5 million laying hens are produced every year in Sweden, which means that equal amounts of laying hens are put down. About 10 % of the chicken dies before reaching end of laying period after 75–80 weeks – these are sent for destruction. Laying hens can be used for food, but the slaughter weight is relatively low and only a few slaughter houses accept laying hens. Most of the chicken meat that is actually produced from laying hens (about 3 million hens) is exported to Germany. The rest is used for pet food, mink fodder or destroyed (Carlsson, et al., 2009). Male chickens of laying hens breed are most often destroyed as day old (Franke, et al., 2013). About 3.5 % of the total Swedish egg production is destroyed due to eggshell deficiencies (cracks or spots) or diseases (Franke, et al., 2013).

Generally, carcasses from primary production are collected by Svensk Lantbrukstjänst and transported to an incineration plant approved by Jordbruksverket. In some areas and with some exceptions regarding contamination risks, carcasses may be buried following local provisions. Farms with pig or poultry production, possessing a boiler, can apply for approval from Jordbruksverket for incineration of carcasses from the farm.

About 3 % of total milking, in ton ECM², is quarantine milk (milk from cow during treatment with antibiotics), milk that should not be used for consumption, neither for human consumption nor animal feed (Bertilsson, et al., 2014). This milk can be spread on crop land. In addition, milk with high somatic cell count has to be destroyed, but the quantity has not been found.

Since the use of animal byproducts from agriculture is surrounded by strict health and safety regulations, laid down in the European regulations on animal by-products (Regulations EC 1069/2009 and EU 142/2009), these flows are not further quantified.

2.1.2 Fisheries and aquaculture

Discard from fisheries, which from 2015 until 2019 gradually will be banned through the “landing obligation” (European Commission, 2015), has been sensitive data, if at all available. This regulation stipulates that catch that has to be landed, but cannot be sold for human consumption, is covered by the European regulations on animal by-products (see Emergence of the current waste management regime below), either as category 3 (catch showing no signs of disease) or category 1 (catch showing signs of disease). Heads

² ECM Energy-corrected milk (ECM) determines the amount of energy in the milk based upon milk, fat and protein and adjusted to 3.5 % fat and 3.2 % protein.
and guts, mainly from cod and saithe, removed onboard represent about 1 500 tons of by-products (SP; Chalmers; Rena Hav AB, 2015).

Aquaculture is similar to animal husbandry in many ways. In Norwegian aquaculture, 17 % of the production ends up as waste, out of which 73 % represent dead fish in the cages, 4 % was discard or reject in slaughterhouse and less than one % was escaping, while 22 % of the waste is unspecified (Franke, et al., 2013). If applied to Swedish aquaculture production of fish for food in 2014, which was 11 152 tons (entire fresh weight, (SCB, 2015), this would correspond to about 1 900 tons of fish. The dominating species (85%) was rainbow trout. Waste from aquaculture is also covered by the European regulations on animal by-products (see Emergence of the current waste management regime below).

The ongoing research project MareValue (Vinnova, 2015) aims to improve the use of marine resources (increased yield and value) in the Swedish seafood sector. The project, which runs from 2014 to 2017, will identify and isolate high-value components from unwanted catches of fisheries and from processing (by-products). The project has mapped current flows and utilization of marine resources, both in fishery and in fish processing. By-products from processing 2011-2014 represented between 30 000 and 50 000 tons yearly, depending on method for the assessment. The by-products were mainly used directly for mink feed and also for production of fish meal used for feed in aquaculture, mink farming and in pet food. Marine by-products, rich in proteins and sometimes also in fat, are also commercially used for production of e.g. enzymes, nutritional additives and proteins (SP; Chalmers; Rena Hav AB, 2015).

### 2.1.3 Crop production and horticulture

Waste in Swedish crop production is related to losses and waste at harvest and threshing, quality losses at storing, and discard caused by aesthetic aspects or other deficiencies. Some potatoes and field vegetables are deliberately left in the field due to size, damage or pest attacks (Franke, et al., 2013). It must be emphasized that the quantities below represent theoretically available amounts, and that practical, economical and other sustainability aspects have not been considered.

Data on straw and chaff from grain and oilseed production are found in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Straw and chaff per kg crop and moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kg straw</strong></td>
</tr>
<tr>
<td>Spring wheat (14 %)</td>
</tr>
<tr>
<td>Winter wheat (14 %)</td>
</tr>
<tr>
<td>Rye (14 %)</td>
</tr>
<tr>
<td>Barley (14 %)</td>
</tr>
<tr>
<td>Oat (14 %)</td>
</tr>
</tbody>
</table>
Together with data on harvest in 2014 (Jordbruksverkets statistikdatabas, 2015), the total amounts of straw and chaff are calculated (Table 2). Collected straw is used as litter for animal production and, to some extent, as fuel. Straw is also left in the field to maintain or increase the organic content in the soil (SOU, 2017). As a “rule of thumb”, about 50 % of the chaff is pelletized, and about 90 % of this is used as fuel for biogas production, while the remaining pelletized chaff is used for heat and power production, and for heat production at farms (Gundberg, 2015, personal communication). Unpelletized chaff is often left in the field, but new technology enables concurrent collection of straw and chaff, hence increasing the possibility to recover organic matter at harvest (Lundin & Rönnbäck, 2010).

Table 2 Straw and chaff from grain and oilseed production in Sweden 2014

<table>
<thead>
<tr>
<th></th>
<th>Total (ton)</th>
<th>harvest</th>
<th>Straw (ton)</th>
<th>Chaff (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter wheat</td>
<td>2 750 800</td>
<td></td>
<td>2 476 000</td>
<td>825 000</td>
</tr>
<tr>
<td>Spring wheat</td>
<td>335 600</td>
<td></td>
<td>336 000</td>
<td>101 000</td>
</tr>
<tr>
<td>Rye</td>
<td>173 600</td>
<td></td>
<td>243 000</td>
<td>52 000</td>
</tr>
<tr>
<td>Winter barley</td>
<td>85 800</td>
<td></td>
<td>43 000</td>
<td>8 600</td>
</tr>
<tr>
<td>Spring barley</td>
<td>1 488 400</td>
<td></td>
<td>744 000</td>
<td>149 000</td>
</tr>
<tr>
<td>Oat</td>
<td>665 900</td>
<td></td>
<td>466 000</td>
<td>67 000</td>
</tr>
<tr>
<td>Triticale</td>
<td>226 400</td>
<td></td>
<td>260 000</td>
<td>68 000</td>
</tr>
<tr>
<td>Mixed grain</td>
<td>48 900</td>
<td></td>
<td>29 000</td>
<td>4 900</td>
</tr>
<tr>
<td>Peas</td>
<td>46 500</td>
<td></td>
<td>46 000</td>
<td>0</td>
</tr>
<tr>
<td>Broad beans</td>
<td>61 100</td>
<td></td>
<td>122 000</td>
<td>0</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>336 400</td>
<td></td>
<td>908 000</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6 219 400</strong></td>
<td><strong>5 673 000</strong></td>
<td><strong>1 275 500</strong></td>
<td></td>
</tr>
</tbody>
</table>
In addition, there are post-harvest losses of crops, due to e.g. inappropriate storage or treatment (Table 3). Since these losses represent mainly “avoidable” waste that occurs in several stages after harvest, no quantification of these streams has been made.

