Bioforsk Rapport
Bioforsk Report
Vol. 9 Nr. 82 2014

Utilisation of co-streams in the Norwegian food processing industry

A multiple case study

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Title:

Utilisation of co-streams in the Norwegian food processing industry – A multiple case study

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Front page photos:

Bioforsk A.-K. Løes and S. Adler

Date: 21st May 2014	*Availability:* Open	*Project No.:* 20245	*Archive No.:* 12/784
Report No.: No. 82, 2014	*ISBN-No:* ISBN 978-82-17-01283-2	*Number of pages:* 58	*Number of appendices:* None

Employer: The Research Council of Norway	*Contact person:* Steffen Adler, steffen.adler@bioforsk.no

Keywords: Food industry, Norway, co-stream, feed ingredient, fertiliser, bioenergy, vegetable, potato, white fish, pelagic fish, poultry, regulation	*Field of work:* Food and agriculture

Sammendrag:

Matsvinn oppstår i hele matkjeden, fra primærproduksjon via postharvest-håndtering og lagring, til matvareindustri, distribusjon, handel og forbruk. Det antas at det globale matsvinnet står for om lag en tredjedel av den totale matproduksjonen. Målet med denne rapporten var å kartlegge produksjonen og anvendelse av biprodukter i den norske matvareindustrien og å diskutere muligheter for alternativ utnyttelse med bakgrunn i biproduktenes kvalitative egenskaper og gjeldende forskrifter. Denne rapporten er produsert av arbeidspakke 3 i CYCLE-prosjektet (2013-2016) "Utnyttelse av råvarer i matkjeden i et bioøkonomisk perspektiv". CYCLE-prosjektet har som mål å bedre ressursutnyttelsen i utvalgte norske verdikjeder for mat ved å utvikle bærekraftige bioprosesser og ny teknologi i nært samarbeid industripartnere. Strømmen av organisk materiale ble kartlagt på utvalgte foredlingsanlegg i tre norske matvarekjeder: 1) Grønnsaker og poteter; 2) hvit og pelagisk fisk; og 3) kylling. Data ble samlet inn ved bedriftsbesøk i juni 2013, og er senere kvalitetssikret av kontaktpersoner i bedriftene. Rapporten beskriver biproduktenes kvalitative egenskaper, og hvordan de ble brukt per juni 2013 som fôr, gjødsel eller som råstoff for energiproduksjon. Viktige forskrifter i EU og Norge vedrørende behandling og utnyttelse av relevante biprodukter presenteres, og alternativ utnyttelse blir diskutert. Foredlingsanleggene hadde tilsammen betydelige markedsandeler innenfor ferske poteter (38%), salat (17%), fjørfekjøtt (24%) og hvitfisk og pelagisk fisk, der en stor andel går til eksport. Generelt ble en stor andel av råvarene utnyttet i mat og fôrprodukter. I gjennomsnitt for alle foredlingsanleggene ble 75% av råmaterialet benyttet i matvarer, 21% i fôrprodukter, 1% i gjødsel- og energiproduksjon og 3% ble deponert. Foredlingsanleggene brukte i gjennomsnitt 8,6 tonn prosessvann per tonn leveringsklare matvarer, men mengden varierte mye mellom anleggene. Mulige forbedringer i råvareutnyttelsen inkluderer generelt høyere utnyttelsesgrad i matvarer og utvikling av nye eller forbedrede fôrkomponenter fra biprodukter. Potensialet for gjødsel- og energiproduksjon er sannsynligvis begrenset til visse risikomaterialer på grunn av den allerede høye graden av utnyttelse i mat- og fôrprodukter, som har en betydelig høyere salgsverdi. Utsorterte poteter og grønnsaker og fjær, bein, blod, innvoller og skinn fra fisk og fjærfe har et stort potensiale for bedre utnyttelse til mat eller fôr. Aktuelle prosesseringsmetoder er fraksjonering, hydrolyse, fermentering og tørking.

Summary:

Food losses occur throughout the entire food chain, from primary production via postharvest handling and storage, to food processing, distribution, retailing and consumption. Globally, food losses account for about one third of the total food produced for human consumption. The aim of this report was to map the production and utilisation of co-streams in the food processing industry in Norway and to discuss possibilities for alternative utilisation based on qualitative aspects of the co-streams, and current legislation. This report is produced by work package 3 in the CYCLE project (2013-2016), “Total utilisation of raw materials in the supply chain for food with a bio-economical perspective”. The CYCLE project aims to improve resource utilisation in the Norwegian food chain by developing sustainable eco-friendly bio-processes and novel technology, in close relationship with food industry partners. Inputs and outputs of organic materials were roughly mapped at selected food processing plants presenting three Norwegian food chains: 1) Vegetables and potatoes; 2) white and pelagic fish; and 3) poultry. Data was collected during plant visits in June 2013, and later checked by staff from the described plants. The report describes the qualitative properties of co-streams, and their current utilisation as feed, fertiliser and as substrate for bioenergy production. We also present relevant regulations in EU and Norway regarding processing and utilisation of co-streams, and discuss alternative utilisation. Altogether, the food processing plants had significant market shares in Norway within fresh potatoes (38%), lettuce (17%), poultry meat (24%) and white and pelagic fish, where export makes up a large proportion. Generally, a large proportion of the raw materials were utilised as food and feed. On average for all plants, 75% of the raw material was utilised in food products, 21% in feed products, 1% in fertiliser and bioenergy production and 3% was deposited in landfill. The plants used in average 8.6 tonnes of process water per tonne of food produced, but the amount varied considerably between the plants. Possible improvements in the utilisation of raw materials and co-streams include a higher degree of utilisation in food products, and developing new or improved feed components from co-streams with increased nutritional value. Due to the current high degree of utilisation in food and feed applications with high economic values, the potential for bioenergy and fertiliser production is limited to certain risk materials. Feed potatoes and vegetables and feathers, bones, blood, viscera and skin from fish or poultry have considerable potential for better utilisation for food or feed. Relevant processing methods for these co-streams are fractionation, hydrolysis, fermentation and drying.

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Acronyms

ABP	Animal by-products
DM	Dry matter
PAP	Processed animal protein
TSE	Transmissible spongiform encephalopathy

1. Preface

This report is an early deliverable from the CYCLE project (2013-2016), "Total utilization of raw materials in the supply chain for food with a bio-economical perspective". The CYCLE project was initiated by SINTEF Fisheries and Aquaculture in 2012. The main objective is to improve resource utilization in the food chain in Norway by developing sustainable eco-friendly bio-processes and novel technology, with research and innovation at its core. The project is based on three central food chains in Norway: Vegetables and potatoes; white and pelagic fish; and poultry.

In May 2012, the Research Council of Norway called for large research projects in the program Bionær (Sustainable innovation in food and bio-based industries). Bioforsk was invited by SINTEF Fisheries and Aquaculture as a research partner, together with VTT Technical Research Centre of Finland and many more. In CYCLE, Bioforsk leads the work to utilise food co-streams for animal feed and fertilisers (work package 3), in close cooperation with VTT who leads the work to utilise co-streams not currently used for edible products for innovative food products (work package 2). Enzymatic and chemical hydrolysation are among the methods that will be utilised in work packages 2 and 3.

During a study tour in June 2013, scientists from all CYCLE work packages visited seven industry partners processing raw materials in the three food chains. The gathered information provided a starting point for this report, which will function as a reference for the selection of food co-streams for more detailed studies, aiming at a development of feed products, feed ingredients, fertilisers and biofuel production. In CYCLE we are aiming at developing technologies to use co-streams for products of the highest possible value. The CYCLE project aims at decreased food losses and wastes, and increased raw material utilisation in the food chains of vegetables and potatoes, white and pelagic fish, and poultry. Hence, co-stream utilisation is the central topic, and we need to know what kinds of compounds these co-stream materials comprise of in the food processing cases.

We are grateful to the industry partners for inviting the CYCLE scientists into their plants and sharing valuable information, and for allowing us to publish this report.

Tingvoll, April 2014

Anne-Kristin Løes, leader of work package 3 in CYCLE.

2. Introduction

Efficient utilisation of raw materials in the food sector generally implies that a high proportion of the raw material is processed to food or pharmaceutical applications. According to the waste management hierarchy of the EU (Figure 1), avoiding to produce waste should always be the main strategy in any sector, followed by re-use, recycling, recovery and disposal of waste. Waste is defined as any substance or object which the holder discards, or intends to discard, or is required to discard (EC, 2008). For the food processing industry, utilisation of co-streams for feed or technical applications often gives a lower rate of return than for food applications, but should still be more profitable than to treat the co-stream as waste. Due to the high energy prices and economic support for renewable energy, biofuel and other bioenergy production[1] from food industry co-streams may be profitable enough to allow for a payment to the industry. In Norway, energy prices are generally low due to access to hydroelectric power. The industry has to pay a fee for waste disposed of as landfill or incinerated for destruction by methods, which do not provide bioenergy production. For waste incinerated for energy production, there is no end-treatment fee since 1st October 2010 (MD, 2013), but local incineration plants may still be paid for disposal of high-risk animal co-streams where it may be cheaper for the industry to pay a plant for sanitizing the material than to sanitise it themselves. The Norwegian waste classification system comprises the categories recycling, biological treatment (i.e. composting, anaerobic digestion), filling and covering compounds (e.g. for road construction), incineration for energy production, incineration without energy production (i.e. destruction), and landfill.

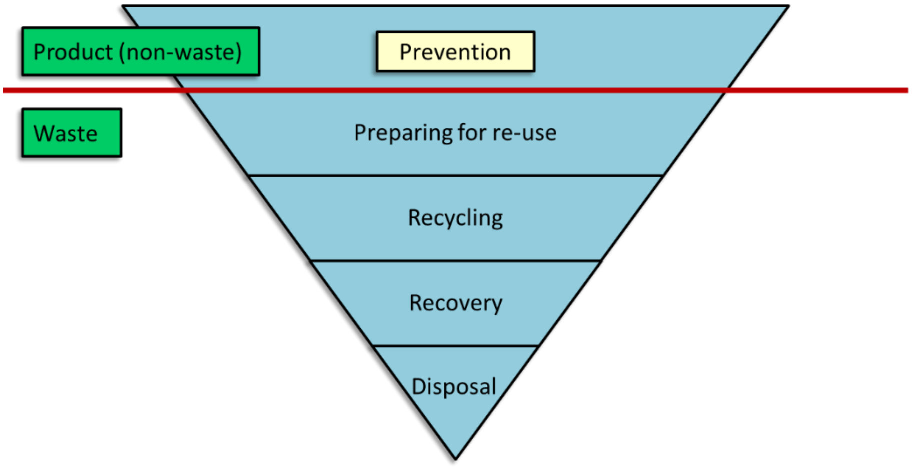

Figure 1. The waste management hierarchy of the EU (EC, 2008)

2.1 Terms and clarifications

Food losses occur throughout the entire food chain, from primary production via postharvest handling and storage, to food processing, distribution, retailing and consumption (Figure 2). Globally, annual food losses are estimated to account for about 1,300 million tonnes, about one third of the total food produced for human consumption

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[1] According to the law of conservation of energy the total energy of an isolated system is constant. Energy cannot be created or destroyed, but transformed from one form to another. However, the term «energy production» is widely used and relates to the conversion of energy.

(Gustavsson et al., 2011). In the Nordic countries, food losses are largest in households and in primary production, but also losses from the food-processing segment are significant (Hanssen and Schakenda, 2011). According to a Finnish study, 335 to 460 thousand tonnes of food, 62 to 86 kg per capita, is lost annually in Finland by consumers, retailers, food services and food industry (Silvennoinen et al., 2012).

The understanding of food losses and food wastes is complicated, and different authors have defined food losses and food wastes differently. The definition of Parfitt et al. (2010) was utilised in a recent FAO-report on food losses and wastes (Gustavsson et al. 2011). There, ***food losses*** is used to describe a decrease in edible food mass within part of a food supply chain that leads to edible food for human consumption. Hence, food losses take place at production, postharvest and processing stages. When food is utilised for non-food purposes, we may distinguish between ***planned and unplanned non-food use***. Utilisation for feed, fertiliser or bioenergy production may be a planned non-food use, whereas ploughing down a non-harvested crop may be an unplanned non-food use (Gustavsson et al., 2011). Still, both non-food utilisations are included in the food losses. In the same report ***food wastes*** is used to describe food losses occurring at the end of the food chain, where the losses are related to retailers' and consumers' behaviour. The terms food losses and food wastes only refer to products that are directed to human consumption, and are not used to describe a decrease in the amounts of materials integrated in the raw materials, such as fish skin or potato peel. ***Raw materials*** are defined at each processing stage as materials in the state they are delivered from the preceding stage; e.g. living poultry, slaughtered fish, unpeeled vegetables from the primary producer, or feathers, blood, viscera and poultry carcasses from the slaughterhouse. Mogensen et al. (2013) emphasise edibility in their study of food waste in the Danish food supply chain. They distinguish between food that could readily have been eaten by humans (i.e. ***real food waste***), and food that could have been eaten by humans if the material in question had been treated in an optimal way from primary production until retail (i.e. ***hidden food waste***). The term "waste" does not necessarily refer to the inherent qualities of a co-stream, but is rather a subjective term, as a material may be waste for one user and a resource for another. Therefore, we do not use the term waste in this report. Instead, the term used here to describe the utilisation of all food processing by-products, including materials that are or may be utilised for food commodities and by-products that cannot be utilised for food, is ***co-streams***. Economically efficient co-stream utilisation implies that materials are used for products of highest possible economic value at lowest possible environmental costs. Generally, the production of feed and feed components will have higher priority than the production of fertilisers or bioenergy, and the lowest priority goes to deposition as landfill. In EU regulations, the term ***animal by-products*** (ABP) is used for co-streams of animal origin and therefore we use ABP in Chapter 4.2 (Regulations).

Food losses will decrease if co-streams that are currently not used for food can be utilised in novel food processing methods. This presupposes agreement with prevailing legislation and consumer acceptance. However, what is ***edible*** depends strongly on tradition, access to food and economic wealth, and developments in food technology may change the status of a material from inedible to edible. Will consumers be willing to eat e.g. more viscera and other animal organs currently being utilised for animal feed? Should science persuade people to do so, or should we leave people's diets to be a personal choice?

Co-stream utilisation will improve if disposal as landfill decreases or if co-streams can be utilised at a higher priority level, or with better payment than in the current situation. For example, co-stream utilisation will be improved if chicken feathers are no longer utilised as feed with low digestibility for fur-bearing animals but upgraded to feed components with high digestibility.

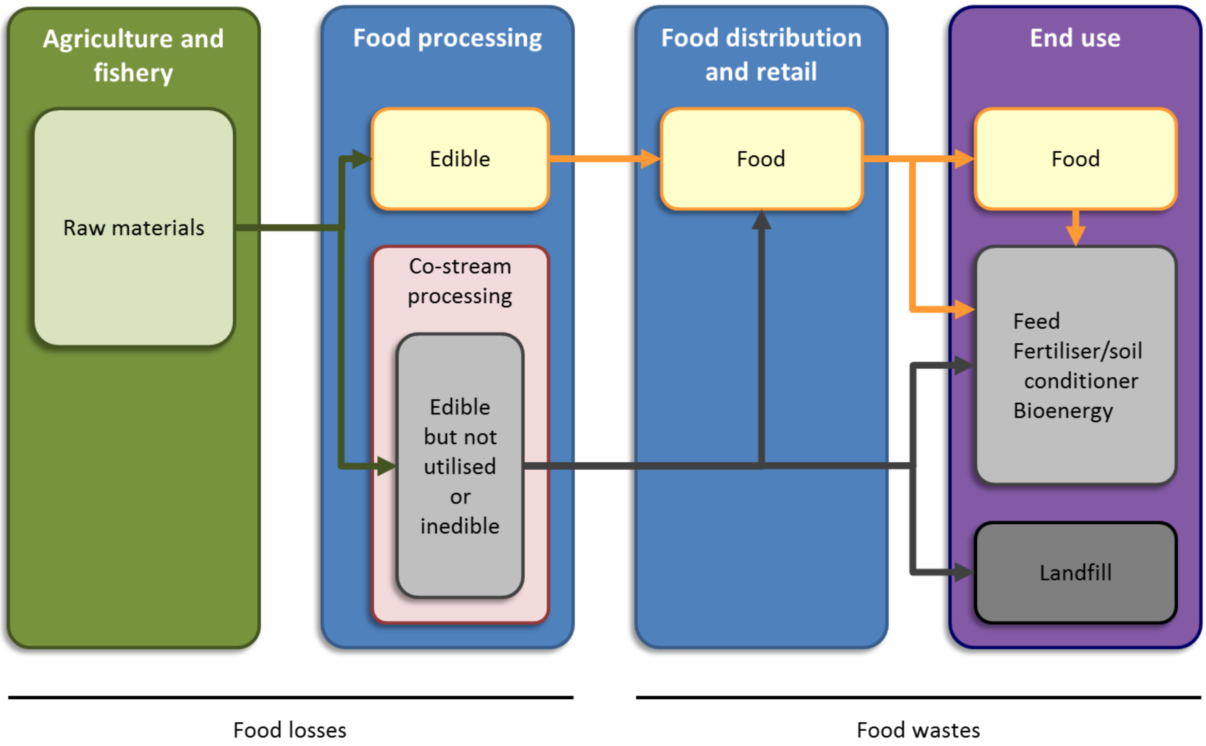

Figure 2. Flows of raw materials, food and co-streams from agricultural production and fishery via food processing industry, food distribution and retail to food consumption, and utilisation of co-streams for feed, bioenergy etc.

