Technology Innovations and Business Models for Valorisation of Industrial Waste Biomass in Sparsely Located Enterprises (SYMBIOMA)

Circular economy cases and their business models in fish, potato and alcoholic beverage industries

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The project is being implemented by the following partners:

Lead Partner

Centria University of Applied Sciences, Finland (CENTRIA)

Other Partners

Institute of Technology Sligo, Ireland (ITSligo)

Norwegian Institute of Bioeconomy Research, Norway (NIBIO)

Hermanni Winery Ltd, Finland (Hermanni)

Luleå University of Technology, Sweden (LUT)

Bottenvikens Bryggeri Ab (Bottenvikens)

EXECUTIVE SUMMARY

This report is prepared in the framework of the co-financed EU Norther Periphery and Arctic (NPA) Programme project - "Technology Innovations and Business Models for Valorisation of Industrial Waste Biomass in Sparsely Located Enterprises. Case: Industrial Symbiosis for Valorisation of Waste Biomass from Food and Beverage Industries" project (SYMBIOMA), project no. 352. The project aims to kick start a circular transformation and make a measurable contribution to delivering the boost in economic development, environmental services and entrepreneurial innovation in rural areas. For this purpose, a viable multidisciplinary circular economy related SYMBIOMA Technology Innovation Platform (TIP) focused for use in NPA regions will be established, and a related service package created. The TIP service will include access to research, laboratory and pilot scale infrastructures and expertise available in research institutions to achieve potential bio-waste streams valorisation in bio-based industries. The platform will also seek to support innovation and the development of useful relevant technologies, technology transfer support, knowledge about similar or compatible waste streams in the region in order to increase volume and improve possible profitability via aggregation, and assist in exploring collaborative dynamics and business models such as clustering and industrial symbiosis.

In this report, through in-depth interviews, field study and document analysis, the project has mapped the situation in the NPA project partner countries and identified challenges and potential opportunities in existing business models. This report presents case studies from all four partner countries (Finland, Norway, Sweden, and Ireland) and from the three focus industries (alcoholic beverage, potato, and fish). These results create a valuable understanding of the current situation in the partner countries. By highlighting the challenges and opportunities from each industry and country, learnings are presented to support the development of future businesses and the ongoing project work.

In conclusion, it is of importance to highlight that the trend of sustainable, locally produced bio-based production and circular business modelling becomes essential in many industries globally as well as for companies in remote sparsely populates areas. This study has shown that there are good examples of industrial cases, where companies follow innovative and sustainable mind set to keep in balance business challenges and business opportunities to shift towards circular business models.

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1.0 Project Description

The SYMBIOMA project mainly aims to kick start a circular transformation and make a measurable contribution to delivering a boost in economic development, environmental services and entrepreneurial innovation in rural areas, goals envisaged by the European Commission (EC) and the Northern Periphery and Arctic (NPA) programme. The project is specifically designed to address the key circular economy and related technology knowledge gaps and deficits especially facing food and beverage industry segment SMEs that dominate the sectors operating in sparsely populated / remote areas. The project will achieve this goal by initially working closely with such bio-based SMEs, providing valuable laboratory and pilot scale infrastructure and expertise currently unavailable to the SMEs to assess and evaluate the valuable side and waste streams from their processes. The project will also aim to map similar or compatible waste streams in the region in order to increase volume and improve possible profitability via aggregation, to identify economically viable valorisation routes and products, and assist in finding other industrial partners for collaboration.

As a final and main output of the project, the open and easily accessible and multidisciplinary circular economy (CE) related SYMBIOMA Technology Innovation Platform (TIP) will be developed to provide SMEs and other targeted stakeholders with knowledge and technology transfer expertise for better utilisation of waste and process streams in bio-based value chains. The platform will also assist in exploring collaborative dynamics, potential markets and business models such as clustering and industrial symbiosis.

1.1 Main Objectives of the Report

This report maps, identifies and proposes different business models for circular economy (CE) implementation in the participating NPA project partner countries (See Figure 1).