Table 3 Post-harvest losses in Swedish crop production and horticulture

<table>
<thead>
<tr>
<th>Crop</th>
<th>Losses (%)</th>
<th>Moisture (%)</th>
<th>Reference</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain (wheat, rye, barley, oat)</td>
<td>2</td>
<td>14</td>
<td>Stenberg et al (2014) and SOU (2007)</td>
<td></td>
</tr>
<tr>
<td>Oil seeds</td>
<td>2</td>
<td>9</td>
<td>-“-”</td>
<td>Assumption: same as grain</td>
</tr>
<tr>
<td>Broad beans</td>
<td>2</td>
<td>15</td>
<td>-“-”</td>
<td>-“-”</td>
</tr>
<tr>
<td>Peas</td>
<td>2</td>
<td>15</td>
<td>-“-”</td>
<td>-“-”</td>
</tr>
<tr>
<td>Ley silage</td>
<td>20</td>
<td>45</td>
<td>Stenberg et al (2014) and Gunnarsson et al 2014</td>
<td>Before fodder table</td>
</tr>
<tr>
<td>Corn silage</td>
<td>23</td>
<td>45</td>
<td>-“-”</td>
<td>Before fodder table</td>
</tr>
</tbody>
</table>

Figure 4 shows the quantity of waste generated from the main grain crops (i.e., wheat, rye, barley, oat) and oilseed crops (i.e., rapeseed) geographically distributed. Residue generation is estimated by using average values for crop production from 2013-17 at NUTS3 level from (SCB, 2019a) and assuming the residue-to-product ratios (RPR) in Table 1. The data is spatially desegregated from NUTS 3 to 1000 m resolution following the method in (Cintas, et al., 2018). Figure 4 represents available amounts of waste, i.e., theoretical quantities, excluding the harvesting losses and fraction that needs to be left on the ground to avoid negative impact on soil organic carbon. Based on (Cintas, et al., 2018) and (Haase, et al., 2016) it was assumed that 80% and 40% of crop residues are left on the ground if the topsoil carbon content is below and above 2%, respectively. The soil carbon data is available in the CAPRI database at 1,000 m for Europe.

3 After harvest, e.g. in storing, sorting
Figure 4 shows that with a few exceptions, grain and oilseed production takes place in the southern part of the country (Götarland and Svealand up to Dalarna and Gävleborgs län), dominated by Skåne län (representing about 30% of the total grain production and 48% of the total oilseed production), followed by Västra Götalands län (approx 20% and 10%) and Östergötlands län (approx. 10%). Of total national volume, 96% is produced south of Stockholms län. The figures are based on data from (SCB, 2019a) and are also
in line with (Baky, et al., 2013). Location of crop production corresponds to location of waste availability. Only in a small area in Skåne, a higher fraction of residues needs to be left on the ground due to a low organic carbon content (lower than 2%).

There are two types of potato in statistics: potato for consumption, including potatoes that are processed to readymade food, french fries, potato powder etc, and potato for starch production. At harvest, 9,5 % of the potatoes for consumption are discarded due to decay and other damage or wrong size (Avfall Sverige , 2008). As mentioned above, potato is also occasionally left unharvested (Avfall Sverige , 2008) (Franke, et al., 2013). 0,4 % of the potatoes for starch production are discarded, and only because of decay (SCB 2007a in (Avfall Sverige , 2008)). Generally, the entire harvest of sugar beet is accepted at the sugar refinery, except for rare occasions of frost damages, which make the beets unfit for storing. At other rare occasions, the harvest does not pass inspection already at the farm. In these cases, the beets are returned to the field or used either for feeding game or for biogas production. The quantities, however, are very unpredictable and vary significantly between years (Landquist, 2015, personal communication).

Franke et al (2013) report on losses of carrots, beetroots, cabbage, onions and tomatoes, and (Franke, 2014) reports on losses of lettuce, the numbers can be found in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrots</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Beetroots</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Cabbage</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Onions</td>
<td>16-20</td>
<td>n.a.</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>10-15</td>
<td>n.a.</td>
</tr>
<tr>
<td>Lettuce</td>
<td>50</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Together with data on harvest in 2014 (Jordbruksverkets statistikdatabas, 2015), the total amounts of waste are calculated (Table 5).
Table 5 Waste in potato and sugar beet production, and in horticulture at sorting and storing 2014 (moisture in %)

<table>
<thead>
<tr>
<th></th>
<th>Total harvest (ton)</th>
<th>Waste (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes, consumption (approx 80 %)</td>
<td>551 600</td>
<td>52 400</td>
</tr>
<tr>
<td>Potatoes, starch production (approx 80 %)</td>
<td>270 500</td>
<td>1 100</td>
</tr>
<tr>
<td>Sugar beets (approx 76 %)</td>
<td>2 326 200</td>
<td>Data not available</td>
</tr>
<tr>
<td>Carrots (approx 90 %)</td>
<td>119 000</td>
<td>30 000</td>
</tr>
<tr>
<td>Beetroots (approx 85 %)</td>
<td>17 500</td>
<td>3 500</td>
</tr>
<tr>
<td>Cabbage (approx 95 %)</td>
<td>15 900</td>
<td>2 400</td>
</tr>
<tr>
<td>Onions (approx 90 %)</td>
<td>53 300</td>
<td>9 600</td>
</tr>
<tr>
<td>Tomatoes (approx 95 %)</td>
<td>14 600</td>
<td>1 800</td>
</tr>
<tr>
<td>Lettuce (approx 95 %)</td>
<td>29 800</td>
<td>14 900</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3 398 400</strong></td>
<td><strong>115 700</strong></td>
</tr>
</tbody>
</table>

In addition, Franke et al. (2013) report that 15 % of cultivated cabbage and dill, and 1-5 % of other field vegetables are left un-harvested.

Data on tops/foliage/leaves/shells from potatoes and sugar beets are found in Table 6.

Table 6 Tops/foliage/leaves/shells/haulm per kg crop and moisture content

<table>
<thead>
<tr>
<th>Per kg crop</th>
<th>Kg tops</th>
<th>Moisture (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>0.5</td>
<td>85</td>
<td>SOU (2007) and calculations based on this</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.68</td>
<td>86</td>
<td>- “-”</td>
</tr>
<tr>
<td>Carrot</td>
<td>0.3</td>
<td>85</td>
<td>Assumptions</td>
</tr>
<tr>
<td>Beetroot</td>
<td>0.3</td>
<td>85</td>
<td>- “-”</td>
</tr>
<tr>
<td>Onion</td>
<td>0.3</td>
<td>85</td>
<td>- “-”</td>
</tr>
<tr>
<td>Peas for consumption</td>
<td>5.0</td>
<td>80</td>
<td>Avfall Sverige (2008-) and Jordbruksverket statistikdatabas (2015)</td>
</tr>
</tbody>
</table>

Together with data on harvest in 2014 (Jordbruksverkets statistikdatabas, 2015), the amounts of tops/foliage/leaves/shells are calculated (Table 7). Usually, potato tops are defoliated chemically to stop growth and facilitate harvest (Avfall Sverige, 2008). Sugar beet tops are generally left in the field after harvest (Avfall Sverige, 2008). Tops can also
be used as fodder to ruminants. Pea haulm has been evaluated as biogas substrate with promising results, but since the pea harvest is carried out during only a couple of weeks and biogas digesters are sensitive to spikes in feed compositions, storing is needed. If tops are removed from the field, the loss of nutrients must be compensated for by e.g. commercial fertilizers or biodigestate (Almgren, 2011).

### Table 7 Tops/foliage/leaves/shells/haulm from production of potatoes, sugar beets and some horticultural produce in Sweden in 2014 (values for sugar beets respresent 2013 and for peas for consumption an average 2007-2010).

<table>
<thead>
<tr>
<th></th>
<th>Total (ton)</th>
<th>harvest (ton)</th>
<th>Tops (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato, human consumption</td>
<td>551 600</td>
<td>275 800</td>
<td></td>
</tr>
<tr>
<td>Potato, starch production</td>
<td>270 500</td>
<td>135 300</td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>2 326 200</td>
<td>1 581 800</td>
<td></td>
</tr>
<tr>
<td>Carrot</td>
<td>119 000</td>
<td>35 700</td>
<td></td>
</tr>
<tr>
<td>Beetroot</td>
<td>17 500</td>
<td>5 200</td>
<td></td>
</tr>
<tr>
<td>Onion</td>
<td>53 300</td>
<td>16 000</td>
<td></td>
</tr>
<tr>
<td>Peas for human consumption</td>
<td>40 300</td>
<td>201 375</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3 378 000</strong></td>
<td><strong>2 251 000</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5** shows the amounts of waste from potato and sugarbeet production geographically distributed in Sweden. Data is estimated by using to average values for crop production from 2013-17 at NUTS3 level from (SCB, 2019a) and RPR from Table 5. The data is spatially desegregated from NUTS 3 to 1000 m resolution following the method in (Cintas, et al., 2018).
Figure 5: Available waste generated from potato and sugarbeet production at 1000 m resolution. The data includes harvesting losses and fraction that needs to be left on the ground to avoid negative impact on soil organic carbon.