Novel processing techniques for food and feed applications have the potential to improve ***raw material utilisation***. Such methods include e.g. fermentation, enzymatic and chemical hydrolysis. We define partial ***raw material utilisation efficiencies*** as the total mass of produced food, feed or organic materials utilised in fertiliser and bioenergy production divided by the total input of raw materials at a processing plant. We also calculated the consumption of ***process water*** per tonne of food products.

2.2 Risks related to the use of co-streams

Food processing includes cleaning and gutting steps, which accumulate co-streams that may pose a risk for infecting the environment, soil, water, crops, natural plants, wild and domestic animals[2], and humans with disease or pests. For co-streams of animal origin, detailed regulations have been developed (e.g. DEFRA, 2014), whereas vegetable and potato co-streams are regulated by laws governing general feed hygiene and disposal of organic waste.

Certain animal co-streams pose a risk of infecting humans and animals with transmissible spongiform encephalopathies (TSE), also known as prion diseases. Thus, animal co-streams are divided into three risk categories (Regulation (EC) 1069/2009; Figure 3). **Category 1** materials comprise the highest risk, consisting of material that may be an agent for a prion disease. Examples of this group of materials are bovine brain and spinal cord. Category 1 materials must be disposed of by incineration. **Category 2** materials also comprise risks of infectious disease, and include e.g. fallen stock and digestive tract content. After ***pressure sterilisation*** (Chapter 4.2), Category 2 materials may be utilised as a substrate

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[2] Domestication refers to artificial selection by humans.

for anaerobic digestion, composting or rendering. Rendering converts animal fatty tissue into purified fats like lard or tallow (oleo-chemical products). **Category 3** materials comprise low-risk materials, including parts of animals that are not intended for human consumption, but technologically possess a hygienic quality that could allow for human consumption. Examples of Category 3 materials are bones, skin and feathers. Besides rendering, anaerobic digestion and incineration for bioenergy production, Category 3 materials may be processed by appropriate methods (e.g. hydrolysis) and used as feed, technical products or fertiliser. Appropriate processing methods and relevant processed materials of Category 3 origin are described in Chapter 4.2.2.

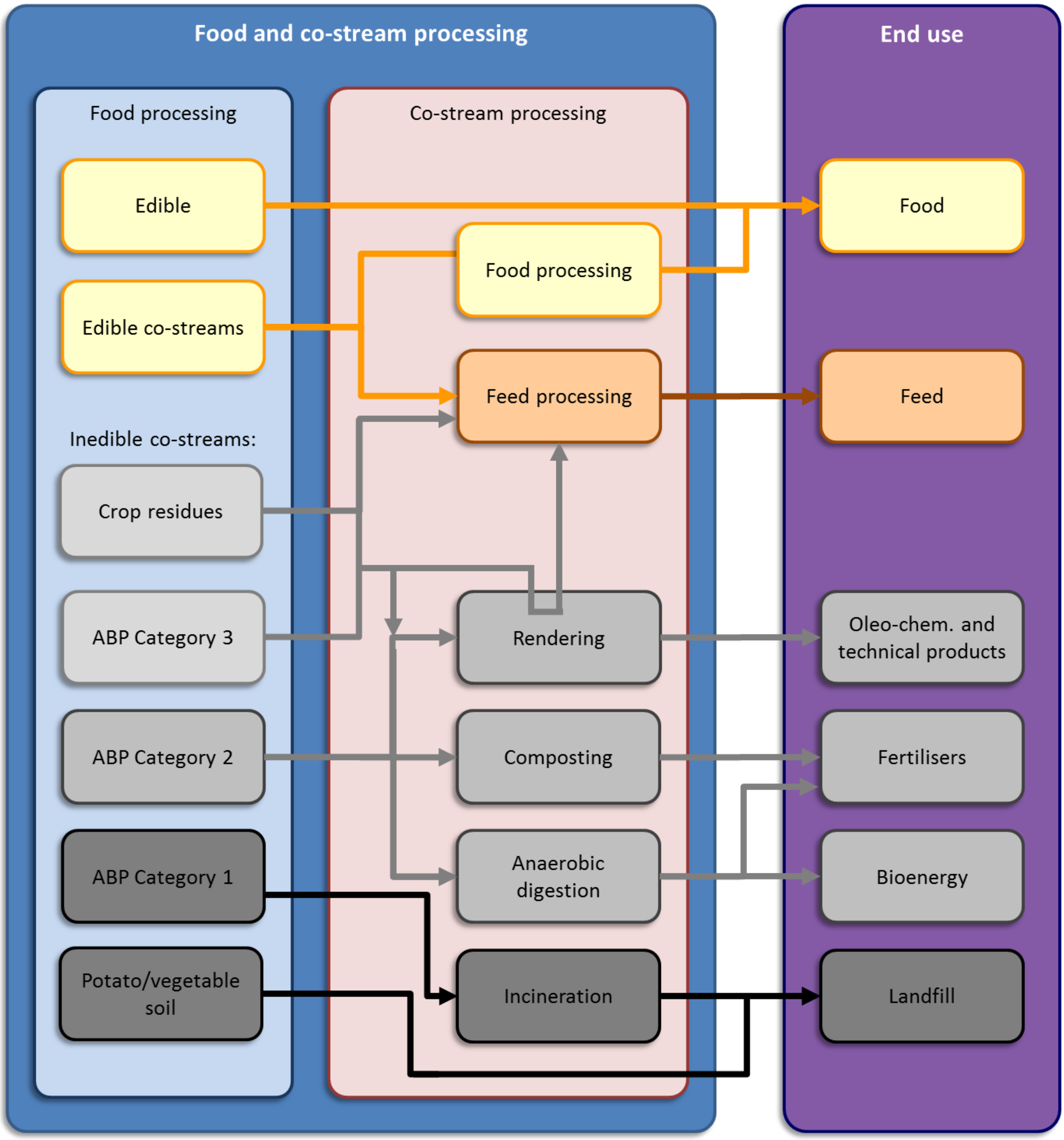


Figure 3. Main flows and utilisation of raw materials and co-streams (ABP: animal by-products).

Co-streams from processing of imported vegetables and potatoes may pose a risk for infecting soil or the environment with pest organisms not yet identified in Norway, e.g. Colorado beetles (*Leptinotarsa decemlineata*) and plant pathogenic bacteria such as *Clavibacter michiganensis* subsp. *sepedonicus*a and *Ralstonia solanacearum*. This is discussed further in Chapter 5.

Even domestic vegetable co-streams may be risk materials, because raw materials and soil are brought together from many different primary producers that may have soils infected by soil borne pathogens. Potato soil is considered a high-risk-material due to the risk of spreading pests such as potato cyst nematodes (*Globodera pallida, G. rostochiensis*), which have been found in a significant proportion of Norwegian agricultural land, hampering the use of such land for potatoes and other crops with intensive soil tillage for decades. Currently, soil and sludge from potato processing plants is disposed of as landfill, but the content of organic matter is often higher than is allowed in landfills according to waste regulations (maximum 10% total organic carbon or 20% ignition loss; SFT, 2008). Wet potato peel and waste products constitute a “hot spot” for microbial growth, and co-streams intended for use as food or feed have to be treated and stored appropriately.

2.3 Multiple case study

The present report is based on a multiple case study of food-processing plants in three food chains in Norway; five plants processing vegetables and potatoes, one plant processing white and pelagic fish, and one plant processing poultry. Produsentpakkeriet Trøndelag AS, Hvebergsmoen Potetpakkeri AS, Potetpartner AS, BAMA Lier and Findus Tønsberg represent ***vegetable and potato*** processing; Nergård Senja AS, Senjahopen represents ***white and pelagic fish*** processing; and Nortura Rakkestad/Norilia represents ***poultry*** processing (Figure 4). The information described here was gathered during a visit by several scientists participating in CYCLE in June 2013 and subsequent contact with company representatives. The data included input and output of organic materials, including raw materials, food and feed products, materials used for fertiliser and bioenergy production, and materials disposed of as landfill in 2012. Additionally, processing methods, qualitative description and temporal availability of co-streams, and consumption of process water were recorded. As a background for the empirical data, statistical information was collected regarding the total production and human consumption of relevant food products in Norway.

Science meets industry; Randi Seljåsen from Bioforsk discussing with general manager Elling Ødegaard at Hvebergsmoen Potetpakkeri AS, June 2013. (Photo: Bioforsk S. Adler)

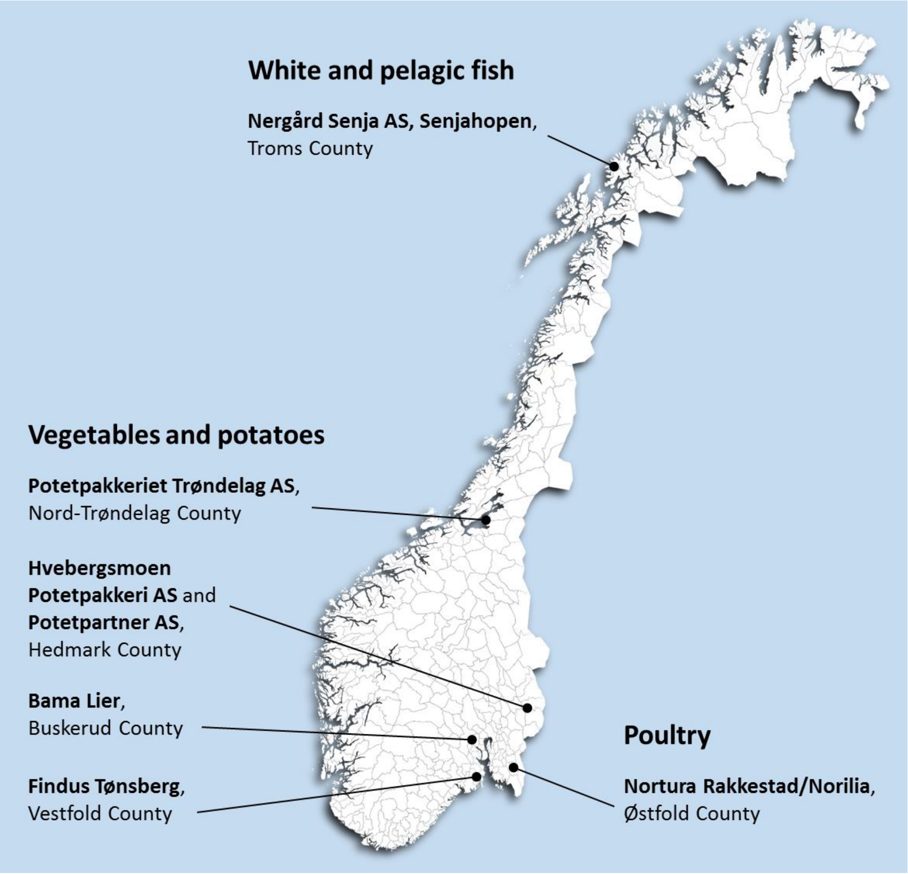


Figure 4. Locations of the cases of food processing plants presented in this report.

3. The flow of organic materials in three food chains

Below, the flow of raw materials, food products and co-streams is described for each case. The flow is illustrated by arrows where the arrow width is proportional to the flow in tonnes per year. The market share for each produce has been calculated, by dividing the reported food commodity production in each case by the total volumes on national level (wholesale). In addition to the flows of organic materials, we focus on the availability, qualities and properties of co-streams that may be used in production of feed, feed components, fertilisers and bioenergy.

3.1 Vegetables and potatoes

3.1.1 Production and consumption in Norway

In 2012, Norwegian farmers harvested 333,200 tonnes of potatoes; 45,677 tonnes of carrots and turnips; 36,860 tonnes of brassicas (cabbages, cauliflower, broccoli and others); 20,192 tonnes of leeks and onions; 14,896 tonnes of lettuce and chicory; 14,841 tonnes of cucumbers and 12,159 tonnes of tomatoes (FAOSTAT, 2014).

Carrot was the vegetable consumed in highest quanta per capita in Norway in 2012 (8.0 kg fresh weight), followed by tomato (7.0 kg), onion (5.3 kg) and cucumber (4.8 kg). The total amount of vegetables consumed per capita was 49.8 kg, amounting to 250,635 tonnes fresh weight in total, including 22,263 tonnes of lettuce (NFVMB, 2013). Consumption of fresh potatoes was 19.2 kg per capita (96.9 tonnes in total). The percentage of consumed products that were domestically produced were 78% for carrot, 78% for fresh potatoes, 65% for cucumber, 59% for onion, 50% for lettuce, 34% for tomato and 51% for vegetables and potatoes in total (NFVMB, 2013).

The volumes of produce handled at wholesale level in 2012 were 40,269 tonnes of carrots, 96,867 tonnes of fresh potatoes and 9,234 tonnes of sous-vide potatoes (vacuum packed before heat treatment). In total, 200,910 tonnes of domestic and 490,192 tonnes of imported vegetables, potatoes, fruits and berries were delivered to wholesalers in Norway in 2012. The profits from sales totalled 14,500 million NOK (NFVMB, 2013).

3.1.2 Case presentations

We visited five vegetable and potato processing plants:

Produsentpakkeriet Trøndelag AS is a sorting and packing facility for vegetables and potatoes in South Trøndelag and North Trøndelag Counties, established at Frosta in 2007. Produsentpakkeriet is a private limited company with about 140 shareholders, mainly potato and vegetable producers and receives 10,000 tonnes of potatoes, 1,500 tonnes of carrots and smaller quantities of other vegetables yearly. We estimated Produsentpakkeriet's market share in Norway as 6% for fresh potatoes and 2% for carrots.

Hvebergsmoen Potetpakkeri AS is a sorting and packing facility for potatoes owned by BAMA Trading. BAMA is a private Norwegian company processing and distributing fruit, vegetables, potatoes and flowers. BAMA was established in 1886 by C. Matthiessen, who was the first in Scandinavia to import bananas. This explains the name of the company – BAMA ("Banan-Matthiessen"). The estimated market share in Norway for fresh potatoes packed at Hvebergsmoen in Grinder (Hedmark County) is about 30%.

Potetpartner AS is owned by BAMA Industry and Columbus Eiendom and located at Hvebergsmoen in Grinder. Besides Potetpartner, at BAMA Industry potatoes are also processed in Moss (Østfold County) and Lier (Buskerud County). Potetpartner produces about 1/3 of the processed potatoes at BAMA (calculated by product value). Potetpartner produces sous-vide potato products from potatoes purchased from Hvebergsmoen Potetpakkeri and imported from BAMA Trading (Denmark). The estimated market share of Potetpartner for sous-vide potatoes in Norway is 22% (for BAMA Industry in total about 60%).

BAMA Lier is owned by BAMA (92.1%) and Gartnerhallen SA (7.9%). Gartnerhallen SA is the largest horticultural producer cooperative in Norway, with an annual turnover of 1,700 million NOK. BAMA has its headquarters and central packaging plant in Lier. In this plant, lettuce, vegetables, fruit and potatoes are processed and packed for retail stores and commercial kitchens. BAMA Lier produces for distribution to retailers (43%), caterers and institutional kitchens (57%). They have a rapid turnover system, which ensures a product ordered before 10:00 am will be in the grocery shops the day after. The estimated market share in Norway is 17% for lettuce, 1% for vegetables and 2% for fresh potatoes.

Findus Norge AS has processing plants in Larvik (Vestfold County), Tønsberg (Vestfold County), Lier and Ullensvang (Hordaland County). In **Tønsberg**, Findus processes potatoes (potato chips; Norwegian pommes frites) and frozen mixed vegetables. The estimated market share for both potato chips and frozen vegetables in Norway is 75%.

3.1.3 Raw materials, food commodities and co-streams

3.1.3.1 Produsentpakkeriet Trøndelag AS

Produsentpakkeriet sorts and packs potatoes and carrots almost the whole year round, from 20th June to 20th May for potatoes and 20th July to 1st June for carrots (Figure 5). Raw materials are stored at the producers' farms until delivery. Soil is removed mechanically (potatoes) or washed off (carrot and potato). Potatoes over 65 mm in diameter are removed. Potatoes, which do not fulfil the visual quality requirements of fresh food potatoes are detected by optical sensors or manually, and removed. Potatoes, which fulfil the requirements of food quality, but cannot be sold as fresh potatoes due to inadequate size or mechanical damage are sold to the potato processing industry (HOFF AS, Gjøvik, Oppland County) or given away as feed for cattle. Carrot grading is done mechanically by sorting lines where the diameter and length of carrots are used to sort them into size categories. In addition, there is a manual inspection of the belts to remove carrots with damage and decay. Of 10,000 tonnes potatoes per year, more than 50% are packed as fresh potatoes and 40% for industrial processing. Annually, 600 tonnes of residual potato soil is collected. Of 1,500 tonnes carrots per year, 60% are packed as fresh carrots and 33% for industrial processing. Annually, 200 tonnes of residual carrot soil is collected. Other vegetables like swedes and leeks are sorted, processed and packed for distribution in separate production lines.