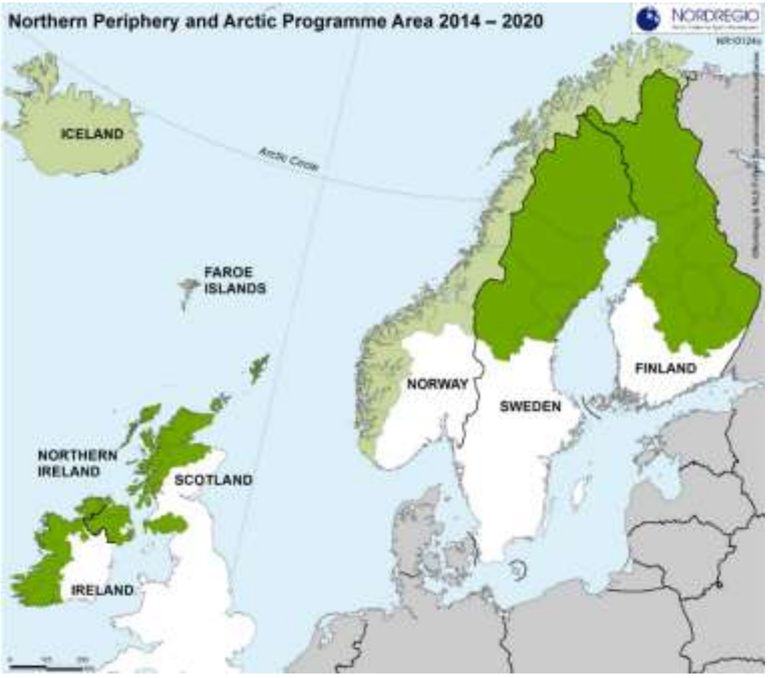


Figure 1 NPA programme areas (borrowed image from http://www.interreg-npa.eu/).

The report will assist in systematization of strategy for developing commercially viable CE business models. It will also set the bases for transformation to value network of the product and/or service itself, i.e. multiple actors involved in the value network and operations.

The in-depth interviews and field work based on action research with key actors from SMEs were performed to support this report. Our mapping identifies existing business cases and utilised technologies for waste utilisation and assists in developing criteria for clustering SMEs based on valorisation routes. Mapping will assist in proposing circular business models for the industry to valorise wastes successfully and sustainably, based on the available biomass waste (clusters of SMEs), available technologies, while considering local institutional arrangements and market structures.

In this report, through in-depth interviews, field studies and document analysis, the project has mapped the situation in the NPA project partner countries and identified existing circular economy business model challenges and future opportunities. This report presents case studies from all four partner countries (Finland, Norway, Sweden and Ireland) and from the three focus industries (alcoholic beverage, i.e. breweries and distilleries, potato and fish). These results create a valuable understanding of the current situation in the partner countries. By highlighting the challenges and opportunities from each industry and country, learnings are presented to support the development of future businesses and the ongoing project work.

2.0 Existing circular economy cases and their business models

To map the existing circular economy cases and their business models, the NPA region in the four partner countries have been analysed. Each industry is described in an overview and current business models are illustrated through representative cases. From the analysis, conclusions about the challenges and opportunities are drawn.

The assessments for each regional industry subsection (2.1-2.3) includes:

- description of steps in industrial process
- description of current business situation per country with highlights concerning the NPA area
- presentation of existing companies within the industry, their side stream, by-product and waste handling
- future opportunities for better valorisation of by-products, side streams and waste
- current bottlenecks for more effective valorisation.