Potato cultivation for starch production is concentrated to three counties in the south part of the country (Skåne, Blekinge and Kalmar län), while potato production for human consumption is slightly more distributed over the country; 8% of the national production volume takes place north of Stockholm. Figure 5 shows that sugarbeet production is concentrated to Skåne län, representing 95% of total production. Horticulture is concentrated to Götaland, although the production of carrots takes place in other parts of the country as well (Baky, et al., 2013). The data in Figure 5 is consistent with (Baky, et al., 2013), which was based on data from (Jordbruksverkets statistikdatabas, 2015) on harvest 2011.

There is little data on losses of fruit and berries but data on apples and strawberries from (Franke, et al., 2013) indicates that 2 % of the Swedish production of apples (about 500 tons, based on Swedish production 2014) and 10-25 % of the strawberries (between 1700 and 5000 tons, based on Swedish production 2014) are lost at harvest. Furthermore, 2 % of the conventional and 5 % (about 500 tons in all) of the organic apples are lost at sorting (based on overall production of apples in Swedish 2014).

2.1.4 Drivers for food waste generation in primary production and primary processing

In order to ensure delivery of agreed quantities while anticipating unpredictable bad weather or pest attacks, farmers sometimes make production plans on the “safe side” and end up producing larger quantities than needed. Such farmer-buyer sales agreements may contribute to quantities of farm crops being wasted or downgraded, since some
surplus crops are sold as animal feed, but with less profit than sold for human consumption. Produce can also be wasted due to quality standards (weight, size, shape and appearance of crops), and large portions of crops never leave the farms. Trade with some fruit and vegetables is framed by mandatory European trading schemes, which stipulate that the products should fulfil sound market quality. For ten products, there are specific trading European norms which include provisions for classification of size, colour, shape and uniformity. In addition, there are also UN norms that are applicable if the product is to be classified first grade product. (Franke, et al., 2013) and (Jordbruksverket, 2014b) suggests that aesthetic aspects as they are perceived by consumer probably are more important in practice than the formal European or UN rules; as an example, there are no EU provisions on potatoes, yet retail overall has the same requirements on size and shape as a result of consumer demands.

2.2 Food industry

Food industry is another sector where food waste quantities are difficult to monitor. The estimation for 2012 is somewhere between 171 000 tons and 642 000 tons (Naturvårdsverket, 2013), as there is no clear-cut delimitation between food waste, by-products and other waste. Furthermore, the possibility to define “avoidable” and “inevitable” waste is very limited. The figures above are based on data in mandatory public environmental reports from 135 companies. These reports have also been used for assessing waste from smaller companies (Naturvårdsverket, 2013).

In Sweden, there are about 3 700 food producing companies, out of which about 40 % are single person businesses. Dairy, slaughterhouse, bakery, grain processing, sugar processing, brewing and juice production often consist of larger production sites, therefore also larger point sources for waste (Naturvårdsverket, 2013). There are also a number of fairly large sites for production of ready-made or semi-ready-made food, e.g. Findus, Orkla Foods Sverige (brands inter alia: Abba, Frödinge, Kalles, Bob, Ekströms) and Dafgårds.

2.2.1 Dairies

The dairy industry processes raw milk into products like consumer milk, butter, cheese etc. Typical waste streams from dairy production are found in Table 8. Waste from dairy processing is classified as animal by-products (ABP), most often as ABP 3 (except untreated milk, quarantine milk and milk with high somatic cell count), see section Emergence of the current waste management regime below. It is often used for animal feed (except fatty sludge) or as substrate for biogas production. Whey is also often further processed to whey powder, resulting in whey permeate as waste stream. The dry matter contents can vary significantly, and the values below represent data from (Avfall Sverige, 2008).

Table 8 Dairy waste streams (dry matter content in brackets), kg dry matter per kg delivered (incoming) milk

<table>
<thead>
<tr>
<th></th>
<th>kg dry matter/kg delivered milk</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fodder milk (2 %)</td>
<td>0,006</td>
<td>Avfall Sverige (2008)</td>
</tr>
<tr>
<td>Fatty sludge (0,07 %)</td>
<td>0,00328</td>
<td>-“-</td>
</tr>
</tbody>
</table>
The total amounts of delivered milk in Sweden 2014 was 2,900 ktons, out of which 23.5% was used for cheese production (LRF Mjölk, 2016). Together with data in Table 8, the total amounts of dry matter in waste streams is calculated (Table 9).

### Table 9 Dry matter in dairy waste streams 2014

<table>
<thead>
<tr>
<th></th>
<th>kg dry matter/kg delivered milk</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whey (5.5 %)</td>
<td>0.0495</td>
<td>-</td>
</tr>
</tbody>
</table>

Dairies are generally large-scale industries, though smaller dairies have emerged in recent years. The largest dairies are found in the southern part of Sweden. 80% of the total amount of milk that arrived at Swedish dairies is processed in or south of Stockholm (Svensk Mjölk, 2015).

### 2.2.2 Slaughter houses

Slaughter gives rise to animal by-products (ABP). As mentioned under section Emergence of the current waste management regime below, ABPs are split in three categories based on the risk they pose, where category 1 is high risk waste and category 3 is low risk waste, with category 2 presenting medium risks.

Data on animal by-products (% of live weight) are found in Table 10 (data from (Edström, et al., 2003) in (Edström, et al., 2006)).

### Table 10 Animal by-products (% of live weight = lw)

<table>
<thead>
<tr>
<th></th>
<th>Beef (adult, 545 kg lw)</th>
<th>Slaughter pig (113 kg lw)</th>
<th>Chicken (1.9 kg lw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABP 1</td>
<td>7.1</td>
<td>0.9</td>
<td>0</td>
</tr>
<tr>
<td>ABP 2</td>
<td>15.5 (digestive tract content)</td>
<td>6.1 (digestive tract content)</td>
<td>1.6 (carcasses discarded at inspection after slaughter)</td>
</tr>
<tr>
<td>ABP 3 blood</td>
<td>3.0</td>
<td>2.9</td>
<td>3.7</td>
</tr>
</tbody>
</table>

4 Not corrected for whey further processed to whey powder.
An important amount of category 3 materials from beef and pig production, e.g. offal and blood, is used for food production. However, two thirds of the lungs and one third of the kidneys and stomachs from beef slaughter are used for other purposes than human consumption, e.g. pet food. Corresponding figures for pig slaughter have not been found. Animal byproducts from chicken slaughter is often used as mink fodder.

Figure 6 shows animal by-products from slaughter of cattle, pig, and lambs at the municipal level. Data on the location of slaughterhouses, their capacity, and animal type is based on (Baky, et al., 2013). The data is geographically represented by using a shapefile with the municipality boundaries.

---

Table 11 Animal by-products from slaughter of beef, pig and lamb (ktons)

<table>
<thead>
<tr>
<th>Animal by-products category</th>
<th>1</th>
<th>2</th>
<th>3 blood</th>
<th>3 feather</th>
<th>3 other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef</td>
<td>9,3</td>
<td>20,4</td>
<td>3,9</td>
<td>0</td>
<td>25,5 (out of which 1,8 difficult to grind)</td>
</tr>
<tr>
<td>Pig</td>
<td>2,1</td>
<td>14,4</td>
<td>6,8</td>
<td>0</td>
<td>35,0</td>
</tr>
<tr>
<td>Lamb&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0,4</td>
<td>0,8</td>
<td>0,2</td>
<td>0</td>
<td>1,0 (out of which 0,1 difficult to grind)</td>
</tr>
<tr>
<td>Chicken</td>
<td>0</td>
<td>2,1</td>
<td>4,7</td>
<td>8,8</td>
<td>44,2</td>
</tr>
</tbody>
</table>

---

<sup>5</sup> Assumed same animal by-products for lamb as for beef (in percent of live weight)
Today, the main volumes are slaughtered at a few, large facilities in the southern part of Sweden. 90% of total slaughter is carried out in or south of Stockholm (Figure 6 and (Baky, et al., 2013)). Animal by-products are mainly concentrated in Skåne (24%), Västra Götalands (24%), Blekinge (16%), Östergötlands län (11%), and Kalmar (10%). Larger slaughterhouses have better possibilities to take care of food grade animal by-products than smaller ones. As an example, taking care of blood requires sophisticated equipment out of reach for smaller slaughterhouses (Jordbruksverket, 2014c).