Manager Thor-Eirik Albrektsen presents the activities at Produsentpakkeriet Trøndelag AS for the scientists from the CYCLE project, June 2013. (Photo: Bioforsk S. Adler)

Potatoes and carrots before washing and grading at Produsentpakkeriet Trøndelag AS, June 2013. (Photos: Bioforsk S. Adler)

Potatoes and carrots with inadequate size or mechanical damage give a poor return under the current utilisation, and ideas for utilising them as products that could generate more revenue was a topic that was much discussed during our visit. Rotten vegetables are treated as organic matter and sorted out for disposal with the soil residues. Potato soil is partly treated as dry soil in containers, and partly as sediment in outdoor tanks for sedimentation of washing water. Dry soil contains soil, stones and plant material (small potatoes), whereas the sediment contains soil, organic matter (e.g. carrot peel) and water. Due to the risk of spreading potato cyst nematodes, all residual soil and sediments from the plant are disposed of as landfill for 30 years in an area with restricted access. Since the current landfill will soon be filled up and deposition costs are high, Potetpakkeriet is working hard to find a more sustainable utilisation of the residual soil. About 100,000 tonnes of process water were consumed in 2012.

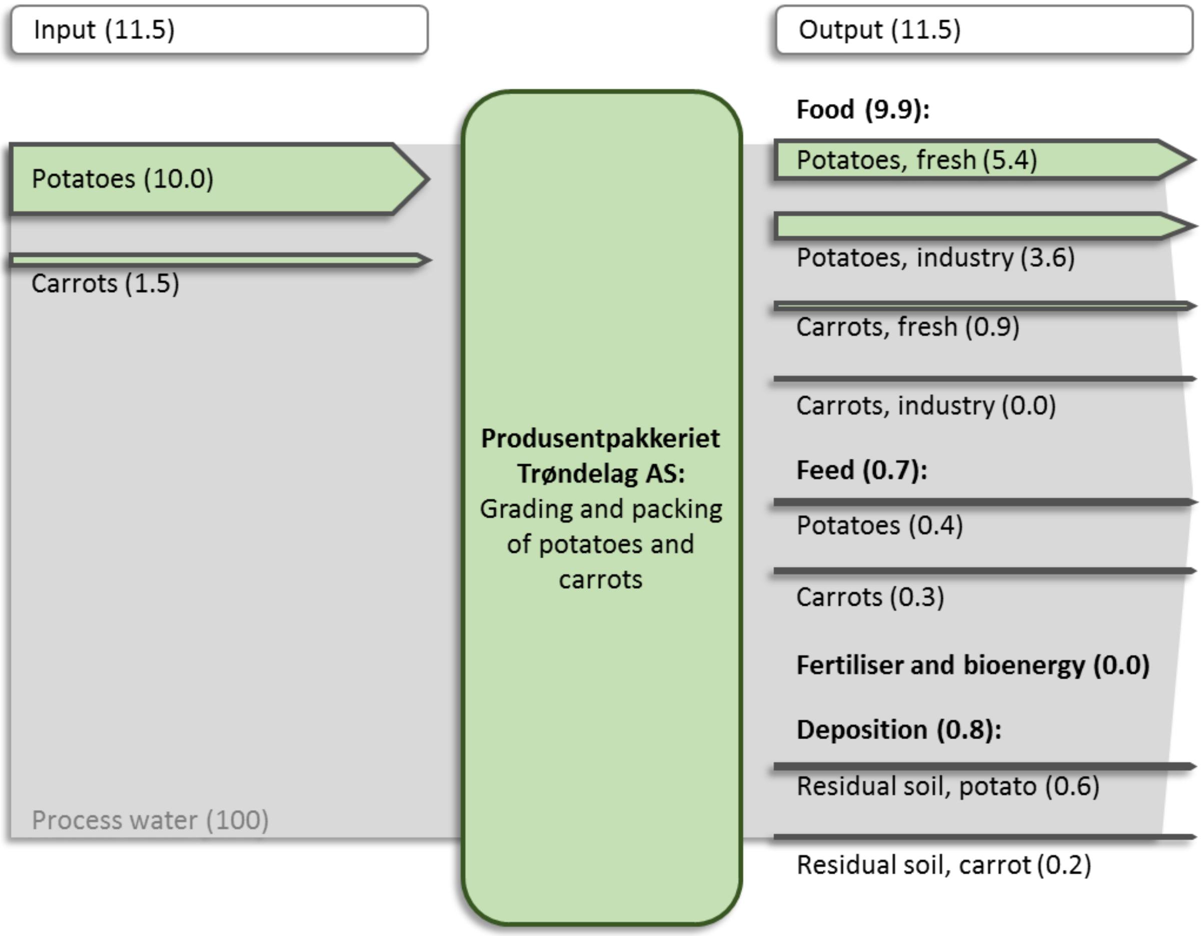


Figure 5. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width corresponds to the annual flow) at Produsentpakkeriet Trøndelag AS in 2012.

Machinery for carrot washing at Produsentpakkeriet Trøndelag AS, June 2013. (Photo: Bioforsk S. Adler)

Soil with a large proportion of organic material at Produsentpakkeriet Trøndelag AS, June 2013. (Photo: Bioforsk S. Adler)

Deposition of potato residual soil at Frosta municipality, June 2013. (Photos: SINTEF E. Bar and Bioforsk S. Adler)

3.1.3.2 Hvebergsmoen Potetpakkeri AS

Hvebergsmoen Potetpakkeri AS received about 40,000 tonnes of potatoes in 2012 (Figure 6). The main product is fresh potatoes for wholesale distribution and commercial kitchens (28,000 tonnes/year). Optical sensors (Newtec A/S, Odense, Denmark) are used to detect surface defects in the peel and decay or cracks on the tubers. Faultless potatoes of 42 to 65 mm are sold as food potatoes whereof about 90% are washed before packing. Food size potatoes with visual quality issues (3,700 tonnes) are sold to Potetpartner for further processing (next section). Potatoes smaller than 42 mm or bigger than 65 mm are sold to the food processing industry (starch, alcohol etc.) or as feed. About 1,900 tonnes of dry soil residues and 100 tonnes of sediments are disposed of as landfill, as described for Produsentpakkeriet. The use of process water was about halved after 2012, when a water cleaning plant, separating organic matter and soil, was put into operation. In 2012, about 23,000 tonnes of process water were used.

Hvebergsmoen Potetpakkeri AS, June 2013. (Photo: SINTEF E. Bar)

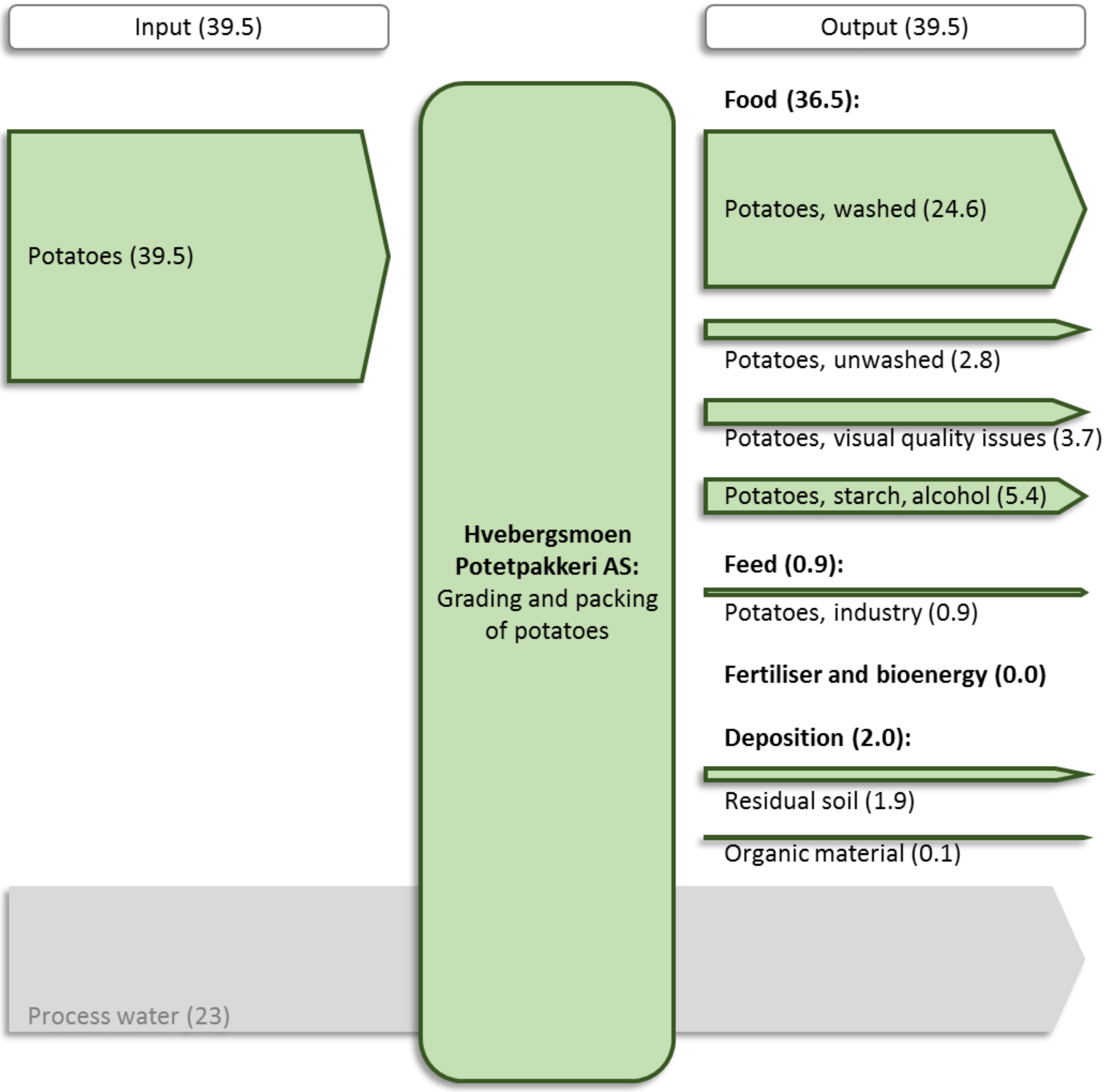


Figure 6. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width corresponds to the annual flow) at Hvebergsmoen Potetpakkeri AS in 2012.

Optical sensors are used to detect surface defects in potatoes. Potatoes of a size within 42 to 65 mm and acceptable visual quality are sold as fresh food potatoes. Potatoes of other sizes are sold to the food processing industry. Hvebergsmoen Potetpakkeri AS, June 2013. (Photo: Bioforsk S. Adler, SINTEF E. Bar)

Potato residual soil with organic material (left). Separation of organic material from process water allows recycling of water (right) at Hvebergsmoen Potetpakkeri AS, and significantly reduces the water consumption, June 2013. (Photos: SINTEF E. Bar, Bioforsk S. Adler)

3.1.3.3 Potetpartner AS

Potetpartner AS is a potato processing company located in the same site as Hvebergsmoen Potetpakkeri AS. In 2012 they processed approximately 3,000 tonnes of potatoes with visual quality issues in the peel (e.g. common scab; Norwegian: skurv). This defect does not reduce the product quality after peeling, but restricts the use as fresh potatoes. Potetpartner AS buys most of their raw material from Hvebergsmoen Potetpakkeri AS, but in 2012 they also imported approximately 400 tonnes from BAMA Trading Denmark (Figure 7). The potatoes are first peeled by a carborundum peeler, then washed and subsequently peeled two times with knife peelers. Peeled potatoes are sorted optically into three categories: 1) potatoes ready for further processing, 2) potatoes to be peeled once more and 3) feed potatoes (including potatoes with green colour). Potatoes ready for processing are graded into four categories, packed and sous-vide cooked; possibly with other recipe ingredients such as cream and seasoning. In addition, small amounts of other potato-based commodities are produced. Potato washing water contains starch, which is separated by centrifugation and mixed with discarded potatoes and given away as feed. The annual amount of dry starch produced is 200 to 300 tonnes. Annually, about 22,000 tonnes of process water is used.

Potato starch is a co-stream in the production of sous-vide potatoes at Potetpartner AS, June 2013. (Photos: Bioforsk S. Adler)

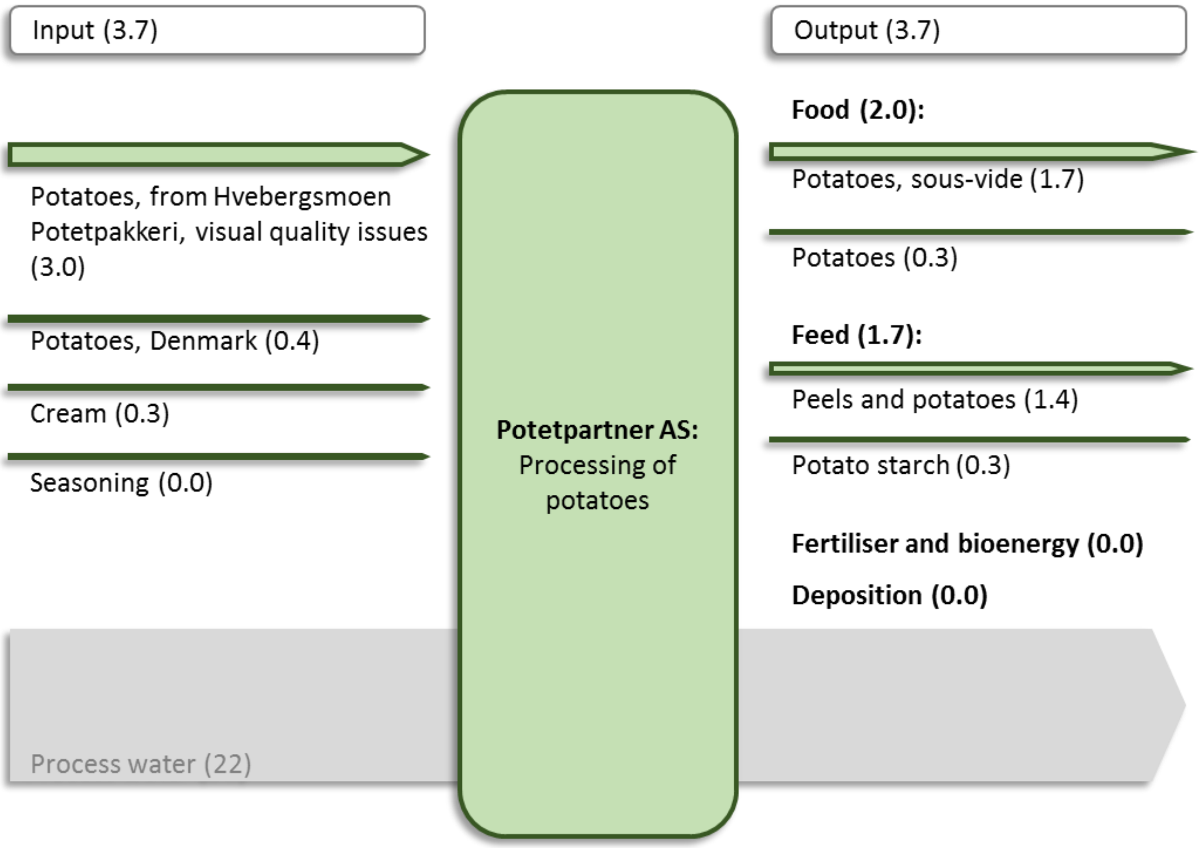


Figure 7. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width corresponds to the annual flow) at Potetpartner AS in 2012.

Plant manager Lars Olav Rojd describes the different stages in processing sous-vide potatoes at Potetpartner AS, June 2013. (Photos: Bioforsk S. Adler)

3.1.3.4BAMA Lier

BAMA Lier has grading and packing lines for lettuce, baby leaf, other leafy vegetables, root vegetables, potatoes and fruits (Figure 8). The plant purchases over 70 different raw materials adding up to 11,600 tonnes per year. The production processes are mostly automated including receiving raw materials, removing stems etc., shredding, cutting, repeated washing procedures, drying and packing. They have equipment for modified atmosphere packaging, by replacing O_2 with N_2, in order to improve the shelf life.

At BAMA Lier, left-over raw materials are transported free of charge to a dairy farmer who uses raw vegetables as feed. A small share of products has to be thrown away (not separated into organic and packing material) due to restricted shelf life if sales are lower than expected. The washing process is performed in two steps, in the first step recycled water is used and in the second step fresh water is used. About 130,000 tonnes of process water were consumed in 2012.