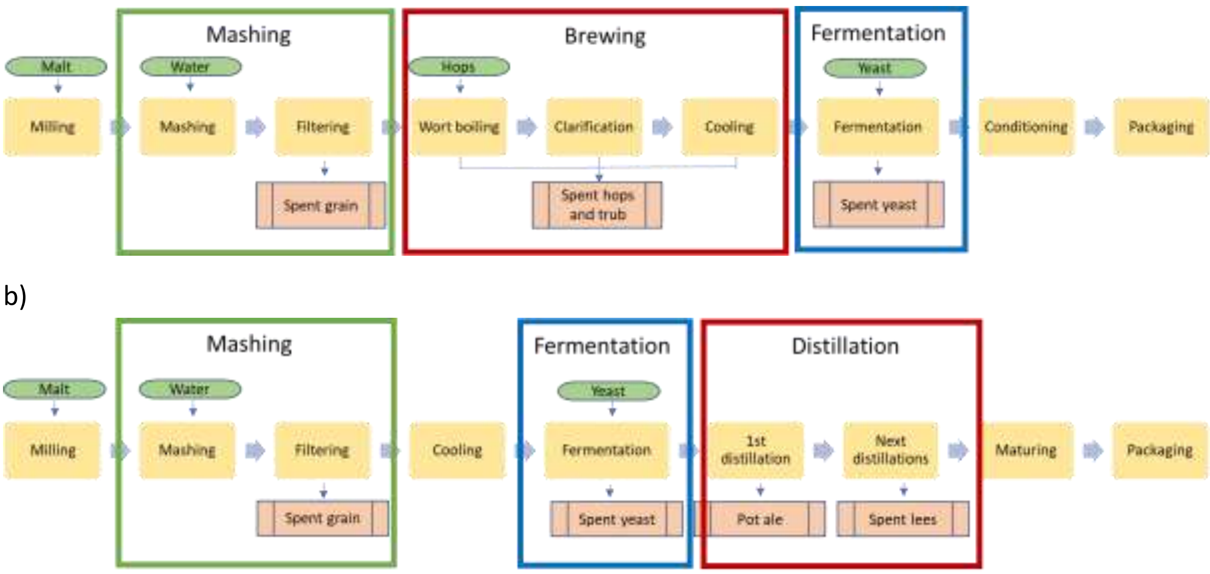
2.1 Brewery and distillery processes

Breweries and distilleries have a long tradition in the NPA region. Apart from very few larger companies most producers operate in small or micro-sized companies. This industry is particularly interesting because it is resource intensive and huge amounts of biomass are remaining after the production process.

Commonly, the brewing beer is a 9 stage-process which consists of milling, mashing, filtering, wort boiling, clarification, cooling, fermentation, conditioning, and packaging stages as shown as Figure 2a. Depending on type of beer, before packaging additional filtration and clarification might be needed.

a)

b)



Error! Reference source not found. Malt, water, hops and yeast (highlighted in green) are input i ngredients in the particular stage which result in the main by-products generated from the production process which are spent grain, spent hops and trub, and spent yeast (highlighted in red). The brewers' spent grain (BSG) is the main solid by-product generated in large quantities by the beer industry and is obtained after the mashing and filtration stage. It is estimated that worldwide, the annual output is around 30 million tons, about 200 tons of wet BSG (70–80% water content) being produced per 10,000 hl of beer (Farcas et al. 2017).

Spent grains are main by-product stream also from distilleries as mashing process is the same. Distillery process though has no brewing and after separating spend grains from wort, fermentation starts. Spent yeast stream is also formed here. After fermentation alcohol is distilled for several times and finally it is matured. Side stream of distilling process is called pot ale (1^{st} distillation) and spent lees (further distillations). Distilling process shown in Figure 2b.

Breweries and distilleries are both energy and water intensive industries. Energy is needed for boiling liquids, cooling requires substantial amount of cooling water. Additionally, fermentation process produces CO_2 which in most cases is emitted to air.

The follow up chapters describe the characteristics of the breweries and distilleries in NPA regions of the four partner countries, Finland, Sweden, Ireland and Norway. Regional differences, historical developments and existing collaborations affect the industries and the presented case studies give a representative illustration of the conditions in each region.

Finland

In the NPA region there are 21 small breweries (producing less than 10 million litres of beer annually), additionally 9 breweries are in less than 150 km proximity to the NPA border (Pienpanimoliitto,2020). Small breweries in and close to NPA regions produce some 8 million litres of beer annually. Only 7 breweries in NPA are producing more than 100 000 litres of beer, others are microbreweries, some of them produce less than 10 000 litres annually.

In the Finnish NPA region, a big brewery, Olvi Ltd, which produces annually 219 million litres of beer is also located (Olvi,2020).

Finnish whisky industry is also small scale, it is represented with 5 distilleries. In the NPA area there is one distillery in East Finland. It produces 120 000 liters of pure alcohol annually (data from interview). From time to time small batches of alcohol are distilled in several breweries, e.g. in Tornio.

Figure 2 shows location of breweries and distilleries in the Finish NPA area.

The main by-product, brewers Spent Grains (BSG) is used mostly as feed to animals with few exceptions where it is used for biogas production. Farmers usually pick up the BSG quantities by themselves. Such collection practices aid a potential reduction in the transportation costs by the brewery, and in addition saves biowaste handling costs, which depending on the region can be between 50-90 €/ton.

Based on the EU waste hierarchy, BSG utilisation as animal feed should be prioritised (Directive 2008/98/EC, 2008). The cascading use of resources and especially of biomass prioritise higher value uses that allow the reuse and recycling of products and raw materials and promotes energy use only when other options are starting to run out. Using BSG as feed first also reduces environmental impact of beer or whisky production as it reduces need for virgin feed sources for animal production.

Higher value products which can overpower pre-treatment and transport costs would inspire entrepreneurs in creation of value chain for better utilisation of waste and side streams.

Although BSG is mentioned as main by-products, need for investments to energy recovery solutions was mentioned as a priority in most of the interviews. It is understandable, brewery is energy and water intensive process, up to 10 litres of water is used to produce 1 litre of beer in a linear process.