2.2.2.1 Meat processing

Small amounts of ABP 3 occur in meat processing. However, data has not been searched for, since volumes are small and scattered.

2.2.3 Grain processing and bakeries

Making flour often include removing parts of the grain, e.g. bran and germ, during milling, i.e. unavoidable waste, while industrial bread production gives rise to production losses when products do not fulfil certain sensory or aesthetic qualities and when products cannot be sold, which mainly represent avoidable waste. Avfall Sverige has estimated the amount of bran and other grain processing waste to about 57 000 tons and the amount of dough and bread from bakeries (including unsold bread from retail) to about 24 000 tons (Avfall Sverige, 2008). Grain processing waste is often used by the mills in own boilers for heating purposes, while bread and dough are often used as fodder.
Mills are generally large scale facilities, situated in southern part of the country. Large-scale bakeries are found mainly in the southern part of the country (exceptions are e.g. some facilities producing hard bread in Leksand and Filipstad and flat bread in Älvsbyn and Bredbyn), producing bread for a national market. In addition, there are also smaller-scale bakeries, producing for a regional or local market.

2.2.4 Sugar processing

Producing sugar from sugar beets gives rise also to a large amount of fodder products with a fairly large market value. Today, there is only one plant producing sugar from sugar beets and one sugar refinery, both located in Skåne (Nordic Sugar, 2016). The fodder products (about 200 000 tons) are based on sugar beet molass, containing about 65% carbohydrate (mainly sugar), and beet fiber (Engdahl, et al., 2011).

2.2.5 Potato processing

Potato starch production results in two main by-products: potato pulp, most often used as fodder, and potato juice, used as fertilizer or for biogas production. Swedish potato starch production is located to two plants in the region around Kristianstad, where about 100 000 tons (wet weight) of potato juice and about 3 000 tons (wet weight) of potato pulp are produced. Potato juice contains nitrogen, phosphorous and potassium, and some of the juice is processed to fodder protein. Some of the potato pulp is processed to potato fibers for use in bakeries and meat processing. (Engdahl, et al., 2011).

2.2.6 Breweries

Brewers’ spent grain and yeast are by-products from breweries that are used as fodder or, in some cases, for biogas production. The amount has been estimated to about 800 000 tons (wet weight) (Avfall Sverige, 2008). However, this figure does not account for any of the large number of micro-breweries that have emerged in recent years; the production in these new micro-breweries is difficult to overview.

2.2.7 Distilleries

By-products from the Absolut Vodka distillery in Nöbbelöv, represent about 345 000 tons of distillers’ spent grain (Engdahl, et al., 2011), mainly used as fodder. Dry matter content is low (8%) (Carlsson & Uldal, 2009).

The ethanol production of Lantmännen in Norrköping results in about 550 000 tons of distillers’ spent grain at about 33% dry matter content. It is dried to a dry matter content of about 90% before it is sold as fodder (Karlsson, 2015, personal communication).

---

6 Although potato starch also can be used for non-food purposes, all waste streams are considered as food waste.
2.2.8 Drivers for food waste generation in the food industry

From a Swedish perspective, (Lindbom, et al., 2014) presents results on the amounts and causes of food waste and possible ways to prevent food waste in the supply chain, with special attention to the manufacturing industry, wholesale and retail segments. In (Lindbom, et al., 2014), food waste is split into two groups: 1) actor-internal causes, 2) actor-shared causes. In the first group, the causes of waste can be found in the same company as the waste occurs, e.g. malfunctioning equipment, unstable processes, product changeover losses and low capacity to adapt processes to variations in incoming raw material, while in the second group, the waste and the causes are found in different companies, e.g actual purchase order from retail differ from prognosis, hence creating both surplus of raw material and surplus stock of readymade product, which both risk perishing before sale.

Industrialized food processing lines often carry out trimming to ensure the end product is in the right shape and size. Food is also lost during processing because of spoilage down the production line, leading to final products not complying with narrow specifications in terms of shape, weight and size. In a standardized production line these products often end up being discarded ((Stuart, 2009) and Naturvårdsverket, 2008, in (FAO, 2011)).

2.3 Distribution and retail

In 2012, about 70 000 tons of food waste was generated in Swedish retail, out of which about 91 % was considered avoidable (see Food waste definitions above). Most of the waste disposed of in the waste collection system consisted of fruit and vegetables (40 %), followed by meat (29 %) and bread (27 %). The figures are based on indicators for kg waste per employee and year from a number of shops, where source separation enables monitoring food waste both in the food waste fraction and in the mixed fraction, together with total number of employees in food retail (Stare 2013, in (Naturvårdsverket, 2013)). Dairy products and industrial bakery products are often returned to the producer or to a waste treatment facility, where special equipment for breaking, crushing and squeezing enables recovery of the content as biogas substrate or animal feed.

Before food waste from retail can be biologically treated, packaging such as paper, metal or glass needs to be removed. This can be done manually in the store, or mechanically through various technical solutions for pre-treatment in anaerobic digestion plants (except for food packaged in glass containers, as there is no available technology for mechanically removing this type of packaging). There are 18 Swedish anaerobic digestion plants where food waste can be treated, and several of these facilities can treat packaged food waste (Avfall Sverige , 2013). There is very little available information on amounts of packaged food waste from retail.

Food waste of animal origin from retail needs to be treated as animal by-products (ABP), described in previous section. This legislation does not apply to consumer food waste (Avfall Sverige, 2009).

There are a few local studies regarding source separation and treatment of packaged and unpackaged food waste from grocery stores, but national data is scarce. A survey collecting data from Swedish municipalities regarding municipal treatment of food waste from grocery stores indicates that 50 of the 134 respondents provide source separation of food waste from grocery stores, at least to some extent. The most common treatment...
methods are composting and anaerobic digestion. For packaged food waste, 18 of these municipalities stated that packaging is removed in the stores, while packaging is removed in a central location in 10 municipalities. According to 17 of these 50 municipalities, packaged food waste from grocery stores is collected as mixed waste and incinerated. (Andrée & Schütte, 2010)

Food waste from retail is similar to food waste from households (see characteristics in the following section), but the quality of the sorting from retail is often better (Carlsson & Uldal, 2009).

### 2.3.1 Drivers for food waste generation in distribution and retail

To get beneficial prices, retail needs to order a variety of food types of brands from the same manufacturer. The consumer also expects a wide range of products, with about 2/3 of the total shelf life remaining at point of purchase, and well filled shelves when shopping. However, a wide range of products in large amounts increase the probability of some food items approaching or passing their “sell by” date before being sold. Selling campaigns contribute to unpredictable demand-supply effects in stock keeping, both for the campaigning product and similar products, potentially resulting in waste from warehouses. In industrialized countries, these are some causes for food waste from retail. (FAO, 2011).

### 2.4 Consumer food waste (restaurants, catering and households)

In 2012, about 142 000 tons of food waste was produced in Swedish restaurants, out of which about 62 % was considered avoidable (see Figure 3 above). Meat was the single most important waste (40 %), followed by pasta, rice and potatoes (37 %), and fruit and vegetables (12 %). Bread and dairy products represented 5 and 3 % respectively (Naturvårdsverket, 2013). The figures were calculated using the same method as for retail and distribution. Food waste that goes down the drain is not included in the assessment.

Catering (school canteens, prisons and arrests, homes for elderly and hospitals) produced about 58 000 tons of food waste, including 52 % avoidable waste (see Figure 3 above). School canteens produced the largest amounts of food waste (43 000 tons). Fruit and vegetables represented 72 %, pasta/rice/potato 11 % and meat 9 % of the catering food waste. The figures were calculated using the same method as for retail and distribution, but the number of employees was replaced by number of pupils, guests or users.