Preparation of lettuce mix and red pepper at BAMA Lier, June 2013. (Photos: SINTEF E. Bar, VTT M. Vikman)

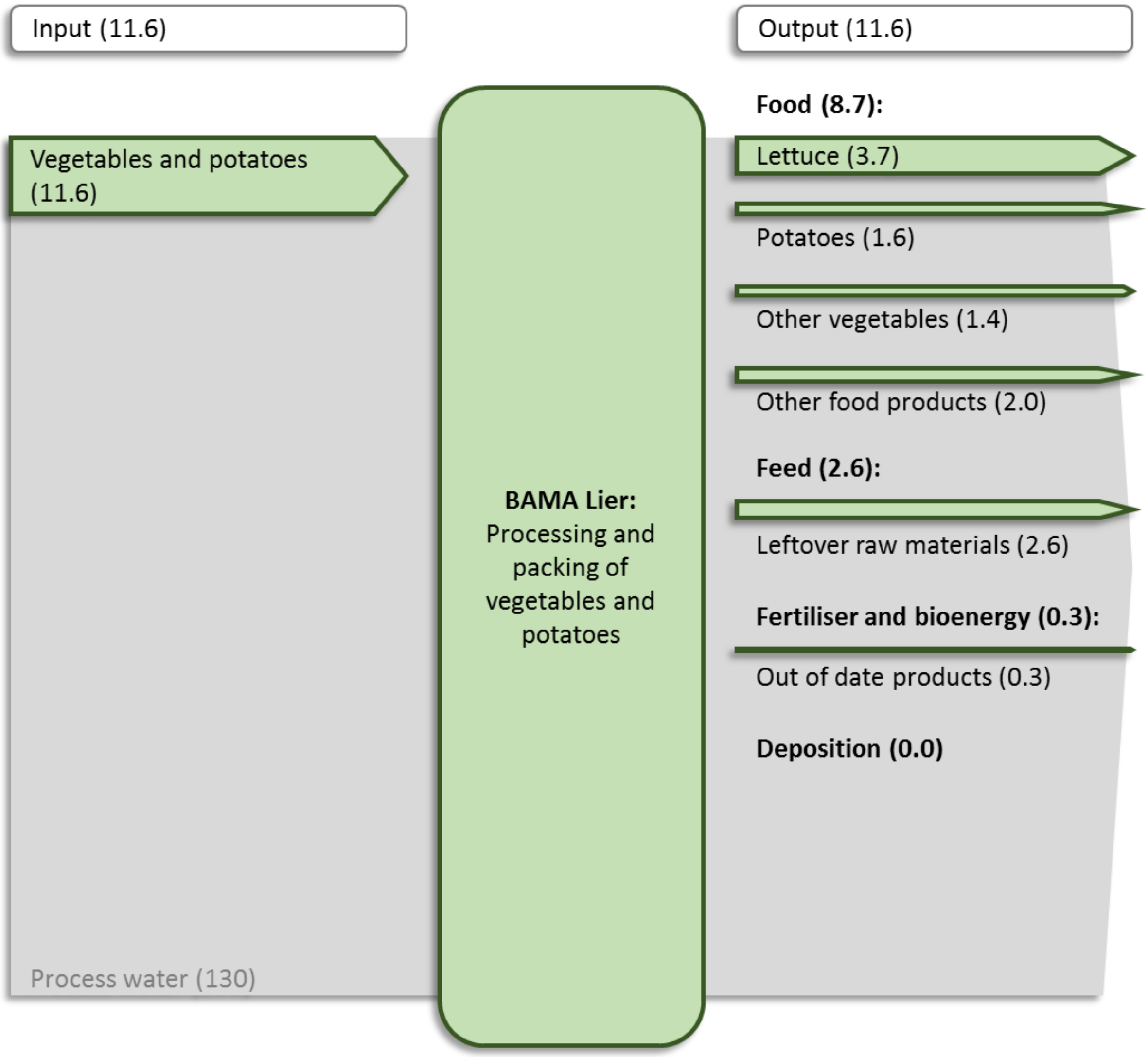


Figure 8. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width corresponds to the annual flow) at BAMA Lier in 2012.

3.1.3.5 Findus Tønsberg

Findus division Tønsberg has processing lines for potatoes and vegetables such as carrots, swedes, parsnips, peas and beans and produces a variety of frozen food products (Figure 9). The production process is highly automated. The potatoes are peeled with hot water steam and cut in pieces, and the pieces are then washed. Starch dissolved in the washing water is separated by centrifugation and sold for alcohol production. Potato pieces with defects are located with optical sensors and automatically removed. For production of chips, the potatoes are blanched and dried before frying process in rapeseed oil. Finally, the potato chips are frozen and packed. Findus Tønsberg has one packing line for potato chips and three packing lines for frozen vegetables. Yearly, 27.5 thousand tonnes of different potato and vegetables food commodities are produced. About 4,400 tonnes of potato peel (about 10% of potato weight) and 7,400 tonnes other feedstuff from vegetables are sold every year as feed. Potato peel is collected in tanks, supplied with enzymes to liquefy the starch and delivered to a pig farm, as feed. About 1,000 tonnes of organic material for composting is produced. Potato residual soil (2,300 tonnes/year) is disposed of as landfill. About 417,000 tonnes of process water were consumed in 2012.

Potato chips are fried in rapeseed oil at Findus Tønsberg, June 2013. (Photo E. Bar)

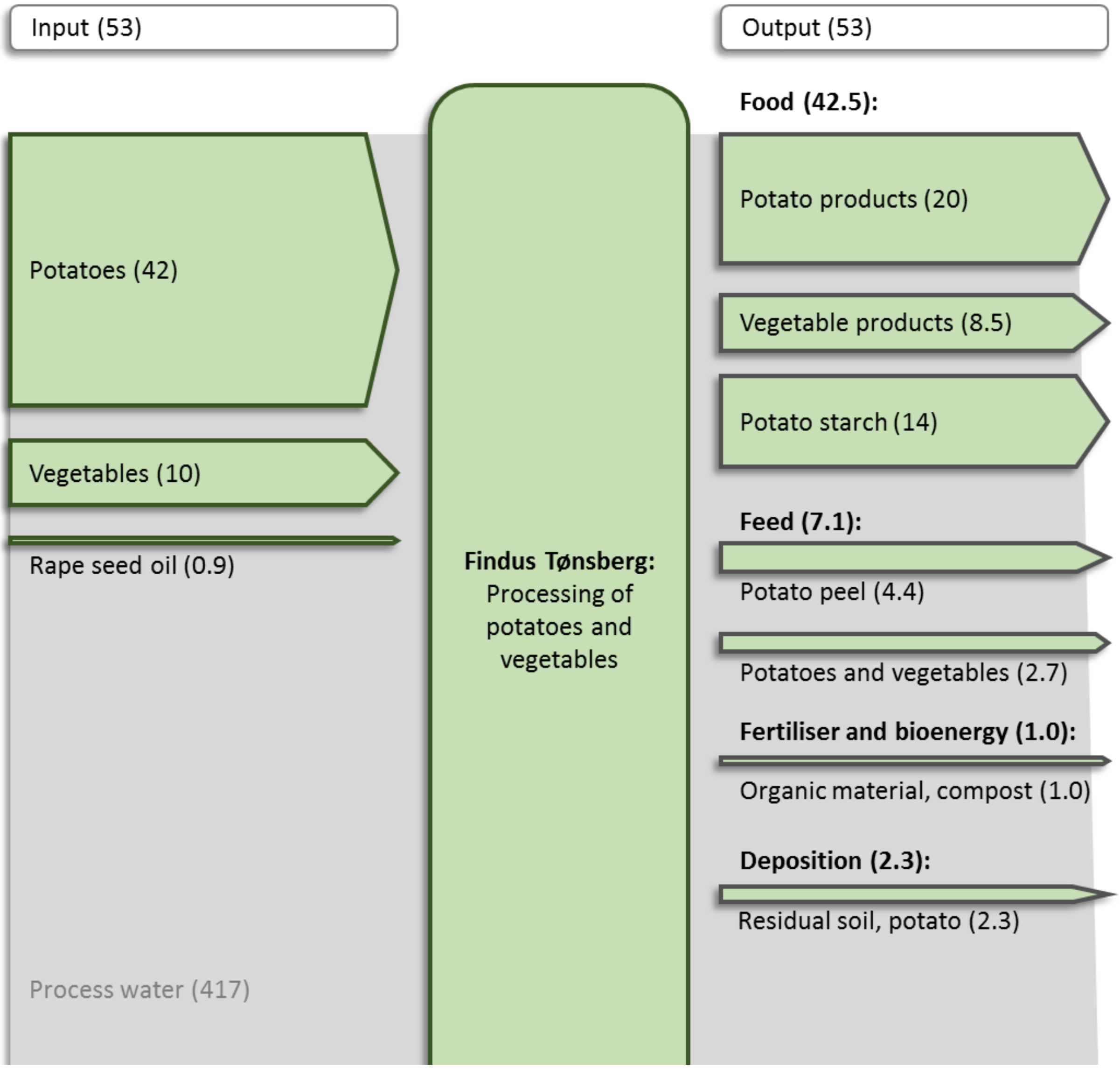


Figure 9. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width corresponds to the annual flow) at Findus Tønsberg in 2013.

Product fractions that are sorted out to be sold as feed. Findus Tønsberg, June 2013. (Photos: SINTEF E. Bar)

3.2 White and pelagic fish

White fish refers to sea fish living mainly on or near the seabed in contrast to ***pelagic fish*** living in the water column away from the sea floor. White fish also refers to fish with white and dry meat; white fish store oils in the liver rather than in their gut, and therefore white fish can be gutted on board of the ship. In contrast, pelagic fish store oils in their tissues and in the belly cavity around the gut. Important white fish species caught in the North Atlantic Ocean are cod (*Gadus morhua*, Norwegian: torsk), haddock (*Melanogrammus aeglefinus*, hyse), saithe (*Pollachius virens*, sei), Atlantic pollock (*Pollachius pollachius*, lyr), common ling (*Molva molva*, lange), silver hake (*Merluccius bilinearis*, hvitting), tusk (*Brosme brosme*, brosme), Greenland halibut (*Reinhardtius hippoglossoides*, blåkveite), and angler (*Lophius piscatorius*, breiflabb). Important pelagic fish species are Atlantic herring (*Clupea harengus*, sild), Atlantic mackerel (*Scomber scombrus*, makrell), capelin (*Mallotus villosus*, lodde), European sprat (*Sprattus sprattus*, brisling) and blue whiting (*Micromesistius poutassou*, kolmule).

3.2.1 Catch and consumption in Norway

In 2012, Norwegian vessels landed 2.1 million tonnes sea fish, shrimps, shellfish and shells from the Norwegian Atlantic Ocean, with a total market value of 14,100 million NOK. Of that, white fish accounted to 0.8 million tonnes and pelagic fish accounted to 1.2 million tonnes (NMFCA, 2013; Olafsen et al., 2013; SSB, 2014, preliminary data). In addition, 0.3 million tonnes fish and shellfish were caught by foreign vessels. Of the total catch by Norwegian vessels, 81% was sold for consumption and 19% for fishmeal and oil production. The predominant white and pelagic fish species caught by Norwegian vessels in 2012 were Atlantic herring (31%), cod (18%), capelin (13%), saithe (9%), Atlantic mackerel (9%), haddock (8%) and blue whiting (6%) (SSB, 2014). In 2012, Norway exported 2.4 million tonnes of fish, shrimps, shellfish and shells, including 1.1 million tonnes of farmed salmon and trout (SSB, 2014). The largest importer was Russia (13%); 64% of the caught Atlantic herring and 47% of the cod was exported (SSB, 2014).

In Norway, the consumption per capita was 22.2 kg for white fish and 4.3 kg for pelagic fish 2009 (FAOSTAT, 2014). In Finland, the per capita consumption of sea fish was lower than in Norway and with opposite proportions: white fish (2.7 kg) and pelagic fish (16.4 kg) (FAOSTAT, 2014). The per capita consumption of freshwater fish was 15.3 kg in Norway and 13.7 kg in Finland (FAOSTAT, 2014).

In 2012, available co-streams of white fish processing accounted to 325.000 tonnes and co-streams of pelagic fish processing accounted to 239.000 tonnes (Olafsen et al., 2013). The relatively low amount of co-streams from pelagic fish is because a large proportion is sold round, whereas a large proportion of white fish is filleted. About 98% of co-streams from pelagic fish were utilised, but only 38% from white fish. Co-streams from cod such as liver, roe, stomach, head, swim bladder, skin, milt, cheeks and tongue (Nybø, 2004; NSEC, 2011) are used for human consumption or other production of value-added products such as ingredients for health products, "functional food", pharmaceuticals or cosmetics (Olsen, 2001). According to Nybø (2004), markets for cod heads are found in the Republic of Korea, China, Hong Kong, Singapore, Taiwan and Nigeria when cleaned from blood and with gills removed. These additional operations are costly and reduce export possibilities. Swim bladder is a product of interest in Portugal and Asian countries. Roe is a popular product in the Norwegian market. Liver can be sold frozen or canned, or it can be used for production of liver oil (Olsen, 2001). Stomach, roe and milt have markets in Asian countries. However, these products must also comply with special requirements: co-streams must be obtained from large fish, separated from other visceral parts, washed, dried or prepared and packed in certain ways. All these requirements complicate selling. The backbones, which make up to 15% of fish (Gildberg et al., 2002), are currently not a product of interest for producers or sellers (Nybø, 2004). However, muscle removed from bones after splitting of cod can be salted and sold (Olsen, 2001). Bones, after solubilisation of remaining muscle proteins, can be used as starting material for recovery of gelatine and calcium (Gildberg et al., 2002). Enzymatically hydrolysed co-streams like viscera, bones and cut-off are used in the production of fish feed, fish silage (feed) and sauces for human consumption (Olsen, 2001). White fish heads (36% of co-stream mass) and bones (19%) comprise large volumes that are poorly utilised today, and have therefor potential for development of processing techniques.

3.2.2 Case presentation: Nergård Senja AS, Senjahopen

The business activities of the fishery group Nergård includes catching, processing and sales. Nergård has five fishing vessels and is the second-largest sea fish company in Northern Norway (Nergård, 2012). The Nergård-owned company Nergård Senja AS has three factories in Troms County: Gryllefjord, Senjahopen and Grunnfarnes. During the CYCLE tour, the plant in Senjahopen was visited.

Representatives of Nergård Senja AS guide scientists from the CYCLE project at the processing plant at Senjahopen, June 2013. (Photo: SINTEF E. Bar)

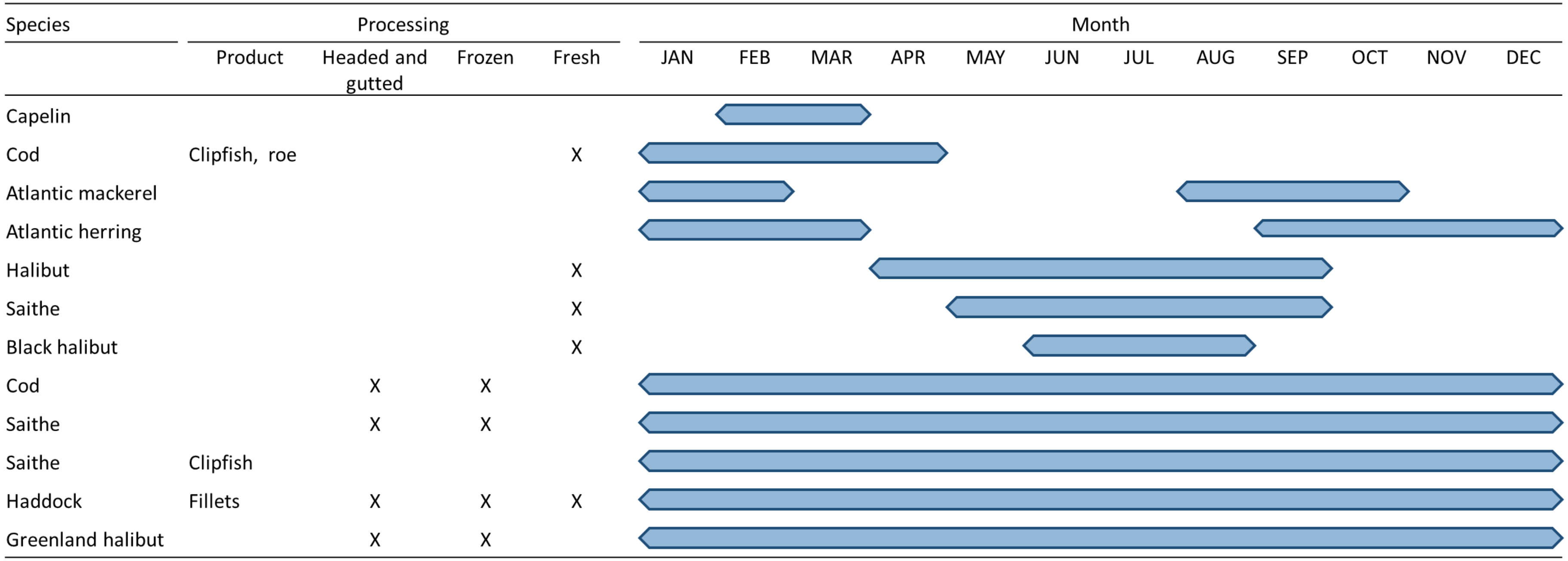
3.2.3 Raw materials, food commodities and co-streams

Atlantic herring was the dominant raw material at Nergård's processing plants in 2012, accounting to almost 100,000 tonnes, whereas other fish species amounted to 61,000 tonnes (Nergård, 2012). The season for catching Atlantic herring is September to March and it is sold round, as filets or flaps (Figure 10). The season for catching capelin is February to March and it is sold round, graded or ungraded. Atlantic mackerel has two catching seasons, August to October and January to February, and it is sold round. At Nergård, pelagic fish amounted to 78% of the total catch in 2012. In contrast to pelagic fish, white fish is headed and gutted on the vessels and the catching season for cod, saithe and haddock is all year round. However, cod for the fresh fish market is mainly caught in January to April, and saithe in May to September. Salt fish and dried salted fish (clipfish) are produced from cod and saithe. Stockfish is dried outdoors and mainly produced from cod, saithe and haddock. Frozen fillets are produced from haddock, while Greenland halibut is eviscerated and frozen round. In addition, sugar salted or frozen roe is produced from cod. Owing to the fact that about 70% of the caught sea fish is exported we have not estimated the market share for sales in Norway. Cod is economically one of the most important species and Nergård processed over 20,000 tonnes in 2012.