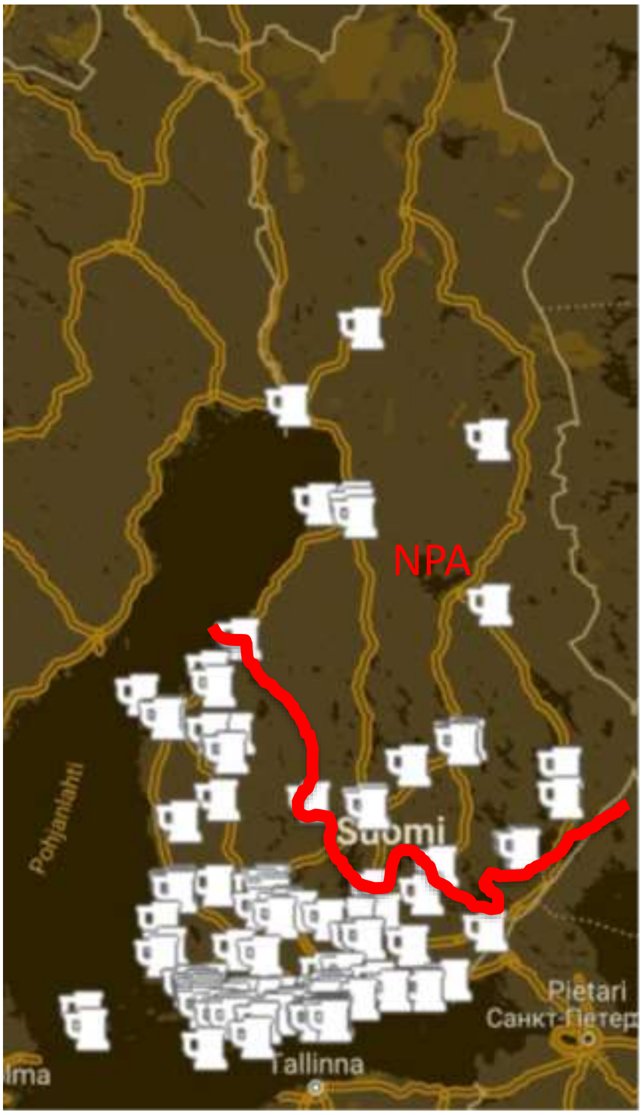


Figure 2 Finnish small breweries (image borrowed from pienpanimoliitto.fi).

Case descriptions

Case 1: Brewery (interview)

Case 1 brewery is the biggest brewery in the category of small breweries, it produced 440 000 litres of various beers in 2019, and also recently started production of whisky. Capacity is planned to increase in future as a new production line is being planned. The brewery is owned by a company, which not only develops and verifies recipes for brewery, but also provides laboratory services, including preparation of yeast cultures, enzymes and extracts for the brewers and distilleries. The brewery is situated near the border between Sweden and Finland and therefore has market in both countries, also cooperates with breweries in Sweden.

The company invested in 2016 into fully automated brewing process and has a personnel strength of 10 employees. Although the company has very modern technology process, side and waste streams are fairly utilised. The BSG quantities after the mashing process is currently utilised as an animal feed, with the other streams considered as waste. The spent yeast is drained to the municipal wastewater plant as well as all other liquid streams emanating from the brewery processes.

For future cooperation on by-products and side stream utilisation, a potential network with other breweries can be established. This is since within a 130km proximity radius of the brewery, there are 4 breweries in Finland and 1 in Sweden.

Case 2: Micro-Brewery (interview)

A microscale brewery situated in Kokkola., which employs 3 people. The company currently produces about 25 000 litres of beer currently. The brewery has strong interest in developing special yeasts for beer produced, is working with researchers from Umeå University. Due to small scale production, the amount of waste produced is relatively small, and wastewater pre-treatment is not required and therefore all the liquid streams are presently discharged to the municipal sewage plant. Only BSG is given away to farmers as feed, who are responsible for the BSG pickup. The company saves 40 €/batch (50 batches annually) from this arrangement.

Drinking water from municipal supply is used for cooling and it is not recovered, therefore energy recovery is one of the biggest interests by company.

The closet brewery for potential collaboration in the future is situated about 40 km away, with more breweries in distances of 100-120 km.

Case 3: Brewery (information from report by Pesonen et al., 2018**)**

The brewery is situated in Kuopio, East Finland. It currently has an annual capacity of production of 100 000 litres. Iso-Kalla intends to triple its production from the current 100,000 liters in the near future. The brewery plans to expand its product range by the additional manufacturing of gin, whiskey, and vodka after the completion of the expansion process.

The production waste streams are very similar to other beer productions facilities. The produced BSG is transported to biogas production (distance of 15 km). Small amounts of BSG is given to a producer of bread. To make this latter utilisation on a bigger scale, the drying of BSG would be needed.

In the near proximity of the brewery (20 km radius), there are 3 other microbreweries, and 2 more if 100 km distance is deemed economically acceptable. Iisalmi, which is some 80 km from Kuopio is home of Olvi Oy, one of the biggest beer producers in Finland.