Swedish households produced about 771 000 tons of food waste in 2012, out of which about 35 % was considered avoidable (see Figure 3 above). The figures were calculated from amounts separated for biological treatment (composting and anaerobic digestion) and amounts of food waste found in the mixed fraction according to the Swedish Waste Management together with statistics on types of housing and on municipalities.
with/without source separation of food waste, correcting for the fraction of food waste from business similar to households, that also is covered by the municipal responsibility.

The characteristics of source-separated food waste from households vary due to the quality of the sorting and the composition of the waste. As consumer food waste is depending on individual consumption patterns, it is a rather heterogeneous substance. In addition, it is generally very rich in water with a dry matter content normally around 30-35 %. Due to these characteristics and the occurrence of e.g. plastics and metal in the source-separated food waste from households, it needs to be pre-treated before anaerobic digestion. The pre-treatment typically includes shredding, dilution and separation of other material. The composition of two different samples of pre-treated, source-separated food waste from households is shown in Table 12 below. (Carlsson & Uldal, 2009)

In general, food waste from restaurants and the food service sector is similar to the food waste generated in households, but can be better sorted, richer in fat and the dry matter content can be lower. The composition of a sample of food waste from the food service sector is found in Table 12 below. (Carlsson & Uldal, 2009)

**Figure 7: Unavoidable food waste from households, caterings, and restaurants at the municipal level in Sweden.** Figure 7 illustrates the food waste generated by households, caterings, and restaurants, which cannot be avoided. Data on food waste is based on (Naturvårdsverket, 2013) and spatially disaggregated at the municipal level by using a map on Fel! Hittar inte referenskälla. population by municipality (SCB, 2019b). Food waste depends on population density and therefore the areas with larger food waste generation are the most populated: Stockholm (23%), Västra Götaland (17%), Skåne (13%), Östergötland (5%), Uppsala (4%), Jönköping (3%).
Table 12 Some chemical characteristics of two samples of source-separated food waste from households and one sample of source-separated food waste from the food service sector. (Svenskt Gastekniskt Centrum 2009)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fat (% of dry matter)</th>
<th>Carbohydrates (% of dry matter)</th>
<th>Protein (% of dry matter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treated, source-separated food waste from households (10 % dry matter)</td>
<td>15</td>
<td>53</td>
<td>7</td>
</tr>
<tr>
<td>Pre-treated, source-separated food waste from households (13 % dry matter)</td>
<td>31.5</td>
<td>43.8</td>
<td>13</td>
</tr>
<tr>
<td>Source-separated food waste from food service sector (13 % dry matter)</td>
<td>9.2</td>
<td>60</td>
<td>24.6</td>
</tr>
</tbody>
</table>

2.4.1 Drivers for consumer food waste

Restaurants serving buffets at fixed prices, retail offering “getting one for free” bargains and food manufacturers producing oversized ready to eat meals contribute to large amounts of consumer food waste (Stuart, 2009), in (FAO, 2011). A growing number of single-person households, which per capita tend to waste more food than larger households, is another reason (Lindbom, et al., 2014).

Some studies on consumer food waste related to socioeconomic status show that lower income groups waste less than higher income groups in terms of weight, calories, and spending (World Bank Group, 2014). People in industrialized countries can simply afford to waste food, and consumer attitudes are not prohibitive. However, a British study comes to a somewhat another conclusion: households with higher income and higher education tend to waste less food than households with lower income and lower education. When comparing on a per-capita basis, however, the differences are equaled out since low income households tend to be larger (WRAP, 2008) in (Naturvårdsverket, 2012b).

3 Reducing food waste

In recent years the amount of food that is thrown away has been increasingly debated. The amounts of wasted food are large: roughly one-third of all food produced for human consumption is lost or wasted which amounts to about 1.3 billion tons per year (FAO, 2011). Overall, much more food per capita is wasted in the industrialized world than in the developing countries (FAO, 2011). In the European Union, over 100 million tons of food is wasted annually in the EU (2014 estimate). With anticipated increase in income...
and population, it is expected to rise to about 126 million tons by 2020. In Sweden, about 1,200,000 tons of food wasted each year in different parts of the food supply chain. As a part of this, Swedish households produce approximately 81 kg food waste per person annually, out of which 35% is considered to be “avoidable” (Naturvårdsverket, 2013).

It is considered as a big loss of the earth’s resources not to take advantage of the food produced. Land area, energy, labor, livestock, feed, fertilizer and transport are all resources that are used for food production, and food that goes to waste causes major environmental impacts but no value. Only in Sweden, discarded food accounts for two million tons of greenhouse gases during its life cycle, which corresponds to 3% of Sweden’s emissions of greenhouse gases (Naturvårdsverket, 2013). Most preferably is to better plan, produce, and handle the food so that a greater share of the food produced becomes nutrition instead of waste, but some food will still be wasted. In primary production, photosynthesis in growing crops and animal metabolism produce a lot of nutrients and valuable components, substances that are useful both for human and animal consumption. Waste from these flows are often used for animal feed or fuel, but might be used to produce even more high-value products.

In the study on global food losses and food waste, FAO states that the issue of food losses is of high importance in the efforts to combat hunger, raise income and improve food security in the poorest countries in the world. Economically avoidable food losses have a direct and negative impact on the income of both farmers and consumers. Improving the efficiency of the food supply chain, thereby reducing production costs and consumer prices, could help to increase access to food (FAO, 2011).

Food losses also represent a waste of resources used in production such as land, water, energy and inputs. (Naturvårdsverket, 2012b) lists the environmental impact from a ton of average waste from different parts of the food chain, based on (European Commission, 2010c) and (ETC/SCP 2009). As an example, waste at food factory gate has caused approximately 1.7 ton CO₂-eq/ton, and when ending up as waste from households, this has increased to 2.1 CO₂-eq/ton.

### 3.1 Institutions influencing the amounts of food waste

The reduction of food waste is very high on the European policy agenda. There is a wide range of initiatives aiming at a reduction of waste in general and food waste in particular. Waste prevention and management are central parts in many of the main overarching EU documents such as *Europe Strategy 2020* and the *6th and 7th Environment Action Programmes*. The *Waste Framework Directive (2008/98/EC)* lays out the basis of waste management and includes e.g the *waste hierarchy* (prevention, preparing for re-use, recycling, recovery, disposal) and a target that:

> “50% of household waste and similar material shall be prepared for re-use or recycled by 2020.” (Waste framework directive)

The directive also requires all member states to adopt waste management plans and waste prevention programs.

In addition to this focus on waste in general, food waste in particular has gained a special status as a prioritized area. The *Roadmap for a Resource Efficient Europe* and the
Circular Economy Package (including the communication “Towards a circular economy: a zero waste programme for Europe” COM/2014/0398 final) particularly stresses the need to reduce the amount of food waste. In the Roadmap for a Resource Efficient Europe (EC 2011), for example, food is recognized as a “key sector” and there is a call for:

“incentives for healthier and more sustainable production and consumption of food and to halve the disposal of edible food waste in the EU by 2020.”

The draft legislation associated to the circular economy package also sets a 30% food waste reduction target for member states between 1 January 2017 and 31 December 2025. However the entire package was put on hold by the new commission in December 2014 (European Commission, 2015).

In addition to legislative measures, the EU also invests in research and development related to reduction of food waste, such as the above mentioned FUSIONS project, (Food Use for Social Innovation by Optimising Waste Prevention Strategies), an EU Framework Programme 7 project working towards a more resource efficient Europe by significantly reducing food waste (http://www.eu-fusions.org).

The reduction of food waste is in focus also on an international level. As an example, FAO and Messe Düsseldorf are collaborating with donors, agencies, financial institutions and private sector partners to develop and implement the program on food loss and waste reduction, the SAVE FOOD - Global Initiative on Food Loss and Waste Reduction. The initiative aims at encouraging dialogue between industry, research, politics, and civil society on food losses. For this purpose, the initiative will regularly bring together stakeholders involved in the food supply chain at conferences and in projects and will support them in developing effective measures. Another goal will be to raise public awareness of the impact of food waste (FAO, 2015).