In 2012, Nergård's factory at Senjahopen received about 26,700 tonnes of Atlantic herring, 7,300 tonnes of capelin, 6,800 tonnes cod and about 2,000 tonnes of other fish (Figure 11). Most of the cod heads are dried and sold to Africa. Remaining heads are cut, mixed with other co-streams, block frozen and sent to Finland as feed for fur-bearing animals. Roe and milt are separated from other viscera. Viscera are preserved with acetic acid in preservation tanks and sold to a fishmeal and fish oil factory in Bodø (Nordland County).

For production of silage co-streams including by-catch, backbones, skin, viscera and heads are preserved with formic acid. Annually, about 200,000 tonnes of process water, both seawater and fresh water, are used.

Fish viscera are collected at Nergård Senja AS, Senjahopen, June 2013. (Photo: Bioforsk S. Adler)



Species	Processing				Month											
	Product	Headed and gutted	Frozen	Fresh	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Capelin						▬	▬									
Cod	Clipfish, roe			X	▬	▬	▬	▬								
Atlantic mackerel					▬	▬						▬	▬	▬		
Atlantic herring					▬	▬	▬						▬	▬	▬	▬
Halibut				X				▬	▬	▬	▬	▬	▬			
Saithe				X					▬	▬	▬	▬	▬			
Black halibut				X						▬	▬	▬				
Cod		X	X		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Saithe		X	X		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Saithe	Clipfish				▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Haddock	Fillets	X	X	X	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
Greenland halibut		X	X		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬

Figure 10. Seasonal distribution of catch of different fish species and processing of fish products at Nergård fishery group (Nergård, 2012).

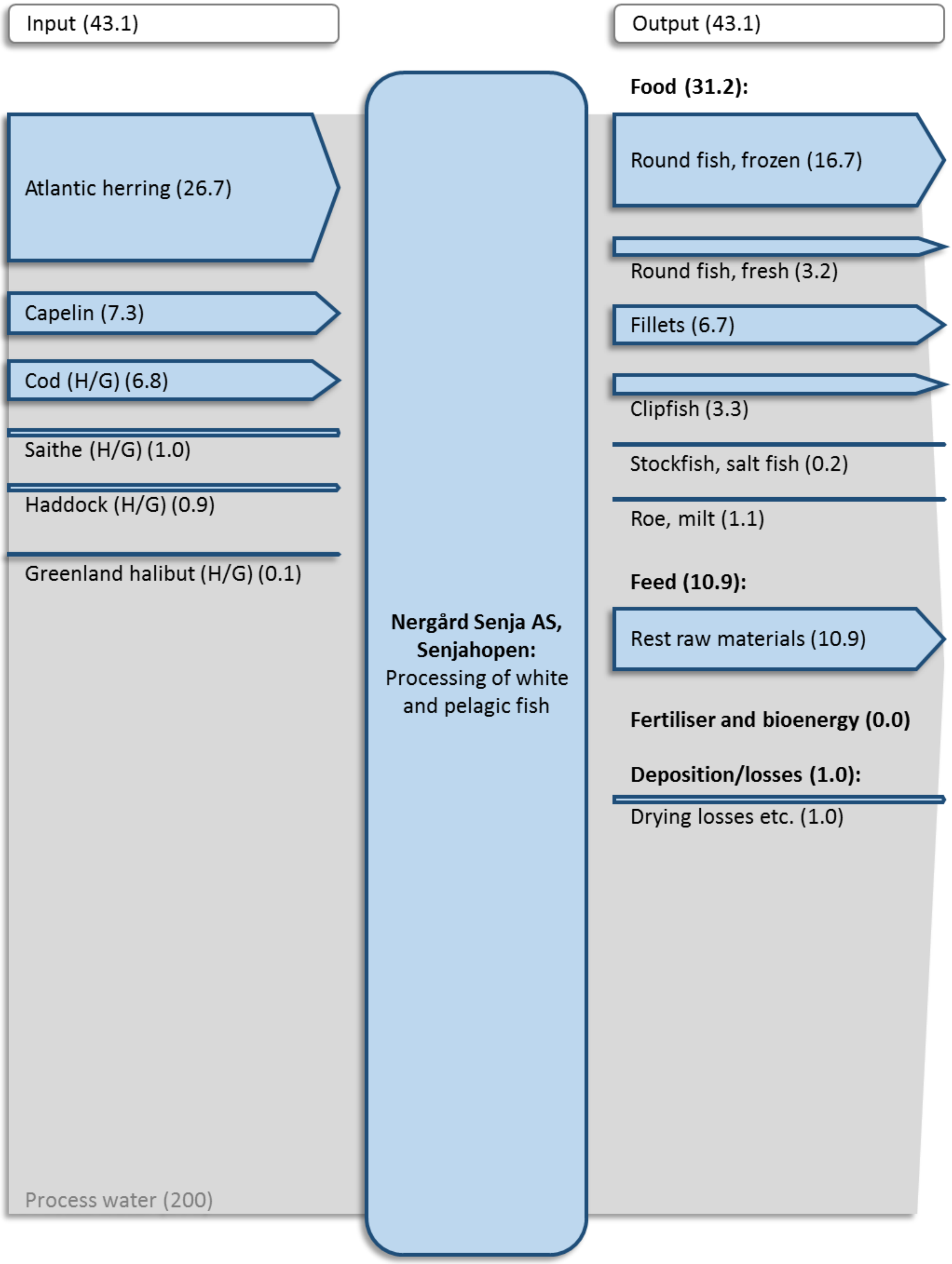


Figure 11. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width is proportional to the flow) at Nergård Senja AS, Senjahopen in 2012.

Heads of Greenland halibut (*Reinhardtius hippoglossoides*; Norwegian: blåkveite), June 2013. (Photo: Bioforsk S. Adler)

Clipfish and left-overs from clipfish production, June 2013. (Photo: Bioforsk S. Adler)

3.3 Poultry

3.3.1 Production and consumption in Norway

In 2009, intake of meat per capita was lower in Norway (66.0 kg), than in Finland (74.8 kg), Sweden (80.2 kg) and Denmark (95.2 kg) (FAOSTAT, 2014). Compared to the Nordic countries, India had an extremely low intake (4.4 kg) and USA a very high per capita intake of meat (120.2 kg). The Norwegian meat consumption has increased steadily since 1945; and was 54 kg in 1990. In Norway, pork accounted for 35% of the meat intake in 2009, followed by bovine meat (30%), poultry meat (26%), sheep and goat meat (8%) and other meat including wild animals and reindeer (2%). The productions of poultry meat and pork have increased significantly during the last decades, whereas the production of meat from other animals has been more or less stable (SSB, 2014). Thus, the amounts of co-streams from the poultry processing industry have increased correspondingly. In 2012, the consumption of poultry meat was higher than the consumption of bovine meat (SSB, 2014). Total meat production (slaughtered carcass) was 324,155 tonnes in Norway in 2012; pork 131,559 tonnes, poultry meat 91,156 tonnes, bovine meat 77,982 tonnes, sheep meat 22,777 tonnes and other meat 681 tonnes (SSB, 2014). Furthermore, 62,535 tonnes of eggs were produced in Norway in 2012. In 2009, per capita consumption of eggs was 11.0 kg in Norway (FAOSTAT, 2014).

3.3.2 *Case presentation: Nortura Rakkestad*

Nortura SA is a cooperative owned by more than 18,000 farmers and holds a market share of about 65% of poultry meat in Norway. We visited Nortura Rakkestad and Nortura Hærland, both in Østfold County. The poultry slaughterhouse in Rakkestad will close down during 2014, and their activities will be moved to the processing plant in Hærland. Norilia is a company 100% owned by Nortura SA, to manufacture and process co-streams from Nortura slaughterhouses. Poultry is slaughtered in Rakkestad and meat is processed as a variety of products. Fresh and frozen products are sold to grocery stores and commercial kitchens. About 40% of the poultry meat produced by Nortura is slaughtered and processed in Rakkestad/Hærland, and the remaining part in Elverum (Hedmark County) and Hå (Rogaland County). Nortura Rakkestad has an estimated market share in Norway of 24% in poultry meat and 19% in fresh eggs.

3.3.3 *Raw materials, food commodities and co-streams*

Nortura Rakkestad slaughters and processes 25,600 tonnes of chicken and 8,600 tonnes of turkey (Figure 12). Food commodities include a variety of raw, roasted and frozen fillets, pickled fillets, meat for salads, chicken drumsticks and other products.

Mechanical deboning of meat increases the raw material utilisation at Nortura Rakkestad. Mechanically deboned meat is used in a variety of meat products such as sausages. Co-streams from this technological process include bones, tendons, cartilages and muscles. Norilia is responsible for utilisation of co-streams from Nortura and sells amongst other thingss feedstuffs for fur-bearing animals and pets. Proteins as well as lipids could be separated by hydrolysis, but this is not performed today. For bones and cartilages new products need to be developed. Annually, almost 2,000 tonnes of feathers and 1,000 tonnes of poultry blood are produced at Rakkestad (Figure 13). Today, feathers are mixed with blood and viscera, frozen and sold as feed for fur-bearing animals.

Heads, necks and feet amount to ca 3,500 tonnes and about 500 tonnes of skin may be collected from neck and feet per year. The total amount of skin is higher, because a small share of the products sold include skin. Annually, 4,100 tonnes of viscera may be collected, intestines constitute about half of that amount and other organs such as gizzard, heart and liver constitute the other half. About 1,000 tonnes of organic material is utilised for bioenergy production. Annually, about 170,000 tonnes of process water are used.

Chicken viscera and chicken hearts are collected in containers at Nortura Rakkestad, June 2013. (Photos VTT M. Vikman)

A representative of Nortura Hærland presents equipment for mechanical deboning of meat, June 2013. (Photos Bioforsk A.-K. Løes)

Mechanically deboned meat is used in food applications (left photo) and leftovers after the process are frozen and fed to fur-bearing animals (right photo), Nortura Hærland, June 2013. (Photos VTT M. Vikman, Bioforsk A.-K. Løes)

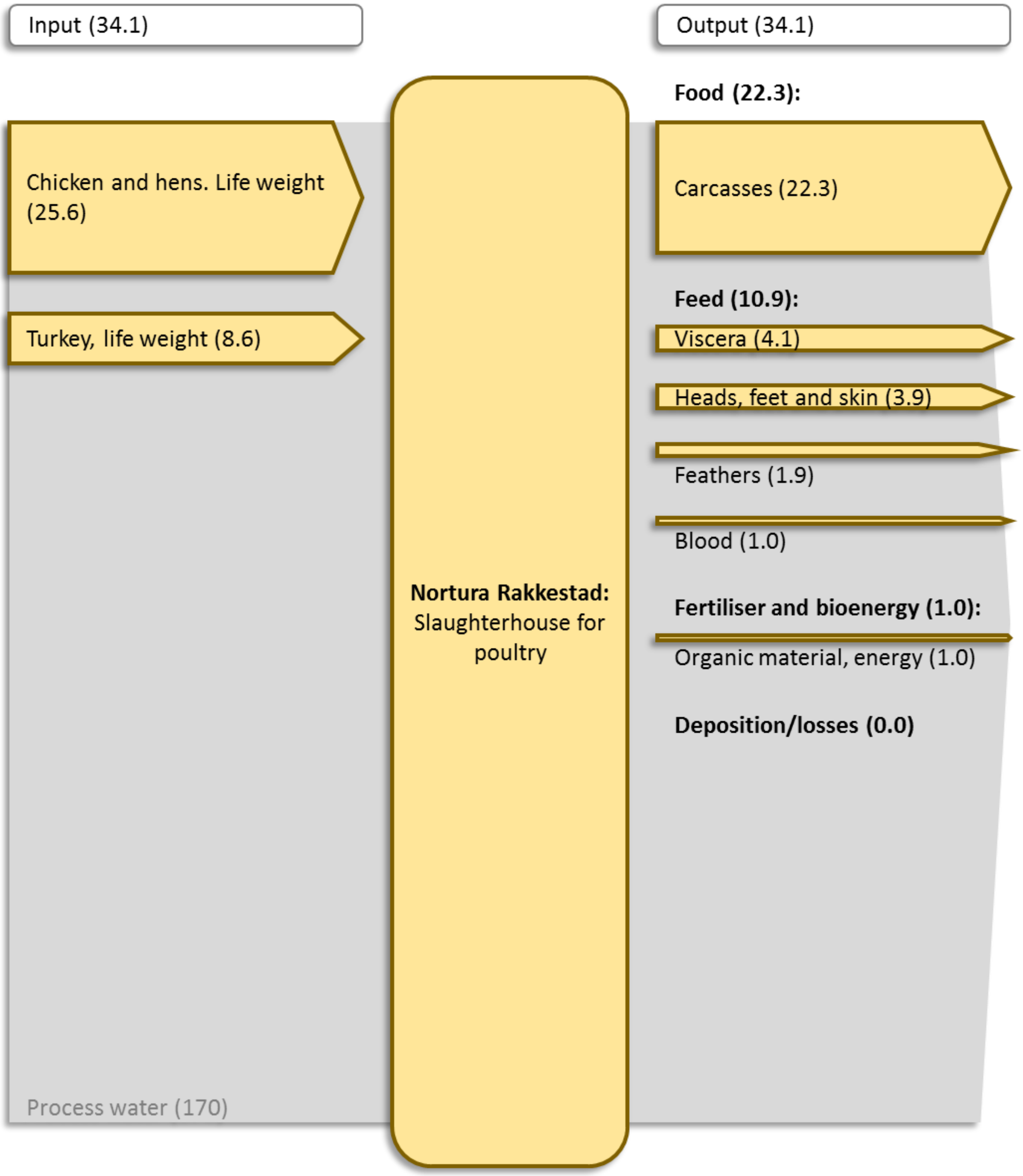


Figure 12. Flows of raw materials, food commodities and co-streams (1,000 tonnes/year, arrow width is proportional to the flow) at Nortura Rakkestad 2012.