Brewery was seeking to find farmers to utilise their BSG, however the search was not successful. Olvi Oy though in their environmental responsibility report (Olvi, 2019) claimed that their BSG is being fed to cattle. This could mean, that farmers in surrounding area have a choice and prefer to make contracts with bigger companies who can provide them with the meal constantly, and with stable supplies, rather than deal with small producers. On the other hand, if Olvi is interested in upgrading utilisation of BSG to higher value products, small breweries from surrounding area could benefit from it also. In this respect, Kuopio region has potential to establish new process for conversion of BSG to more valuable products.

Case 4: Beverage company

The company is situated in East Finland, with operations in several locations. It has broad range of products: berry juices, wines, liqueurs, as well as distillery products, such as gin, whisky, and other spirits. The production plant is in Ilomantsi, where whisky is produced and is stored at Valamo monastery (Heinävesi), which is a distance of 135 km away. The fermentation process for the company is carried out only in Valamo, with distillation units available both in Valamo and in Ilomantsi.

Brewing and distilling capacity in Valamo is for 120 000 dm^3 of pure alcohol. SG (spent grain) from the production is shared to farmers, however there are too little cattle in the near proximity to consume all of the produced SG, resulting in some of the BSG being dumped. To preserve the SG, the company is adding formic acid. Pot ale left after distillation process is used as fertilizer, which is spread on the fields nearby.

For process cooling and for cleaning, lake water is used, which brings about a significant reduction in process costs. Heat recovery from water would be also beneficial, but not currently employed since the company has limited space for storing water.

For potential collaboration opportunities, the closest distillery /brewery to Valamo is a brewery in Joensuu (62 km), with 6 other small breweries in about 120km distance radius.

In the Ilomantsi plant, there are 6 distillation units of different sizes. These units are used for production of gin. The alcohol for production is purchased from the market.

The main concern in the Ilomantsi plant is benefits from hot water streams which are generated during the cooling of distillation units. The water is clean drinking water and after use is directly released to the municipal sewage plant. With the outlet water temperature being as high as 70°C, the potential for heat recovery has been discussed with a local energy company. However, no agreement reached so far.

Future opportunities for waste handling:

- It is clear, that the waste and side streams of the brewing industry are underutilised and therefore there are a lot of opportunities for future development.
- BSG is utilised as animal feed or for biogas production, the possibility for extracting valuables, such as proteins from it would bring additional value for this by-product.
- New products using BSG could be developed, such as e.g. bakery products.

- Spent yeast in most cases was not recovered or further utilisation any way. This by-product is however a protein rich product and could be used at least for animal feed, or further upgraded for other uses.
- Pot ale from distilling process is rich in proteins, which could be extracted and further valorised.
- Significant amount of CO_2 is produced during the fermentation process. The CO_2 is currently not captured or used. If economically feasible, a solution would be available, with the captured CO_2 could be used instead of purchased CO_2 and could be also be sold to other food industries or uses.

Bottlenecks / challenges for efficient waste handling:

- Breweries in Finnish NPA area are small and sparsely located and in many cases distance form brewery to brewery can be more than 100 km. Kuopio region could be an exception, several breweries are located nearby and the presence of a big scale brewery might open new possibilities for creation of added value products from waste and side streams.

Norway

There are 10 breweries and approximately 150 microbreweries in Norway. Approximately, half of these breweries are in the Norwegian NPA area which consists of six counties: Troms and Finnmark, Nordland, Trøndelag, Møre og Romsdal, Vestland and Rogaland. In the last years, home brewing has also expanded considerably.

In the period from January 2019 to January 2020, sales statistics show a total sale of 231 million litres of Norwegian brewed beer, and out of this, 10.3 million litres were brewed by microbreweries (data from The Norwegian Brewery Association, www.drikkeglede.no).

Currently, basically all malt for brewing is imported to Norway. Lindberg et al. (2016) estimate that this adds up to a total of 55 000 tons annually. They further explain that of this amount, the quantities consumed by home brewers is approximately 500 tons, to microbreweries 1 000 - 1 500 tons, while the rest is utilized by the larger breweries. Waste related to brewing is estimated to be approximately 17 000 tons, mainly in the form of Brewers Spent Grain (BSG) - i.e., dried spent grain (Lindberg et al., 2016). BSG is mainly utilized as feed, and the farmers themselves pick up the spent grain directly at the brewery, immediately after the brewing (see example Figure 3). Of special consideration for the utilization as animal feed is the moisture content. Since spent grain has a high moisture content, it gets mouldy easy and has a very short shelf life, if not dried or frozen.