In parallel with these initiatives to reduce food waste, several EU policies have been identified as potentially hindering this development. As an example the EU advisory group on the Food Chain identifies that “donation of surplus food to food banks may be hampered by legal barriers such as the EU Common VAT Framework and the EU Food Hygiene Legislation” (Advisory group on the Food Chain, 2013).

The urge to reduce food waste, and the frustration when targets were not likely to be met, lead to resolution 2012 EU (2011/2175(INI)) on How to avoid food wastage: strategies for a more efficient food chain in the EU. The resolution called for urgent measures, including that 2014 should be appointed the European Year against Food Waste; “as a key information and awareness-raising initiative for European citizens and to focus national governments’ attention on this important topic”.

The need and urge to reduce food waste seem to be generally accepted in the public debate. However, a counteracting norm is also the tradition that it is “considered courteous to prepare more food for a meal than can be eaten, and it is customary to have leftover food” (European Commission, 2010b).

In Sweden, just like in the EU, recent waste policy puts food waste at the center of many policy initiatives. Food waste relates to the two sets of overarching national environmental goals: miljökvalitetsmålen and “generationsmålet”. In accordance with the requirements of the EU Waste Framework Directive Sweden has implemented a national waste management plan and waste prevention program. These documents mirror the EU ambitions of reduced amounts of food waste. The waste hierarchy with a focus on prevention of waste, has a central position in the Swedish Waste Management Plan (Naturvårdsverket, 2012a), and the Swedish Waste Prevention Program identifies
food as one of 4 selected areas (along with textile, electronic and construction and demolition waste).

In line with the EU resolution on food waste 2012, Swedish government appointed a joint three-year mandate in 2013 to the National Food Agency (Livsmedelsverket), the Swedish Board of Agriculture (Jordbruksverket) and the Environmental Protection Agency with the task to “take action that will help to reduce unnecessary food wastage at all stages and to a better utilization of the inevitable food waste” (authors’ translation). The entire project was presented March 31, 2016.

4 Amounts and characteristics of food waste relevant for biobased chemical production

In the introduction to this report, we set out to examine the cross-section of three sets of materials representing the portion of food waste that is both available, also in a longer time perspective, and potentially suitable for industrial fermentation processes (Figure 2).

While the question about availability only briefly has been touched upon, we have seen from the short but broad inventory of food waste streams above that there are waste streams qualified for the short-list of potentially interesting waste streams, presenting one or several of the desired qualities: high dry matter content, high carbon and/or nitrogen content, high sugar content, reasonably concentrated occurrence and homogeneity.

Short-listing of potentially interesting food waste streams primary production:

- Although yield and quality varies depending on weather, and production varies with market price, straw and chaff from grain and oilseed production represent about 7 000 tons of unavoidable waste with a high dry matter content, enabling storing, rich in carbon (mainly cellulose and lignin), almost entirely found in the southernmost part of the country, however in very scattered volumes. Currently, these streams are used in agriculture (litter in animal husbandry, left in the field to increase soil organic carbon or as fuel) or for energy production (heat, heat&power, biogas). New technology may enable increasing recovery of organic matter at harvest through concurrent collection of straw and chaff.

- Discarded potatoes intended for human consumption represent about 50 000 tons of waste, to a large extent unavoidable, with high water content, but rich in starch. Except potato that is left unharvested, these quantities occur at packaging and sorting facilities in the southernmost part of the country, although about 70 sorting and packaging companies have joined a network organized by Svensk Potatis AB (www.svenskpotatis.se).

© RISE Research Institutes of Sweden
10% of the national production takes place north of Stockholm. Currently, these quantities are used for biogas production and, to some extent, fodder.

- The amounts of **tops from sugar beet** and **haulm from pea production** are relatively important (1.6 million tons and 200,000 tons respectively), and they are found scattered in the very southernmost part of Sweden. Although fairly low in dry matter, and therefore offering limited storing properties, they have an interesting content of protein and other nutrients (INRA, CIRAD, AFZ and FAO, 2012-2015). Currently, these streams are left in the field or, to some extent, used as fodder.

**Short-listing of potentially interesting waste streams from food industry:**

- **Whey permeate** is an unavoidable left-over after cheese making and whey powder production in a small number of large facilities. Dry matter content is low, but it is rich in sugar (lactose) and has limited value as fodder.

- Food grade **lungs, kidneys and stomachs** are unavoidable by-products from beef slaughter and often end up as pet food. Although difficult to store, these streams come from some larger slaughterhouses and might offer valuable nitrogen sources.

- **Bran and other grain processing waste** represent about 57,000 tons of unavoidable waste with a high dry matter content, enabling storing, rich in carbon (mainly cellulose and lignin). These streams are found in a limited number of milling plants, situated in southern part of the country.

### 5 Waste treatment market characteristics

This section gives an overview of the contemporary practices for treating, or processing, food waste including a brief overview of the historical emergence of the current waste treatment structure. In addition, future prospects for food waste management are discussed.

Waste is highly controlled and managed resource, at least legislatively. Stringent definitions of waste, how it is to be stored, treated, transported etc and by whom are laid out by Swedish environmental law. The main piece of legislation is the environmental code (Miljöbalken) section 15§ on Waste and Producer responsibility and related statutes, the chief of whom is the directive on waste (Avfallsförordningen 2011:927).

Waste has, and still is, to a large extent seen as a problem, with implications for human health if not managed responsibly. Legislation therefor grew in the context of dealing with the health and sanitation side of waste and then especially household waste (NV 2004). Safe and sanitary waste management was therefore seen as the responsibility of society and the municipalities were given, and still has, ownership of the issue (Miljöbalk 1998:808)
There are market implications of this municipal ownership of waste. Aside from the obvious, that the municipality owns and controls the waste once it is handed over to the waste management services. Municipalities are also governed by laws on public procurement (Lag (2007:1091) om offentlig upphandling), and currently the threshold for when services must be procured in accordance with regulations (Upphandlingsmyndighet, 2019) is about two million SEK. In the waste management arena most contracts exceed this sum (Avfall Sverige, 2019). This means that if the municipality does not themselves collect, transport and treat the waste these services has to be procured on the open market to the lowest cost. The waste resource is therefor from a company perspective a negative costing input, i.e. you get paid by the municipality for the waste treatment service of incineration, composting or anaerobic digestion. Municipalities do however have the option to manage waste in house under own control, thus not having to procure these services on the open market.

Residues streams from industry, distribution and retail operations does not always fall under the strict legal definition of household waste and the phrasing of the definition of household waste in the environmental code has given room for debate, see for instance NV 2015 (Naturvårdsverket, 2015), NV 2008 (Naturvårdsverket, 2008) and Avfall Sverige 2011 (Avfall Sverige, 2011). This is important since household waste is controlled by the municipality and the municipality dictated how it is to be treated.

5.1 Waste hierarchy

The waste hierarchy of EU includes prevention, preparing for re-use, recycling, recovery and disposal. Food waste prevention and re-use has been discussed in the previous section and will not be further elaborated on here, neither will processing of food waste into animal feed.

The translation of the waste hierarchy to preferred food waste management strategies differs slightly between countries and actors. There does not seem to be any consensus on the preferred order between anaerobic digestion and production of chemicals, for example (see e.g. the below from US EPA).

![Food Recovery Hierarchy](image)

**Figure 8: Food Recovery Hierarchy** (US Environmental Protection Agency, 2017)
The EU advisory group on the food chain refer to the *Food Waste Hierarchy* of Wageningen University, NL, where “industrial biobased resources” are prioritized before “bio fermentation + digestate” and composting (Advisory group on the Food Chain, 2013).

The Swedish waste hierarchy follows the EU *Waste Framework Directive* (2008/98/EC) and does not priorities treatment options for food waste specifically (NV 2015 (Naturvårdsverket , 2015)).

### 5.2 Emergence of the current waste management regime

The major option for food waste treatment and indeed waste treatment in general has historically been landfilling (deponering), see Figure 9. Since the 1990-ties, a number of political measures in Sweden have been taken to minimize the amounts of waste deposited in landfills, instead increasing incineration (energåtervinning).