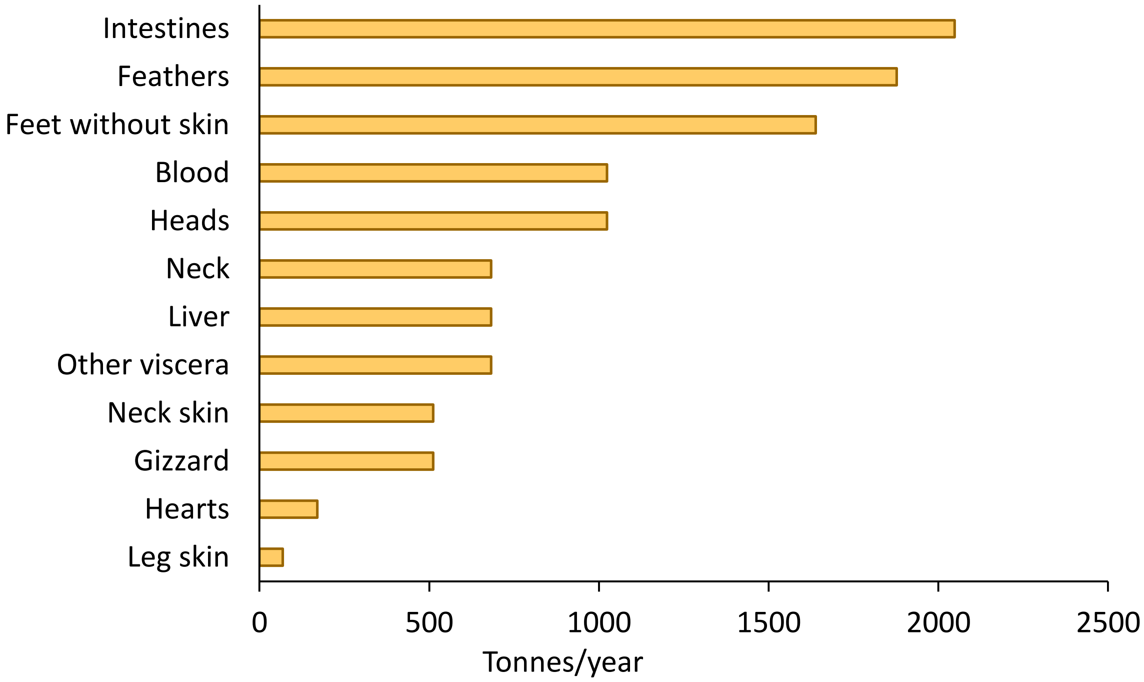


Figure 13. Estimated amounts of poultry co-streams after slaughtering at Nortura Rakkestad.

3.4 Raw material utilisation efficiency

We calculated utilisation efficiencies for different materials for each case. The utilisation efficiencies were calculated for organic material outputs utilised as food, feed, and material for fertiliser and bioenergy production. Furthermore, we calculated the efficiency of process water utilisation per output of total food products (Table 1).

On average for the seven cases of food processing plants, 75% of the organic material input is utilised for food commodities and 21% for feed products, whereas only small amounts were utilised for fertiliser and bioenergy production. The proportion of materials disposed of as landfill or lost during processing were also small. The utilisation efficiencies differed between food chains and between cases in the vegetables and potatoes chain. These differences are most likely due to the nature of the different raw materials used, but used processing methods and available equipment are also important factors, however, these factors could not be analysed in this study. Another aspect not investigated in this study is the fact that food commodity outputs contain varying proportions of inedible compounds, such as potato peel, potato residual soil, fish bones and chicken bones. These compounds may be separated by the consumer and utilised as pet food or collected for municipal utilisation such as composting or bioenergy production. The low utilisation efficiency for food commodities at Potetpartner AS may be explained by the quality of the raw material, as they receive potatoes with visual quality issues and thus a large proportion is utilised as feed. Produsentpakkeriet Trøndelag AS and Hvebergsmoen Potetpakkeri AS utilised only small amounts in feed products. Possible reasons are that a high share of the raw materials can be utilised as food products and that potato residual soil has to be deposited.

On average, process water utilisation efficiency was 8.6 tonnes per tonne of produced food commodities. The efficiency was similar for the three food chains, but the variation within the vegetables and potato food chain was huge. The process water utilisation efficiency depends on type of raw material and type of food products. Cleaning and recycling of process water decreases water consumption and environmental load. At the sea fish processing plant Nergård Senja AS, Senjahopen a share of the process water is sea water.

Based on the raw material utilisation in the studied cases we suggest to focus on developing feed products with higher value for more efficient utilisation of nutrients and to increase the economic value of the products.

Table 1. Raw material and process water utilisation efficiency at seven food processing plants in Norway 2012

Food chain/case	Utilisation efficiency				
	Food mass/ raw material	Feed mass/ raw material	Material for fertiliser and bioenergy production/ raw material	Deposition and losses/ raw material	Process water/ food mass, tonne/tonne
Vegetables and potatoes					
Produsentpakkeriet Trøndelag AS	86%	6%	0%	7%	10.1
Hvebergsmoen Potetpakkeri AS	92%	2%	0%	5%	0.6
Potetpartner AS	54%	46%	0%	0%	10.8
BAMA Lier	75%	22%	3%	0%	14.9
Findus Tønsberg	80%	13%	2%	4%	9.8
Average	77%	18%	1%	3%	9.2
White and pelagic fish					
Nergård Senja AS, Senjahopen	72%	25%	0%	2%	6.4
Poultry					
Nortura Rakkestad	65%	32%	3%	0%	7.6
Average	75%	21%	1%	3%	8.6

3.5 Chemical composition of selected co-streams

The co-streams described above may be utilised for production of feed, fertiliser or bioenergy, depending on the materials' risk category, chemical composition, available processing methods and economic aspects. Reference values for the chemical composition of selected raw materials, food commodities and co-streams are presented in Table 2.

Table 2. Chemical composition of selected co-streams in the food industry processing vegetables and potatoes, white and pelagic fish and poultry

Item	Water, g/kg	Energy, MJ/kg DM	Chemical composition, g/kg DM if not otherwise stated[1]													Other information	Reference
			Protein	Fat	Carbo-hydrates	Fibre	Ash	SFA[2]	MUFA[3]	PUFA[4]	P	Ca	K	Mg	Se, mg/kg DM		
Vegetables and potatoes																	
Carrot	895	14.5	67	19	629	229	57	10	0	10	2.2	2.5	20.0	0.8	0.0		1
Potato[5]	793	15.4	82	5	762	109	45	0	0	0	2.0	0.2	18.6	1.1	0.0		1
Potato starch	160	16.6	12	0	960	17	12	0	0	0	0.1	0.2	0.2	0.1	0.0		1
Potato peel, industrial	838	-	79	-	701	153	68	-	-	-	-	-	-	-	-		2
Lettuce[6]	950	12.0	280	40	220	240	220	0	0	20	6.4	13.0	72.0	2.6	0.1		1
White and pelagic fish, and salmon																	
Alaska pollock, meat	824	16.8	1000	28	-	-	51	6	6	11	8.6	1.4	12.7	1.5	1.1		1
Cod, meat	810	17.3	958	26	-	-	58	5	5	11	11.4	0.6	21.2	1.4	1.4		1
Haddock, meat	798	16.6	911	30	-	-	59	5	5	15	10.9	1.8	15.1	1.2	1.0		1
Saithe, meat	793	16.6	923	24	-	-	68	5	5	10	11.6	0.6	20.3	1.5	1.3		1
Atlantic halibut, meat	751	19.9	751	193	-	-	56	40	72	60	8.4	0.5	16.1	0.9	1.6		1
Atlantic herring, meat	712	21.4	580	313	-	-	63	69	128	80	9.6	1.9	11.6	1.3	0.9		1
European plaice, meat	771	16.7	921	26	-	-	52	4	4	9	8.1	0.5	18.0	1.0	1.3		1
Mackerel, meat	620	23.7	529	397	-	-	74	108	134	105	6.3	0.2	12.2	0.8	1.0		1
Whiting, meat	799	16.6	910	30	-	-	60	5	10	10	9.1	2.5	18.4	1.2	1.2		1
Salmon, farmed, meat	638	24.9	528	431	-	-	44	83	160	133	5.8	0.1	11.2	0.7	0.5		1
Backbones, cod cleaned	78	-	388	25	-	-	570	3	4	4	113	190	0.005	3			3
Backbones, mackerel cleaned	44	-	273	533	-	-	222	109	192	115	86	143	0.007	3			3
Backbones, Baltic cod	-	-	760	-	-	-	280	-	-	-	-	-	-	-	-	Collagen 240 g/kg DM	4
Liver, cod	320	21.6	68	810	-	-	53	-	-	-	-	-	-	-	-		5
Milt, cod	820	3.0	806	61	-	-	100	-	-	-	-	-	-	-	-		5
Roe, cod	700	5.3	810	57	-	-	60	-	-	-	-	-	-	-	-		5

Table 2. (continued)

Item	Water, g/kg	Energy, MJ/kg DM[1]	Chemical composition, g/kg DM if not otherwise stated[1]													Other information	Reference
			Protein	Fat	Carbo-hydrates	Fibre	Ash	SFA[2]	MUFA[3]	PUFA[4]	P	Ca	K	Mg	Se, mg/kg DM		
Poultry																	
Chicken, meat with skin	701	23.8	602	368	0	0	30	117	177	54	6.0	0.3	8.1	0.7	0.3		1
Turkey, with skin	735	19.9	792	174	0	0	34	57	45	53	7.2	0.3	10.8	0.8	0.2		1
Chicken stomach	768	20.0	784	181	0	0	34	52	47	52	5.8	0.3	8.1	0.6	0.4		1
Chicken liver	748	19.1	770	151	28	0	52	48	28	40	13.2	0.3	10.1	0.8	1.8		1
Chicken heart	740	23.6	600	358	12	0	31	96	88	100	6.8	0.5	6.8	0.7	0.4		1
Chicken bones, femur	-	-	405	18	-	-	525	-	-	-	92	200	-	2	-	Hydroxyapatite, collagen	6
Chicken leg skin	388	-	156	836	-	-	8	-	-	-	-	-	-	-	-		7
Chicken blood	808	-	828	14	-	-	48	-	-	-	-	-	-	-	-	Histidine, lysine, methionine	8
Feathers, wet	724	-	893	31	-	-	13	-	-	-	-	-	-	-	-	Low digestibility; lack of histidine, lysine, methionine	8; 9
Chicken soft viscera	668	-	387	475	-	-	43	-	-	-	-	-	-	-	-	Endogenous enzymes	8
Chicken heads and feet	665	-	480	213	-	-	157	-	-	-	-	-	-	-	-		8
Chicken various viscera	628	-	369	455	-	-	104	-	-	-	-	-	-	-	-		8

References: 1) NFA (2014), values are converted to dry matter basis; 2) VTT Technical Research Centre of Finland, unpublished data; 3) Toppe et al. (2007); 4) Skierka et al. (2007); 5) Murray and Burt (2001); 6) Suchy et al. (2009); 7) Badr (2005); 8) Okanović et al. (2009); 9) Grazziotin et al. (2006).

[1] Dry matter.

[2] Saturated fatty acids.

[3] Monounsaturated fatty acids.

[4] Polyunsaturated fatty acids.

[5] Average of 4 potato varieties.

[6] *Lactuca sativa* var. *capitata*.

4. Feed production from co-streams

4.1 Feed requirements for different groups of animals

The nutrient requirements of animals depend on many factors such as species, physiological state and environment. An animal's feed intake is determined by its diet and is mediated by the animals' metabolism.

The most important functions of nutrients are maintenance of bodily functions, tissue growth and production. Therefore, the synthesis of proteins in the animal is central to animal nutrition. The main groups of nutrients are proteins, carbohydrates and lipids, which are building blocks and sources for various forms of energy. Other important components of feed are water, vitamins and minerals. For example, Ca and P are the main constituents needed in maintenance of the skeleton, and trace elements like selenium are important components of enzymes essential to maintain general health.

Energy deriving from feed is used for muscle work, tissue synthesis and heat production. The total amount of energy supplied by a single feed is called ***gross energy***, however, only a share of it is available for the animal. ***Apparent digestible energy*** is the gross energy of the feed consumed minus the gross energy of the faeces. ***Apparent metabolisable energy*** is the gross energy of the feed consumed minus the gross energy contained in the faeces, urine, and gaseous products of digestion. ***Net energy*** is metabolisable energy minus the energy lost as the heat increment. Net energy may include the energy used for maintenance only, or for maintenance and production.

Animals have evolutionarily adapted to very different environments by developing strategies to cover specific nutritional requirements (Table 3). Aquatic predators like the Atlantic salmon feed at the sea on crustaceans (*Crustacea*) and small fishes. Farmed salmon has high protein (40 to 45%) and fat (20 to 24%) requirements, but compared to land animals salmon is very efficient in converting feed to edible protein, which is mainly because fish are poikilotherm organisms. The carbohydrate intake is limited to 12% in salmon (FAO, 2014b). Even domestic[3] cats and dogs require high percentages of protein (for maintenance, adult animals: cats 26%, dogs 18%) in the diet (AAFCO, 1993). Fur-bearing animals have similar feed requirements to carnivorous pets. Carbohydrates are not required, but small amounts of cooked carbohydrates may be included in the diet. Carbohydrates are the principal energy source for poultry and pigs. The protein requirement of broilers decreases from 23% (week 0 to 3) to 18% (week 6 to 8) (NRC, 1994) and the protein requirement of growing pigs decreases from 18% (body weight 10 to 20 kg) to 12% (80 to 120 kg) (NRC, 2012). However, for poultry and pigs the intake of essential amino acids is more important than the actual intake of total protein. In contrast, in ruminants microbial microorganisms digest plant fibres and are able to synthesise essential amino acids (and other nutrients), which become available to the animal when the microorganisms are digested. Typical dry matter (DM) proportions of feed component sources are presented in Figure 14.

Some co-streams from the food industry are important supplements to the diet of livestock[4] and pets. Most likely more co-streams may be utilised as alternative feedstuffs. We evaluated the possibilities to produce feed components for different groups of animals based on availability, chemical composition and regulations for processing and utilisation of co-streams (Table 4). Co-streams may be directly used as feed or processing may be

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[3] Domestication refers to artificial selection by humans.

[4] Livestock refers to domesticated animals raised or kept to produce commodities such as food, fibre and labour.

Table 3. Feeding behaviour and nutritional requirements of livestock and pets

Animal	Atlantic salmon (*Salmo salar*)	Domestic cat (*Felis silvestris catus*)	Domestic dog (*Canis lupus familiaris*)	American mink (*Neovison vison*)	Chicken (*Gallus gallus domesticus*)	Pig (*Sus scrofa domesticus*)	Cattle (*Bos primigenius taurus*)
Ancestor	Atlantic salmon	African wildcat (*Felis silvestris lybica)*	Grey wolf *(Canis lupus)*	American mink	Red junglefowl (*Gallus gallus*)	Wild boar (*Sus scrofa*)	Aurochs (*Bos primigenius*)
Feeding behaviour and feed source of wild ancestors	Carnivore (aquatic predator): aquatic invertebrates, fish; young animals are omnivore	Carnivore (predator): small mammals, birds, reptiles, insects etc.	Carnivore or omnivore and scavenger (apex predator): large herbivores such as moose and small prey such as hare	Carnivore: rodents, fish, crustaceans, frogs, birds	Omnivore: insects, seeds, fruits	Omnivore scavenger: including grass, roots, nuts, berries, carrion, birds, insects etc.	Herbivore: grasses, branches of woody plants, acorn
Production type for requirement	Marine grower	Adult, maintenance	Adult, active	Fur development week 13-30, maintenance, male	Meat type, week 6-8, male,	Growing pigs	Growing and finishing cattle (Angus), average weight gain 1.0 kg/d
BW[1] basis for requirement	2.5 → 4.0 kg[2]	4.5 kg	15 kg	1.5 → 2.4 kg	2.1 → 3.1 kg	80 → 120 kg	400 kg
Daily feed intake	23 → 36 g DM/d[3]	72 g DM/d	55-145 g DM/d	100 → 63 g DM/d[4]	147 → 185 g DM/d[5]	2.8 kg DM/d	8-10 kg DM/d
	9 g DM/kg BW	16 g DM/kg BW	11-29 g DM/kg BW	67 → 26 g DM/kg BW	70 → 59 g DM/kg BW	28 g DM/kg BW	20-25 g of DM/kg BW
Requirements							
Energy[6]	0.5 → 0.8 MJ DE/d (minimum)	1.2 MJ GE/d	3.9 MJ GE/d	1.9 → 1.2 MJ ME/d	2.2 → 2.7 MJ/d	42 MJ ME/d	44 MJ NE_{m+g}/d
	0.20 MJ DE/kg BW	0.26 MJ GE/kg BW	0.26 MJ GE/kg BW	0.59 MJ ME/kg BW	1.05 → 0.87 ME/kg BW	0.42 MJ ME/kg BW	0.11 MJ NE_{m+g}/kg BW
Crude protein	40-45% (minimum)	26% (minimum)	18% (performance dogs: 25%)	22-26%	18%	12%	6.8% MP[7]
Most limiting AA[8]	Arginine: 1.6% of dietary protein, lysine 1.8%, methionine 1.0%, threonine 0.8%	Methionine + cystine: 1.1% of DM	Methionine+cystine: 0.43% of DM	Methionine and cystine: supplementation required in dry feed	Methionine + cysteine: 0.54% of DM	Lysine: 0.55% (Standard ileal digestible), methionine + cysteine: 0.34%	Methionine: 3% of MP intake, lysine: 8.0%, (250 kg BW, gaining 0.5 kg/d)
Other required AA	Histidine, isoleucine, leucine, phenylalanine, tryptophan, valine	Arginine, histidine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan, valine, taurine	Arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine	-[9]	Arginine, glycine, serine, histidine, isoleucine, leucine, lysine, phenylalanine, tyrosine, proline, threonine, tryptophan, valine	Arginine, histidine, isoleucine, leucine, phenylalanine, tyrosine, threonine, tryptophan, valine	-

Table 3. (continued)