Figure 3 Spent grain used as feed for goats. Photo: Anette Tjomsland, NIBIO

Lindberg et al. (2016) estimate that spent grain totals about 31% of the original malt weight, meaning that the total volume of spent grain in Norway is 17 000 tons. The report also explains that BSG consists mainly of the outer parts of the grain, and cell walls of the aleurone layer and the endosperm, but the chemical composition varies with the type of malt (barley) and the type of beer produced. In addition to the carbohydrates, BSG also contains about 15-24% protein, and 1-10% fat (Lindberg et al., 2016).

The total production area for barley in the Norwegian NPA region is 42540 hectares (SSB, 2018, www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/korn/aar-forelopige), and basically all this barley is utilized as feed. However, there is a growing interest in producing barley for malt in all parts of the Norwegian NPA region (Halland et al. 2016).

Other ingredients used in the brewing process include hops, yeast, and herbs, fruit, or berries. Smaller amounts of these ingredients are also left after the processing. There are recent examples in the literature that yeast from the brewing is reused for the functioning of a spa, and that the same brewery has plans for using it in soap production (Bertella et al. in press). In the beverage production, it is estimated that on average, beverage manufacturers use two litres of water per litre of finished product (data from The Norwegian Brewery Association, www.drikkeglede.no).

In its current stage, brewing results in two main streams: beverages for human consumption (mainly alcoholic), by-products which is subdivided into food and agricultural applications (Figure 4).

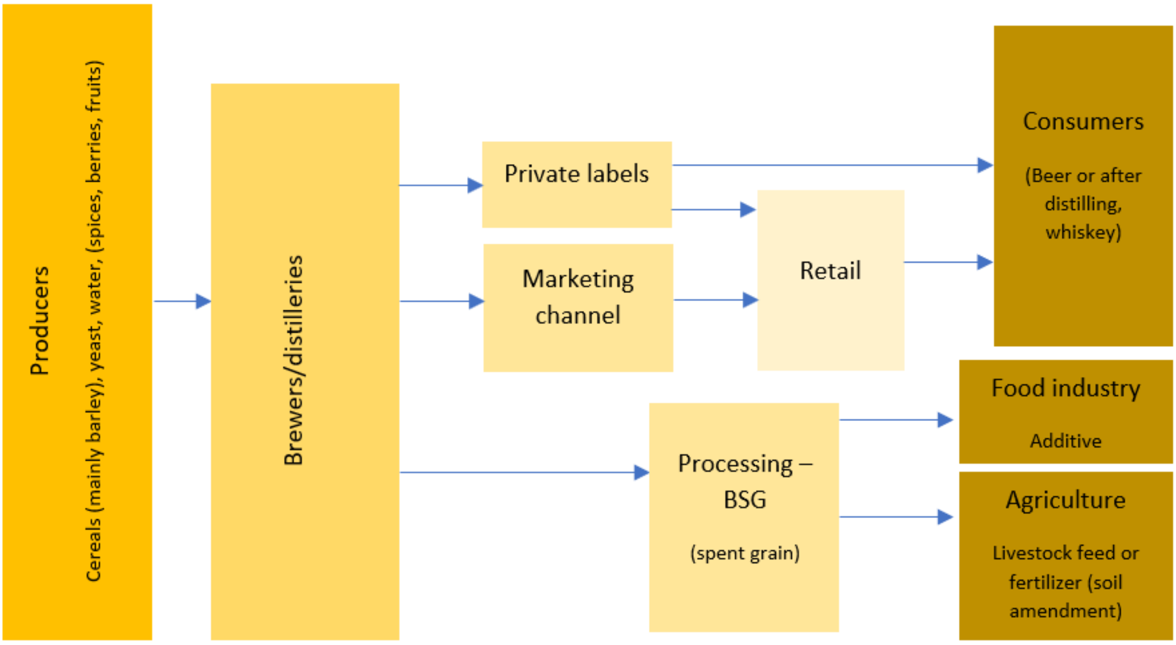


Figure 4 Value chain of brewing and distilleries in northern Norway.

Case descriptions

Case 1: Whiskey producer in northern Norway

The company is a micro distillery that started up 5 years ago. Their main beverage products are whiskey and gin, but a big portion of their income comes from other activities related to tourism. The amount of waste is currently very small, about 750 kg of spent grain per week, and smaller amounts of yeast, pot ale, and some remains of herbs/berries. Today, essentially all waste is discarded directly because of logistical problems. There have however been some attempts on using spent grain as sheep feed and for producing local crispbread. Currently excess energy in production is not utilized, but they see a potential for utilizing it in the future.