![Behavior of household waste 1975-2013](image)

**Figure 9. Treated household waste** (Avfall Sverige, 2015)

A detailed snapshot from 2012 of the amounts of food waste emanating from different activities in Sweden can be seen in Figure 10 and includes agriculture and fisheries (unknown amounts), food industry (171 000 ton), retail (70 000 ton), restaurants (142 000 ton), large kitchens (58 000 ton) and households (771 000 ton). This was treated as animal feed (unknown amounts), incineration (773 000 ton) and biological treatment including in home composting (479 000 ton).
Some food waste streams, particularly animal by-products (ABP), must be incinerated instead of biologically treated. Animal by-products occur in primary production (agriculture, fisheries, and aquaculture), food industry (slaughterhouses, meat processing industries, and dairies), retail and households. ABPs are split in three categories based on the risk of spreading pathogens they pose (Gov.UK 2015, Jordbruksverket 2015):

**Category 1** is high risk waste, including e.g. carcasses and all body parts of animals suspected of being infected with TSE (transmissible spongiform encephalopathy) and specified risk material (body parts that pose a particular disease risk, e.g. cows’ spinal cords). Category 1 material shall be destroyed (e.g. through incineration).

**Category 2** is also high risk waste, including e.g. animals rejected from abattoirs due to having infectious diseases, carcasses containing residues from authorised treatments, unhatched poultry that has died in its shell, carcasses of dead livestock, manure and digestive tract content. Category 2 material shall be incinerated, processed to organic fertilisers/soil improvers or for technical purposes, or (after pressure sterilization) composted or used for anaerobic digestion. They can also be applied to land, and, in the case of manure, digestive tract content, milk, milk products and colostrum, this can be done without processing (Gov.UK 2015).

**Category 3** is low risk waste, including e.g. carcasses or body parts passed fit for humans to eat products or foods of animal origin originally meant for human consumption but withdrawn for commercial reasons (not because it is unfit to eat), domestic catering.

---

Figure 10. Food waste treatment in Sweden 2013 (NV 2014b)
waste, shells from shellfish with soft tissue, eggs, egg by-products, hatchery by-products and eggshells, aquatic animals, aquatic and terrestrial invertebrates, animal hides, skins, hooves, feathers, wool, horns, and hair that had no signs of infectious disease at death and processed animal proteins. Category 3 material can also be incinerated, processed to petfood, applied to land, used for composting or anaerobic digestion or for technical purposes.

Plants destroying, processing, treating or storing animal by-products generally need approval from the national authority, in Sweden represented by Jordbruksverket.

The handling of ABP is regulated through a number of documents at European (EG 1069/2009, EU 142/2011,) and Swedish levels (SJVFS 2006:84), ensuring for example safe handling and traceability (Ragn-Sells, 2014). The Swedish Environmental Protection Agency’s general advice on methods for commercial storage, digestion and composting of food waste (Naturvårdsverkets allmänna råd om metoder för yrkesmässig lagring, rötning och kompstering av matavfall NFS 2003:5) recommends decomposition and hygienization of food waste (Nilsson & Sundberg, 2009). Hygienization is a requirement for waste streams classified as animal by-products 8. This is often not a barrier to biogas production as hygienization already is a part of this process, see below. However, for other biological processes this can be a barrier, e.g. for compost.

Sweden introduced a landfill ban for combustible wastes in 2002, followed by a landfill ban for organic wastes three years later. These bans have had a large impact on the expansion of capacity for both incineration and biological treatment of waste in Sweden (Nilsson & Sundberg, 2009) and their effect on the disposal of waste can easily be seen in Figure 9 above. An EU Landfill Directive (1999/31/EC, Swedish förordning 2001:512) with targets for successive reduction of landfill levels was also adopted in the EU in 1999, but with a less ambitious timeline than the Swedish ban thus not having major impact on Swedish conditions. On a European level, however, this directive has had an impact, e.g. through considerably increased landfill gate fees in Europe (Lin, et al., 2013). Sweden introduced a landfill tax in 2000, but the effect of this tax has probably been quite modest as the prices were already high and the total national ban soon to come (Nilsson & Sundberg 2009).

A range of policy instruments were, and are, affecting the amount of waste going to incineration and biological treatment. Every municipality in Sweden must make a Municipal waste plan, including for example targets for amount and management of municipal waste. The creation of the plans has according to (Nilsson & Sundberg, 2009) had a positive impact on both incineration and biological treatment as the creation of the plans have encouraged collaboration among waste handling actors. Also national environmental goals on e.g. increased recycling has had a "controlling effect" on municipal investments in waste incineration and biological treatment (Nilsson & Sundberg, 2009).

Over the last decade steps have been taken to make better use of the biological fraction of the waste i.e. food waste. Capacity for composting biological waste was widespread throughout the country, see section on composting below; however anaerobic digestion is now seen as a more beneficiary treatment option for food waste. This coupled with the policy drive towards greening the transport sector has favored anaerobic digestion.

8 Regulations on animal by-products also specify that handling and treatment should be performed in a manner that prevents any inadvertent cross contamination leading to cannibalism amongst farm animals. This mainly affects the production of animal feed from residue streams (SJVFS 2006:84).
Furthermore, the national environmental goals and the so called generational-goal (generationsmålet) are associated with a number of “mid-term goals”. The Swedish government has appointed the Swedish Environmental Protection Agency the task of designing a specific “mid-term” goal related to reduction of food waste. The goal named “Increased resource efficiency in the food chain” (Ökad resurshushållning i livsmedelskedjan) was presented in January 2014:

"Measures shall be implemented so that 2018, at the latest, a minimum of 50% of the food waste from households, institutional kitchens, supermarkets and restaurants are sorted separately and treated biologically so that plant nutrients are recovered. Moreover at least 40% of the food waste shall be treated so that energy is recovered as well." (Naturvårdsverket 2014, author’s translation9).

The year when this goal should be achieved was later adjusted to 2020. It should be noted that it is only a goal, and not a binding a target and that the recovered nutrients must be brought back into food production for the goal to be fulfilled. Nevertheless, more and more municipalities are actively engaging in food waste collection (Avfall Sverige, 2015) thus increasing the amounts to be treated; driven in part by environmental goals like the mid-term goal on a resource efficient food chain but also by a willingness to improve local environmental performance.

The collection and treatment of source separated food waste increased by 16% in 2013 compared to 2012. Many municipalities that introduced the voluntary collection of food waste use the charge as an incentive. For example, those who choose a food waste subscription pay a lower charge than those who choose to leave mixed waste for collection (Avfall Sverige, 2014). Some municipalities have made the separation of food waste is mandatory. The overall food waste separation rate in Sweden was about 40% by 2016 (Jensen, et al., 2017) which means that the environmental goal on food waste, stipulating that 50% of the food waste is to be treated biologically in 2020, requires further efforts to be reached.

Public and private companies within the field cooperate under the umbrella of Avfall Sverige (Swedish Waste Management and Recycling association), a trade and stakeholder organization. Avfall Sverige is an important network for exchanging and spreading knowledge, but they also actively engage in development and research.

5.2.1 Platform chemicals

Bio-based chemicals and materials have so far mainly been produced from sugar, but the interest in lignocellulosic feedstocks is increasing (Petersson and Willquist, 2014, personal communication). Food waste is an even less mature feedstock, but some emergent initiatives exist.

In 2012, Starbucks launched an initiative with the University of Hong Kong to produce bio-succinate from used coffee grounds and left-over baked products (Coxworth, 2014). At about the same time, Ford and H.J. Heinz Company started to collaborate to use left-over tomato fibers to develop more sustainable bio-plastic materials for vehicles (Ford, 2014). At KTH, ongoing biotechnological research target platform chemical production from food waste by means of E.Coli fermentation (Larsson, 2013).

---

9 “Insatser ska vidtas så att senast år 2018 sorteras minst 50 procent av matavfallet från hushåll, storkök, butiker och restauranger ut och behandlas biologiskt så att växtnäring tas tillvara, och minst 40 procent av matavfallet behandlas så att även energi tas tillvara”.