Animal	Atlantic salmon (*Salmo salar*)	Domestic cat (*Felis silvestris catus*)	Domestic dog (*Canis lupus familiaris*)	American mink (*Neovison vison*)	Chicken (*Gallus gallus domesticus*)	Pig (*Sus scrofa domesticus*)	Cattle (*Bos primigenius taurus*)
Carbohydrates	Not required, cooked, 12% maximum	Cooked only	Cooked only	Not required, cooked only, 10-30%	Major source of energy	Yes	Major source of energy
Crude lipids	20-24%	No true requirement, Minimum 9% of DM, 5.5 g/d	20% recommended	40-47%	-	-	-
Fatty acids	C20:5 n-3: 0.5% of DM, C22:6 n-3: 0.5-1.0%	C18:2 n-6: 0.5% of DM, C20:4 n-6: 0.02%	C18:2 n-6: 1.3 g/d	-	C18:2 n-6: 1% of DM	C18:2 n-6: 0.1% of DM	-
Selected minerals	Mg: -, P: 0.6% of DM, K: 0.7%, Ca: -, Se: 0.3 ppm	Mg: 0.04% of DM, P: 0.5%, K: 0.6, Ca: 0.6%, Se: 0.3 ppm	Mg: 0.07% of DM, P: 0.4%, K: 0.5%, Ca: 0.5%, Se: 0.3 ppm	Mg: -, P: 0.3% of DM, K: -, Ca: 0.3%, Se: -	Mg: 0.05% of DM, P (non-phytate): 0.3%, K: 0.3%, Ca: 0.7%, Se: 0.15 ppm	Mg: 0.04% of DM, P (available): 0.14%, K: 0.16%, Ca: 0.4%, Se: 0.14 ppm	Mg: 0.10%, P: 0.20%, K: 0.60%, Ca: 0.34%, Se: 0.10 ppm
Selected fat-soluble vitamins	A: 2,250 IU/kg of DM, D: 1,800 IU/kg, E: 90 g/kg	A: 3,330 IU/kg of DM, D: 250 IU/kg, E: 38 mg/kg	A: 6,060 IU/kg of DM, D: 550 IU/kg of DM, E: 36 IU/kg of DM	Demonstrated, but not quantified	A: 1,350 IU/kg of DM, D_3: 180 ICU, E: 9 IU	A: 1,170 IU/kg of DM, D: 135 IU/kg, E: 10 IU/kg	A: 2,200 IU/kg DM, D: 275 IU/kg DM, E: 50-100 IU/d (added in the feed)
References	1; 2	3; 4	3; 5; 6	7	8; 9	10; 11	12; 13

References: 1) FAO (2014a); 2) FAO (2014b); 3) NRC (2006); 4) FEDIAF (2013); 5) NRC (2006); 6) Sallander (2001); 7) NRC (1982); 8) Arshad et al. (2000); 9) NRC (1994); 10) NRC (1998); 11) Chiba (2009); 12) NRC (2000); 13) Wilkerson et al. (1993).

[1] Body weight.

[2] Arrows indicate changes according to growth.

[3] Dry matter.

[4] 15.0 MJ ME/kg DM.

[5] Ad libitum, 12.1 MJ ME/kg DM.

[6] DE digestible energy, GE gross energy, ME metabolisable energy, NE_{m+g} net energy for maintenance and growth.

[7] Metabolisable protein.

[8] Amino acid.

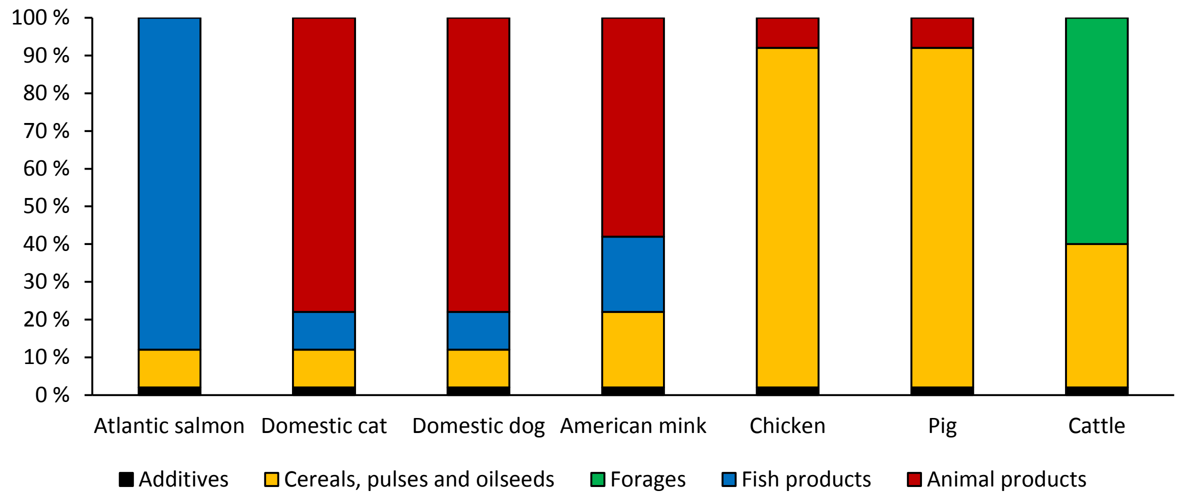

Figure 14. Typical dry matter proportions of feed component sources in the diet of different animals.

Table 4. Evaluation of the possibilities to utilise co-streams from different food processing industries as feed for different groups of animals (– = not permitted, 0 = not prohibited but unlikely, U = currently utilised, P = potential for better utilisation)

Co-streams source	Group of animals					
	Ruminants	Pigs	Poultry	Farmed salmon	Carnivorous pets	Fur-bearing animals
Vegetables	U[1]	U[1]	P	0	P	0
Potatoes	U[1]	U[1]	P	0	P	0
White fish	—[2]	U	U	U	U	U
Pelagic fish	—[2]	U	U	U	U	U
Poultry	—[2]	—[3]	—	P[4]	U	U, P

[1] Nutritional feed, but low monetary value.

[2] Allowed if hydrolysed.

[3] Eggs and egg products are permitted.

[4] Practiced in Chile and Canada, not practiced in Europe but legal (Commission Regulation (EC) 56/2013).

required. The aims of processing can be conservation of the material by e.g. refrigeration/freezing, drying, heat and pressure treatment or acidification, and improvement of its feed value by e.g. mechanic treatment, hydrolysis, fermentation or fractionation.

4.2 Regulations governing the utilisation of co-streams in feed

The EU Regulation (EC) 183/2005 (***Feed Hygiene Regulation***) lays down requirements for the hygienic quality of raw materials and animal feed in general and is the basis for the Norwegian regulation on feed hygiene; “Forskrift om fôrhygiene” (Lovdata, 2010).
The responsibility for the safety of using vegetable co-streams in feed lies with the user and is not directly controlled by EU regulations. In contrast, the use of animal co-streams is heavily regulated.

4.2.1 *Vegetable co-streams*

Vegetable co-streams may be used as feed if registered in the catalogue of feed materials (Commission Regulation (EU) 68/2013); however, their presence in the feed catalogue is not proof that the material can be used as feed. The user has to show that a feed material is safe, and in which amounts it can be added into feed and for which animals. The user is also responsible to choose relevant analyses to document that the quality requirements are fulfilled. However, very detailed regulations define which nutrient levels are safe for various production animals. For example, steamed carrot peelings are listed with number 4.3.2 in the catalogue of feed materials (Commission Regulation (EU) 68/2013). This material is rich in starch, crude fibre and beta-carotene. Thus, regulations regarding these compounds must be checked. A maximum content of 80 mg/kg total carotenoids in complete feeding stuff for poultry is allowed in the update (situation as 30 April 2004) of the list of the authorised additives in feeding stuffs published in application of Article 9t (b) of Council Directive 70/524/EEC concerning additives in feeding stuffs. The European Food Safety Authority Panel on Additives and Products or Substances used in Animal Feed considers beta-carotene safe for the target animals and setting a maximum content in feed legislation is not considered necessary (EFSA, 2012). Following this suggestion, the maximum content of beta-carotene in poultry feed may be removed in future.

4.2.2 *Animal co-streams*

The use of products of animal or marine origin in animal feed is regulated mainly by two EU regulations, the Regulation (EC) 1069/2009 (***Animal By-products Regulation***) and the Regulation (EC) 999/2001 (***Transmissible Spongiform Encephalopathies (TSE) Regulation***). The use of products of animal or marine origin in animal feed in Norway is regulated by national regulations derived from EU regulations, as agreed in the EEA-agreement in 1994. The Norwegian regulations are “Endr. i forskrift om animalske biprodukter” (Amendment on the regulation of ABP) (Lovdata, 2011) and “Forskrift om TSE” (TSE Regulation) (Lovdata, 2004). The processing requirements for ABP are covered by the Commission Regulation (EU) 142/2011 (Chapter II “Hygiene and processing requirements” and Chapter III “Standard processing methods”) (***Implementing Regulation regarding ABP***). In general, all animal and marine products intended for utilisation as feed have to come under Category 3 material.

Animals are defined as invertebrate or vertebrate animals (Regulation (EC) 1069/2009). ***Farm animals*** include animals kept, fattened or bred by humans and used for the production of food, wool, fur, feathers, hides and skins or any other product obtained from animals or for other farming purposes, and horses. In contrast, ***wild animals*** means any animal not kept by humans. ***Fur-bearing animals*** means animals kept or reared for the production of fur and not used for human consumption (Commission Regulation (EU) 142/2011). ***Pet animals*** means any animal belonging to species normally nourished and kept but not consumed, by humans for purposes other than farming. ***Aquatic animals*** means fish belonging to the superclass *Agnatha* and to the classes *Chondrichthyes* and *Osteichthyes*; mollusc belonging to the Phylum *Mollusca* and crustacean belonging to the Subphylum *Crustacea* (Council Directive 2006/88/EC, Article 3(1)(e)), ***Council Directive regarding Aquatic Animals***).

Animal by-products are defined as “entire bodies or parts of animals, products of animal origin, or other products obtained from animals that are not intended for human consumption” (Regulation (EC) 1069/2009). ***Derived products*** means products obtained from one or more treatments, transformations or steps of processing of ABP. The regulations divide ABP into three categories (Chapter 2.2) based on their potential risks with respect to domestic animals, the public or to the environment including wild animals. The regulations set out how each category must or may be disposed of. The regulations also restrict the type of ABP that may be used for feeding animals, so that ***only material fit for human consumption may be used for livestock feeds and pet foods***. The regulation prohibits intra species recycling, and the feeding of catering waste to livestock.

Products of animal or marine origin that can be fed or included in feed products intended for livestock must originate from low risk materials, i.e. Category 3. This includes material that has previously been fit for human consumption, but it must still be safe, and ABP derived from processing of products intended for human consumption. No further processing is required for foodstuffs no longer intended for human consumption, but for other ABP or processed products, processing has to take place in an approved ABP or food processing plant.

Minimum standards are specified for reduction of particle size, heat and pressure treatment for seven processing methods for Category 3 ABP (Commission Regulation (EU) 142/2011, Chapter III) (Table 5). These materials must be processed in accordance with any of the processing methods 1 through 5 or 7, or, in the case of material originating from aquatic animals, with any of the processing methods 1 through 7. This means that origin, type and processing of a co-stream restricts their use as feed for certain groups of animals. Relevant materials and processing methods for Category 3 ABP are described in detail below (Table 6).

Table 5. Overview of standard processing methods for Category 3 animal by-products (Commission Regulation (EU) 142/2011, Chapter III)

Method	Particle size, maximum	Process specification	Core temperature × minimum duration × minimum pressure	Batch/continuous system
1 (Pressure sterilisation)	50 mm	[1]	>133°C × 20 min × 3 bar	Batch or continuous
2	150 mm	[2]	>100°C × 125 min, >110°C × 120 min, >120°C × 50 min	Batch
3	30 mm	[2]	>100°C × 95 min, >110°C × 55 min, >120°C × 13 min	Batch or continuous
4	30 mm	In a vessel with added fat[2]	>100°C × 16 min, >110°C × 13 min, >120°C × 8 min, >130°C × 3 min	Batch or continuous
5	20 mm	Preparation: heated until coagulation, pressed to remove fat and water from the proteinaceous material[2]	>80°C × 120 min, >100°C × 60 min	Batch or continuous
6 (Aquatic animal or aquatic invertebrates only)	50 mm	Preparation: Reduction to pH 4.0 or lower (formic acid) and stored for at least 24 h	>90°C × 60 min	Batch or continuous
	30 mm		>70°C × 60 min	Batch or continuous
7	Any processing method authorised by the competent authority where the following have been demonstrated by the operator to that authority with the capacity to reduce relevant hazards to a level which does not pose any significant risks to public and animal health[3]			

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[1] The pressure must be produced by the evacuation of all air in the sterilisation chamber and the replacement of the air by steam ('saturated steam'); the heat treatment may be applied as the sole process or as a pre- or post-process sterilisation phase.

[2] The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated.

[3] A detailed description of method 7 in the Commission Regulation (EU) 142/2011, Chapter III).

Table 6. Use of animal protein as feed for different groups of animals according to the TSE regulations (adapted from NFSA, 2014a). NP = not permitted, ✓ = permitted

Category 3 materials	Origin	PAP/non-PAP[1]	Group of animals				
			Adult ruminants	Juvenile ruminants	Terrestric mono-gastrics	Fish	Carni-vorous pets/fur-bearing animals
Raw or partially cooked products	Animal	Non-PAP	NP	NP	NP	NP	✓
Processed protein	Animal	PAP	NP	NP	NP	✓[2]	✓
Gelatine	Ruminant	Non-PAP	NP	NP	NP	NP	✓
Hydrolysed protein, <10,000 Da	Ruminant	Non-PAP	NP	NP	NP	NP	✓
Blood product	Ruminant	Non-PAP	NP	NP	NP	NP	✓
Bloodmeal[3]	Ruminant	Non-PAP	NP	NP	NP	NP	✓
Bloodmeal[3]	Non-ruminant	PAP	NP	NP	NP	✓	✓
Blood products[4]	Non-ruminant	Non-PAP	NP	NP	✓	✓	✓
Dicalcium and tricalcium phosphate[5]	Animal	Non-PAP	NP	NP	✓	✓	✓
Fishmeal, processed fish silage[6]	Fish	PAP	NP	✓	✓	✓	✓
Milk, dairy products, colostrum	Mammal	Non-PAP	✓	✓	✓	✓	✓
Egg, egg products	Poultry	Non-PAP	✓	✓	✓	✓	✓
Gelatine	Non-ruminant	Non-PAP	✓	✓	✓	✓	✓
Hydrolysed protein[7]	Non-ruminant	Non-PAP	✓	✓	✓	✓	✓
Hydrolysed protein from hides, <10,000 Da[8]	Ruminant	Non-PAP	✓	✓	✓	✓	✓

[1] Processed animal protein.
[2] Commission Regulation (EU) 56/2013.
[3] Regulation (EC) 999/2001 does not regulate bloodmeal.
[4] Additional requirements in Regulation (EC) 999/2001, Annex IV 2 D.
[5] Additional requirements in Regulation (EC) 999/2001, Annex IV 2 C.
[6] E.g. fish protein concentrate; additional requirement in Regulation (EC) 999/2001, Annex IV 2 B.
[7] I.e. from chicken, pig, fish.
[8] Additional requirements in the Commission Regulation (EU) 142/2011, Annex X, Section 5 D.

Processed animal protein is defined as animal protein derived entirely from Category 3 materials (including blood meal and fishmeal), which have been treated to render them suitable for direct use as feed material or for any other use in feedstuffs, including pet food and fish feed (Commission Regulation (EU) 56/2013) or for use in organic fertilisers or soil improvers (Commission Regulation (EU) 142/2011). However, PAP does not include blood products (other than blood meal), milk, milk-based products, milk derived products, colostrum, colostrum products, centrifuge or separator sludge, gelatine, hydrolysed proteins, dicalcium phosphate, eggs and egg products including egg shells, tricalcium phosphate and collagen. The legislation is complicated, but for example, in circumstances where a Category 3 derived mammalian meat and bone meal is not treated to method 1 (pressure sterilisation) according to Commission Regulation (EU) 142/2011, Annex IV, Chapter III, it will not be considered a PAP. This, however, makes no practical difference as neither Category 3 meat and bone meal, as a PAP, nor Category 3 meat and bone meal as a derived product, could be used for feeding farm animals.

Fishmeal is the most commonly used ***restricted protein*** in non-ruminant feed. In addition, wet products such as fish silage or fish hydrolysate are used. These products are considered as PAP.

The Regulation (EC) 1069/2009 prohibits the feeding of farmed fish with PAP, such as fishmeal derived from the bodies of farmed fish of the same species. The packaging or consignment note should clearly indicate the type of fish used to manufacture the fishmeal. Processing plants producing fishmeal or other feed originating from aquatic animals have to clearly be labelled fishmeal intended for feeding to farmed fish with the following:

(a) In the case of fishmeal from wild fish, bearing the words ‘contains fishmeal from wild fish only – may be used for the feeding of farmed fish of all species’.