Case 2: Microbrewery in northern Norway

The company has been producing beer for two years. In 2019 they produced 10 000 litres and the plan for 2020 is to triple their production. In addition to brewing, tourism is also a part of their business model. In 2020 they estimate that they will have about 11 tons of spent grain, where the main portion will be given to farmers as feed for sheep and cows. In addition, they made a contract with a local bakery that will use spent grain to produce crisp bread. They are also experimenting with producing their own planting soil mixing sheep manure, spent grain, and soil.

Future opportunities for waste handling:

- Food additives, example crisp bread.
- Agricultural applications, such as livestock feed or soil amendment.
- Feed for fish.
- Potential for utilizing excess heat energy from production.

Bottlenecks / challenges for efficient waste handling:

- Collaboration /common projects.
- Distance / location concerns, including logistics.
- Shelf life of spent grain: it easily moulds if not utilized directly, gets frozen, or dried.
- Fewer farmers that can utilize BSG for feed.
- Farmers might need specialized technical equipment for feeding with spent grain.

Sweden

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

In the Swedish NPA region 94 beverage companies are registered including 29 breweries and 5 distilleries (Allabolag.se). All breweries are small and are microbreweries with less than 19 employees. Based on the conducted interviews, certain reflections and conclusions could be highlighted: production and waste volumes are rather small, and the long distances and lack of a branch organization hinders closer collaborations. For most breweries, waste is not a major obstacle and they are happy to get rid of it for no or low costs. The entrepreneurs (the owners of breweries) have a passion for beer but not the same passion for waste utilization and that together with the resource constrains of SMEs results in low activity for the development of circular waste business models. Even though the owners of breweries would like to see a better utilization of the waste products but preferably with little effort from their side.

In addition, during interviews it has been learned that the main waste product from the breweries, spent grain, is commonly collected by farmers, that have cows or pigs, without any payments involved. To be allowed to sell animal food, expensive permits would be needed which hinders SMEs from selling their spent grain. In the regions where no or too few farmers exist, alternatives must be found and the potential for innovation is higher. For example, the use of spent grain in sourdough bread is currently being explored. Private people can also pick the spent grain as fertiliser. One brewery that has no farmer close by, transports the remaining spend grain to the local district heating supplier for energy recovery. Some of the CO2 and the energy from cooling is reused in the production process.

In addition, the main challenges to the development of circular business models based on their by-products are the small, irregular waste volumes produced by the beverage processes that cannot be stored properly. This together with legal restrictions on the potential use and resource limitation leads to a situation where brewers do not sell any of their waste products. There is potential that energy or biogas producers could pay for the biomass, or legislation changes that the production of food or animal food would easily be allowed from such wastes or by-products.

Case descriptions

Case 1: Microbrewery

Is a microbrewery that produces beer in Norrbotten. The brewery was founded in 2014 and by 2020 has a large variety of beers. In 2019, they produced 10 000 litres of beer. The company follows trends and has a great willingness to collaborate for example with tourism industry. So far, they have 3 owners and look for expanding. In their assortment there are beers from 2.25 to 10% alcohol strength (v/v%), 4 standard beers and provisional products that follow seasonal trends thus discovering opportunities to innovate the production line.

The most common ways to utilise the production waste is to send away spent grain for the animal feed (collected by the farmer), wastewater and spent yeast to municipality sewage system. Some energy from cooling and CO_2 is reused in the production. They are also involved in a project where spent grain is used to feed mealworms by also recovering heat from a datacentre.

Case 2: Microbrewery

A microbrewery with sustainability and innovation "thinking" that produces beer in Swedish Lapland. The brewery was founded in 2017, with production commencing in the second part of 2018. There are five owners and one employee. The owners are highly educated e.g. in chemical science and have good understanding of the properties of the waste material. The most preferred ways to utilise the production waste is to send away spent grain for the sourdough bread which is baked in a local restaurant. Private people can also pick up the spend grain to use it as fertiliser. They can bring the rest of the spend grain to the municipalities district heating plant. Their different way of handling the produced waste is due to the lack of farmers in the region. They also recover some CO_2 and energy.

Case 3: **Small beverage company**

A small beverage company inspired by the culture and landscape in the most northern part of Sweden, Norrbotten. The beverage company produces beer, Christmas and Easter must, soft drinks with unique natural ingredients. One of the unique ingredients as well as a product is the spring water filtered for centuries originating from Sulitelma's glacier at the Arctic Circle. The spring water is also sold internationally (Germany and Norway).

There are 6 employees in the production site. The company's aim is to work sustainably with everything from raw materials, packaging, to production and shipping. "Must" production is about 8-10 thousand bottles per day (during Christmas and Easter times), and 6-7 000 bottles of beer.