© RISE Research Institutes of Sweden
Examples of other initiatives include research on production of lactic acid from starch rich feedstocks (IEA Bioenergy, 2013), bacteriological production of bio-hydrogen from pure industry streams like potatoes and carrots, or the use of bacteria strains with higher yield than E.coli or yeast (Yamagishi, 2005).

6 Conclusions

The aim of the analysis in this report was to examine what kind of food waste exists today, if there will be enough food waste of the right quality to allow for a future industrial fermentation process and, in that case, if this food waste would be applicable for use as feedstock in an emerging industry for bio-based chemicals. This corresponds to the research question stated in Chapter 1:

Is food waste physically and practically applicable for use as feedstock for the production of bio-chemicals through industrial fermentation in Sweden?

In this report we have addressed this question through the following sub-questions:

a) What kind of food waste exists today?

b) Will there be enough food waste of the right quality to allow for a future industrial production (amounts and characteristics)?

c) Is it likely that this feedstock would be applicable for use as feedstock in an emerging industry for bio-based chemicals?

What kind of food waste exists today?

The survey carried out by the Swedish EPA (Naturvårdsverket, 2013) quantified the amount of food waste from different sectors of the food chain summarized in Figure 3 in the introduction of chapter 2.

The figure includes a question mark for primary production. In the current study, we have estimated the amount of waste from crop production (chaff, tops, leaves, post-harvest losses) to about 9 000 000 tons. According to SP, Chalmers and Rena Hav (2015), by-products from seafood processing represent between 30 000 and 50 000 tons yearly. Since it cannot be confirmed that the methodology used in Naturvårdsverket (2013) and in SP, Chalmers and Rena Hav (2015) are the same, these amounts are not included in the diagram in Figure 3. No quantification of losses from animal husbandry was made since the use and management of these waste streams are surrounded by severe legal restrictions. Therefore, this type of food waste was in beforehand considered less interesting.

Will there be enough food waste of the right quality to allow for a future industrial production (amounts and characteristics)?

Today, there is no clear-cut delimitation between food waste and food by-products – the classification is to a large extent a matter of supply, demand, quality and price. Despite a general awareness and a range of policy ambitions, the prognosis is that the amount of food waste will continue to increase due to increased consumption. Having said this, the
question about required characteristics of the food waste for the valorization targeted in this project has been approached and answered as follows:

- Animal by-products are largely restricted for valorization either by legislation, which most often requires incineration, or by competition from biogas production, where the rather wet and often biologically unstable, microbiologically active material is fit for purpose.

- Waste from harvested crop production rich in fibers, sugar and/or starch is often valued as animal feed, but also for anaerobic digestion. However, material with low dry matter content and/or high content of cellulose is less valuable from both perspectives, since these uses often are associated with important costs for transport or pre-treatment per output.

- Waste from un-harvested crop production is left in the field mainly for commercial reasons (potential income less than costs associated with harvest) or for maintaining soil carbon (applicable to straw, though effects are contested), and represent potentially interesting material.

- Industrial food waste is relatively homogenous and uncontaminated, interesting for both biogas production and (for vegetable and dairy fractions) animal feed, but would, more profitable than these applications, be potentially interesting for valorization, especially when it comes to food waste in the more “inevitable” part of the food waste spectrum, where the potential for further reduction is limited.

- Food waste from retail and consumers, especially households, represents considerable, but geographically scattered, amounts. Furthermore, source separated food waste from these parts of the food chain is generally inhomogeneous and contaminated by other waste fractions. To make use of these materials in more sophisticated and sensitive processes important efforts would need to be mobilized, both to reduce contamination and for pre-treatment. Moreover, policy making is targeting household consumer waste reduction, since the incentives for reduction, considering today’s food prices share of disposable income, is less pronounced in this part of the chain than within other parts. In addition, the municipal responsibility for household waste and the current surplus capacities in incineration and biogas facilities in Sweden suggest that valorization of consumer food waste is less interesting than food waste from other parts of the food chain.

The statements listed above are supported by (Sanchez-Vazquez, et al., 2013), who conclude that if sufficiently uncontaminated the waste from agriculture, postharvest, processing and distribution, can be used in secondary processes such as polymer production, while consumer waste generally can be assumed too contaminated for secondary processes, except gasification.

A very simplified version of the conclusions on availability can be summarized in two bullet points:

- The nearer primary production, the more homogenous, well defined waste streams and the higher the competition with other purposes – positive price and free market.

- The nearer consumers, the more inhomogeneous, variable, contaminated, impure and degraded waste streams and the lesser the competition with other purposes - negative price and municipal monopoly.
While we hereby have made a delimitation of potentially interesting waste streams, the question about actually interesting waste streams that also can be found in sufficient amounts cannot be answered without prior pinpointing of a specific production process.

**Is it likely that this feedstock would be applicable for use as feedstock in an emerging industry for bio-based chemicals?**

As described in this report, political instruments and visions on national and regional levels support increasing source separation of food waste for extended biogas production, despite low profitability, and there are quite important efforts in research and development to make biogas production and upgrading more efficient and competitive. Moreover, the competition between incineration and anaerobic digestion will probably lead to additional import of waste to Swedish incineration plants. Given these conditions, it is not likely that a development where waste streams are used as feedstock will come about without incentives and/or support (financial, political, organizational etc). Even if this utilization leads to steps in a positive direction in the waste hierarchy.

**Is food waste physically and practically applicable for use as feedstock for the production of bio-chemicals through industrial fermentation in Sweden?**

As the overall conclusion, there are potentially interesting food waste streams for the production of *bio-chemicals through industrial fermentation* in Sweden, but whether they are actually interesting and can be found in sufficient amounts cannot be answered without prior pinpointing of a specific production process. To make them practically available, incentives and support are required.
7 References


European Commission, 2010b. *PREPARATORY STUDY ON FOOD WASTE ACROSS EU 27 October 2010*, Brussels: EU.

European Commission, 2010c. Technical support to identify product categories with significant environmental impact and with potential for improvement by making use of ecodesign measures., Brussels : European Commission.


Larsson, G., 2013. Introducing high value products into the biorefinery. s.l.: Application for research grant to Formas.


Available at: http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__JO__JO0601/SkordarL/?rxid=42885135-9beb-462d-8aa3-026e38329bcb
[Accessed April 2019].

SCB, 2019b. Öppna geodata för DeSO – Demografiska statistikområden. [Online]
Available at: https://www.scb.se/hitta-statistik/regional-statistik-och-kartor/geodata/oppna-geodata/deso--demografiska-statistikomraden/
[Accessed April 2019].

SOU, 2017. Produktionsförutsättningar för biobränslen inom svenskt jordbruk,

SP; Chalmers; Rena Hav AB, 2015. Testbiddu för värdehöjande av marin råvara.
Förstudie om förutsättningar för etablering. Klusterområdena Marin bioteknik och
Marina livsmedel inom det Maritima klastret i Västra Götaland, Göteborg: u.n.


Upphandlingsmyndigheten, 2019. Tröskelvärden och direktupphandlingsgränser.
[Online]
Available at: https://www.upphandlingsmyndigheten.se/upphandla/om-upphandlingsreglerna/Upphandlingsforfaranden/troskelvarden/

Available at: https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy
[Accessed 2019].

Vinnova, 2015. MareValue A sustainable and profitable Swedish seafood sector: Increased yield and value from limited marine resources. [Online]
Available at: http://www.vinnova.se/sv/Resultat/Projekt/Effekta/2013-00117/En-uthallig-och-lonsam-svensk
[Accessed November 2015].


**Personal communication**

Andreas Gundberg (2015). Innovation manager, Lantmännen Agroetanol

Robin Karlsson (2015), Innovationsingenjör Foder, Lantmännen Agroetanol

Birgit Landquist (2015), SP Food and Bioscience

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,200 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

I internationell samverkan med akademi, näringsliv och offentlig sektor bidrar vi till ett konkurrenskraftigt näringsliv och ett hållbart samhälle. RISE 2 200 medarbetare driver och stöder alla typer av innovationsprocesser. Vi erbjuder ett 100-tal test- och demonstrationsmiljöer för framtidssäkra produkter, tekniker och tjänster. RISE Research Institutes of Sweden ägs av svenska staten.