(b) In the case of fishmeal from farmed fish, bearing the words ‘contains fishmeal from farmed fish of the [...] species only – may only be used for the feeding of farmed fish of other fish species’.

(c) In the case of fishmeal from wild fish and from farmed fish, bearing the words ‘contains fishmeal from wild fish and farmed fish of the [...] species – may only be used for the feeding of farmed fish of other fish species’.

Hydrolysed proteins in farm animal feed must originate from parts of non-ruminants or ruminant hides and skins and furthermore, these must have been processed in an approved ABP processing plant (Regulation (EC) No.1774/2002, ***Health rules concerning ABP***). Hydrolysed proteins have not been previously included in farm animal feed due to the difficulty in confirming that the material is free of prions, which are believed to cause bovine spongiform encephalopathy. Prions have a mass of about 30,000 Da[5] and hydrolysed proteins with a molecular weight no larger than 10,000 Da are regarded as safe in feed for ruminants (Office International des Epizooties, Paris, France). However, this is technically difficult to achieve and such products are not commonly available. Currently, the 10,000 Da limit only applies to hydrolysed protein derived from ruminant hides and skins.

Businesses wanting to process ABP into hydrolysed proteins for animal feed use will need to comply with the requirements of the Regulation (EC) 999/2001 and ensure that hydrolysed proteins being used for farm animal feed do not contain animal tissues, such as bone fragments, feather fragments and muscle fibres. This will involve satisfying the Commission Regulation (EC) 152/2009 (***Official control of feed***), describing sampling and analysis for the official control of feed (Microscopic Analysis Testing). Hydrolysed proteins must be produced using a production process involving appropriate measures to minimise contamination. Production plants and products must be approved by the Regulatory Authorities.

Dicalcium and tricalcium phosphate of animal origin are commonly used as minerals in farm animal feed, but most of the material used is of mineral origin and does not originate from animal tissues. There are labelling requirements (Regulation (EC) 999/2001) for the use of material of animal origin in farm animal feed.

Gelatine used in farm animal feed originates from confectionery and bakery products where it has been used as an ingredient. The “feed ban” in the Regulation (EC) 999/2001 prevents the use of products containing ruminant gelatine in all farm animal feed. Feed businesses sourcing confectionery or bakery products must ensure that suppliers only send material containing non-ruminant gelatine. Sourcing and processing standards for non-

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[5] Dalton (Da) or unified atomic mass unit (u) is the unit used for mass on an atomic or molecular scale. One Da is defined as one twelfth of the mass of an unbound neutral C-atom.

ruminant gelatine can be found in the Commission Regulation (EU) 142/2011 (Annex X, Chapter II, Section 5).

Collagen is a protein found in various connective tissues. In the regulations, collagen means protein-based products derived from hides, skins, bones and tendons of animals. Processed collagen can be used for feeding non-ruminant animals and is used in joint supplements for horses, dogs and cats. Sourcing and processing standards for collagen can be found in the Commission Regulation (EU) 142/2011.

Processed fats and fish oil must not contain animal protein i.e. anything defined here as animal tissues must be absent on Microscopic Analysis Testing. Rendered fats derived from ruminant animals must be purified in such a way that the maximum level of total soluble total soluble impurities remaining does not exceed 0.15% in weight.

To be eligible for feeding farm animals the fat or oil must:

(a) for rendered fats – originate from Category 3 ABP, but cannot be made from adipose tissue sourced from aquatic animals, fallen stock animals, carcasses which have failed post mortem inspection or from catering waste

(b) for fish oils – originate from Category 3 ABP:

  - from aquatic animals, and parts of aquatic animals, (except sea mammals) which did not show signs of disease communicable to man or animals
  - ABP from aquatic animals from human food factories or factory ships or from human food no longer intended for human consumption.

Fish oil or fats destined for farm animal feedstuff can have been processed at either an approved ABP processing plant, or at a human food factory or factory ship, in accordance with defined processing standards applicable in the Regulation (EC) No. 852/2004 (Hygiene of foodstuffs). Rendered fat and fish oil must not contain animal protein i.e. anything defined here as animal tissues must be absent on Microscopic Analysis Testing. Rendered fats derived from ruminant animals must be purified in such a way that the maximum level of remaining total soluble impurities does not exceed 0.15% in weight.

5.Production of fertilisers and bioenergy from co-streams

In agricultural production N, P and K are the most essential macronutrients. The most critical nutrient is P, because there is no substitute for P in crop growth and resources of P are limited (Cordell et al., 2009 and 2011). The production of fertilisers from food industry co-streams is one option in which to recycle P, other nutrients and organic matter in general back to the agricultural cycle.

5.1 Relevant fertiliser products

There are different kinds of fertiliser products that can be manufactured from co-streams from the food industry. Fertiliser products in general can be divided into mineral and organic (defined as C-containing material of plant or animal origin) fertilisers, liming products, soil conditioners, fertilised growing media and microbial products (e.g. bio-stimulants). The term soil conditioners is used for materials which improve the physical, chemical and biological properties of soil (Spaey et al., 2012).

Fertiliser products can be manufactured from organic co-streams using various technological approaches including composting and anaerobic digestion. Both methods can be used to return valuable nutrients to the agricultural cycle, but in anaerobic digestion bioenergy is also generated. Consequently, the capacity of anaerobic digestion is increasing rapidly in Europe and its share of all biological treatments is currently 25% (De Baere and Mattheeuws, 2014). In Norway 62 centralised biological plants treated 400,000 tonnes of organic waste (including sewage sludge treated off site) in 2011, but only 62,000 tonnes were treated in anaerobic digestion plants (ECN, 2014).

A variety of thermochemical processes, including pyrolysis and hydrothermal carbonisation are developed to convert food-processing co-streams to profitable products. Thermochemical methods are used as waste management option for non-homogenous materials and as a result of these treatments charcoal, liquid and gaseous products are formed (Berge et al, 2011; Libra et al, 2011). Carbon- and energy-rich charcoal can be utilised either as solid fuel or as soil amendment. At hydrothermal carbonisation organic material is decomposed at an elevated temperature (about 200°C) and pressure (about 20 bar) in the presence of water, generating a coal-water-slurry. At pyrolysis organic material is decomposed at elevated temperatures (about 450°C) in the absence of extra oxygen.

5.2 Regulations in Norway and EU

The current EU Fertilisers Regulation (EC) 2003/2003 covers only certain inorganic (mineral) fertilisers, other types of fertiliser products are not covered. The Fertiliser Regulation aims to ensure the free circulation of 'EC Fertilisers' on the internal market and sets the requirements for their minimum nutrient content, safety, and absence of adverse effects on the environment.

The Commission intends to revise Regulation (EC) 2003/2003 to extend its scope to other fertilisers and fertilising materials including organic fertilisers, growing media, soil improvers and possibly bio-stimulants (Spaey et al., 2012). The revised EU Fertiliser Regulation is estimated to come into effect in 2015-2016.

The national regulations related to fertilisers are very country-specific. In Norway, the utilisation of organic co-streams for fertilisation are currently governed by “Forskrift om organisk gjødsel” (Regulation regarding organic fertilisers) (Lovdata, 2003). This regulation deals with compounds from the agricultural food industry, of both animal and plant origin, as well as compounds from the fish farming industry such as viscera, sludge and feed residues that are used as sources in fertilisers or soil conditioners. The regulation also decides the maximal livestock density in Norway, and hence is of great importance for the management of environmental protection such as eutrophication of water bodies. The regulation is under revision since 2010, and will be divided into two regulations, one focussing on animal manure and the other on production, distribution and import of organic fertilisers and inorganic growing media (NFSA, 2014b). Furthermore, “Forskrift om animalske biprodukter” (Regulation regarding animal by-products) (Lovdata, 2007) is not only relevant for ABP, but also applies to food wastes, possibly sorted from households or catering, treated by anaerobic digestion or composting.

The Regulation on animal by-products etc. describes in detail the treatment of compounds in Categories 1,2 and 3, as described in Chapter 2.2 of the present report. According to the Regulation regarding organic fertilisers (Lovdata 2003), producers of fertilisers and soil conditioners must document the product quality by using the following criteria:

- Concentrations of heavy metals below specified levels defined as classes 0 (low), I, II and III (highest) must be shown on the product label.
- Salmonella bacteria, or eggs from infectious parasites must not be present and contents of thermo tolerant coliform bacteria <must be below 2,500 per g DM.
- Products must be stabilised, causing no problems with odour or other environmental problems during storage or use.
- Content of plastic, glass or metal particles >4 mm shall be lower than 0.5% of DM.
- No vigorous seeds of common wild oat (*Avena fatua* L.) must be present.
- Concentrations of N (tot-N, NO_3, NH_4), P (Al-soluble), K (Al-soluble), Ca (Al-soluble), Mg (Al-soluble), Na, S, B, Co, Cu, Fe, Mn, Mo, Zn must be reported. For the elements Ca, Mg, Na, S, B, Co, Cu, Fe, Mn, Mo and Zn the concentrations have to be above certain limits defined in Appendix 3 of the regulation if this element shall be mentioned on the product label.
- DM and organic matter content must be reported on the product label.
- Products containing sewage sludge must always report the content of heavy metals by analysis.
- The procedure for sanitation and stabilisation must be described on the product label.

The Annex 4 of the Regulation regarding organic fertilisers also mentions waste from potato industry such as peel, storage water, crushed potatoes, potato soil or sludge. These co-streams must not be applied to fields where potatoes are grown, or where such growing is planned to occur during the coming 20 years.

The aim of “Forskrift om plantehelse” (Regulation of plant health; Lovdata, 2000) is to prevent introduction and propagation of plant pests such as potato cyst nematodes that may be spread with residual potato soil, a food industry co-streams disposed of as landfill.

6. Potential and challenges for the utilisation of co-streams

Altogether, the food processing plants described here had significant market shares in Norway within fresh potatoes (38%), lettuce (17%), poultry meat (24%) and white and pelagic fish. Thus, we perceive that the studied cases are representative for the food processing industry in Norway. Utilising a maximum proportion of the raw materials in food applications will decrease the amount of co-streams at food-processing plants and is generally perceived as beneficial for the resource utilisation. However, a high degree of utilisation may also increase production costs and may increase use of other resources such as process water and energy.

We recognised three strategies for improving co-stream utilisation in the food-processing industry: 1) Minimising the amount of co-streams disposed of as landfill or dropped at sea; 2) using co-streams with as little processing as possible, even if sales values are low; or 3) upgrading the value of co-streams by further sorting and processing. In addition to utilisation of co-streams as feed, fertiliser and for bioenergy, other applications may also be considered for best possible utilisation of the raw materials. These applications include medical, pharmaceutical and food supplement applications as well as technical material uses (Jayathilakan et al., 2012). However, such applications are not within the scope of this report, and hence only sparsely discussed here.

6.1 Vegetables and potatoes

Vegetable and potato processing plants receiving crops from primary producers (Potetpartner AS excluded) had a high (82%) utilisation efficiency of the raw material for food products. The high efficiency can be explained by pre-grading at the primary producer and generally a low proportion of parts, which have to be removed before food products can be delivered to grocery shops. However, not all possible co-streams such as potato peel is separated at the processing plants, and thus they are forwarded to the consumer level.

A significant part of the vegetable co-streams now forwarded to feed use would in fact be suitable for human consumption, at least after some modifications in the processes. For instance, with a more effective system for washing potatoes, the hygienic quality of the peel would be suitable for food products). Innovations in product and process development would enhance the direct utilisation of raw materials in food products and thus help in prevention of co-streams. Because this report concentrates on how to use food-processing co-streams as feed or fertiliser, the new ways to use co-streams directly as food are not highlighted here.

Many vegetable and potato co-streams are good feed sources for ruminants, but often the economic value is very low. In many cases, such feeds are transported free of charge to farmers, because cost for disposal would be even higher. This is often an environmentally friendly solution also, minimising the transport of commodities. Procedures to improve the feed value may generate more revenue for vegetable and potato processing plants. For example, fermentation may improve the shelf life and protein content of vegetable co-streams. Adequate sanitation procedures may allow selling feed in cases where risks exist that feedstuffs may spread pests.

Significant amounts of sediment and dry soil mixed with plant materials are currently disposed of. This practice is costly and not environmentally sound. Solutions need to be found. If the soil could be sanitised in a convenient way, e.g. by means of compost heating or excess heating from an energy plant, the soil would be a high quality soil amendment product, with high content of plant nutrients and organic matter.

6.2 White and pelagic fish

Compared to vegetable and potato processing plants, animal processing plants had lower utilisation percentage of raw materials for food products. This can be explained by the higher proportion of inedible parts in animal carcasses than in many products of plant origin. Many animal food products still contain parts such as bones and skin, which cannot be directly used for human consumption. These parts may be valuable co-streams if fractionated at the processing plants and processed to food or feed products. At the consumer level, materials of animal origin that are not consumed can be utilised as pet food. Materials that are not consumed may also be collected for composting or bioenergy production at municipal plants.

Co-streams from the white and pelagic fish processing industry are regarded as valuable feed components due to the content of protein with high biological value; lipids with high proportion of long-chain n-3 fatty acids, and valuable macro and micronutrients like P, Ca and Se. Feedstuffs derived from fish are interesting for pig production, aquaculture and as pet food. There is a potential to increase the low utilisation efficiency of co-streams from white fish. A reason for the low utilisation efficiency is that it is not always profitable for fishermen to transport co-streams to the processing plants, and dumping of leftover raw materials at sea is not restricted or controlled by responsible governmental bodies. The main challenge there is to adapt methods and equipment for separation, preservation and processing of white fish co-streams for use on fishing vessels. In our calculation of the utilisation of raw materials, co-streams from white fish dumped at sea are not included.

Fish farming is a rapidly increasing industry, and the use of ingredients of vegetable origin in fish feed has increased during the last years. This causes a massive transport of plant nutrients like P and K into the sea, depleting soil fertility, unless nutrients are harvested from the sea and brought back to agriculture. Closing the green-blue nutrient transport into a cycle opens the potential for large fields of research and development. Growing macro algae to harvest excess nutrients from farmed fish, and harvested for feeding animals on land, may be an interesting solution.

6.3 Poultry

The poultry slaughterhouse had the lowest utilisation efficiency for food products (65%). Similar to the case of white and pelagic fish, the co-streams have high biological value and were almost completely utilised, however, the utilisation of some co-streams was economically not very beneficial.

Alternative utilisation may be possible for co-streams such as blood, remains after deboning meat, and feathers. Blood has a high nutritional value, adds a desirable colour to pet food and may be stored and transported frozen or dried. Remains after mechanical deboning of meat are ground, frozen in blocks and sold as feed for fur-bearing animals. This material still contains a significant amount of meat that can be separated from bones and cartilages by enzymatic methods and used as an ingredient for human consumption or as a high-quality feed component. Clean bones and cartilages are sources for collagen, biologically available Ca, P or chondroitin sulfate (a dietary supplement for treatment of osteoarthritis). Soluble proteins may be produced from viscera by enzymatic hydrolysis (Lasekan et al., 2013). In case of declining production of fur-bearing animals, alternative utilisation, such as in pig feed, may be considered. Some organs may also be considered for human consumption (Jayathilakan et al., 2012).

Today, feathers are used as feed for fur-bearing animals with limited digestibility. Mitigated legislation regarding PAP makes it possible to use e.g. feather-PAP also as fish feed component and it has been permitted to be used even earlier as a hydrolysed product. This keratin-rich material is difficult to hydrolyse, so new, sustainable processing methods would enable the recycling of the protein from feathers and decrease the need of imported feedstuffs.

Poultry co-streams, which cannot be utilised as food or feed should be utilised as fertilisers due to its high content of nutrients, to close the nutrient cycle. Sanitation followed by anaerobic digestion ensures both bioenergy and fertiliser production, and is a good solution for treatment of poultry co-streams not utilised as food or feed components.

7. Conclusions

Generally, in all cases a large proportion of the raw materials were utilised as food and feed. On average, 75% of the raw material at processing plants for vegetables and potatoes, white and pelagic fish, and poultry were utilised in food products, 21% was utilised in feed products, 1% was utilised for fertiliser and bioenergy production and 3% was disposed of as landfill. However, the utilisation of white fish co-streams as food and feed was lower than that for pelagic fish. Per tonne of food products, the plants used on average 8.6 tonnes of process water. Possible improvements in the utilisation of raw materials include in general a higher degree of utilisation in food products and developing feed components from co-streams with improved nutritional value. Only in the vegetable and potato case was a significant proportion was deposited as landfill, which is not a sustainable solution and alternatives must be found. The potential for fertiliser and bioenergy production is most likely limited to certain risk materials due to the high degree of utilisation in food and feed applications. Feed potatoes and vegetables and feathers, bones, blood, viscera and skin from fish or poultry have considerable potential for better utilisation for food or feed. Relevant processing methods for these co-streams are fractionation, hydrolysis, fermentation and drying.

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