The most common ways to utilise the production waste from the beer production is to give the SG to a pig farmer in Boden a small town which is located about 40 km from the production site). The farmer comes to pick up SG 2-3 times per month by own costs. There is very low production waste from the soft drinks production. The overall wastewater goes directly to the municipality sewage.

Future opportunities for waste handling:

- Biogas/energy production would pay for biomass
- Larger scale for bread production
- Small scale dryers to enable storage and transport

Bottlenecks / challenges for efficient waste handling:

- Legal restrictions
- No collaboration /common projects
- Distance/ location

Ireland

There are currently 125 microbrewing companies operating in Ireland, of which 75 are independent production microbreweries. The majority are craft driven with an emphasis on taste, quality and balance compared to the large-scale brewery ethos which is more concerned with volume of brew output and the efficiency of the brewing process.

The total beer production in Ireland (2017) amounted to 8,019,000 hl of which the independent microbrewery production figures of 157,000 hl represented 1.9% of the production market. Total consumption of beer in Ireland (2017) was 4,479,000 hl. Of the figure produced by independent microbreweries some 126,500 hl were sold in the domestic Irish market, with 30,500 hl going for export (19.4% of total market) indicating an Irish independent microbrewery share of domestic beer consumption of 2.6%. More than one in six microbreweries had a turnover of less than €50,000 and more than one-third had less than €100,000. One in five microbreweries had a turnover in excess of €1m (ICBI, 2018).

Irish microbreweries consume twice as much energy per hectolitre of finished product compared to large breweries, as they do not benefit from the efficiencies of scale. New entrants to the industry in the past two years were partly offset by closures which reflect changed market circumstance, increased competitiveness and a need to adopt measures as an effective way to reduce overheads and stay in business (ICBI, 2018).

In tandem with this change, waste policy in Ireland has been developing in line with the central elements of the Circular Economy resulting in an increased awareness within the Irish beverage industry that potentials exist to harness further growth and value addition from their waste streams. This has resulted in an increased uptake in the establishment of a circular economy ethos amongst micro-breweries in the Irish NPA regions.

Brewers spent grain (BSG) is the major by-product of the Irish brewing industry, representing around 85% of the total by-products generated. Within the sector primary opportunities involving spent grain being utilised as animal feed have highlighted its potential as a by-product rather than a waste while simultaneously reducing feed imports in the Irish agricultural sector.

The Department of Agriculture Food and the Marine (DAFM), as the competent authority for animal feed, is tasked with ensuring the control and safety of the feed. This department also oversees funding initiatives that will seek to underpin greater utilisation of natively produced grain as well as identifying higher value end uses for the waste streams generated from within the sector.

Breweries who are feed business operators (FBO’s) are classified as “Suppliers of Feed Materials”. DAFM requires that any operator producing or supplying feed materials from food or industrial processing must be registered and comply with their obligation as feed business operators (FBO’s). To be compliant, breweries in the NPA region need to ensure that their (Hazard Analysis & Critical Control Point) HACCP is amended to indicate that their by-product is not a waste but a by-product under Article 27 of the Waste Management Acts and designated as animal feedstuffs.

BSG as a potential functional ingredient capable of enhancing the nutritional value of cereal and bakery products due to its high content of protein and fibre (around 20 and 70% dry basis, respectively), continues to be investigated but developments in this respect have been speculative, slow to develop and niche. Noted challenges associated with using BSG as a bakery feedstock includes the existence of a complex outer layer, making it difficult to separate and convert, and a high moisture content (80% - 85%), making it susceptible to microbial growth and spoilage within a 7-10-day period. Research into bioprocessing techniques and enzymes to improve the quality of baked snacks with BSG are ongoing as are evaluation of the consumer acceptance of these products (Ktenioudaki et al., 2012).

Based on the conducted interviews, wastes from sugar fermentations and distillation can be digested anaerobically and the methane generated used as an energy source. Progression from low risk/low return opportunities to this level of waste use for BSG is influenced by a variety of factors most notably, justifiable waste volume accumulations and technological challenges that exist.

Many individual Irish breweries are also located in rural regions and have small outputs, with over 50% currently producing less than 1000 hl per year. Currently, the smaller volume of spent grain being generated by Irish microbreweries reduces the feasibility (both commercially and environmentally) of developing an onsite AD plant, without the intake of third-party feedstock, which adds regulatory complications, as well as transportation requirements and organisational barriers.

The feasibility of anaerobically treating brewery by-product to provide a supplementary energy source would be best supported by a "hub and spoke" industrial symbiosis business model approach with a bio-refinery (see Figure 5). The model approach is best suited to large scale breweries located in centralised regions (Buffington,2004)

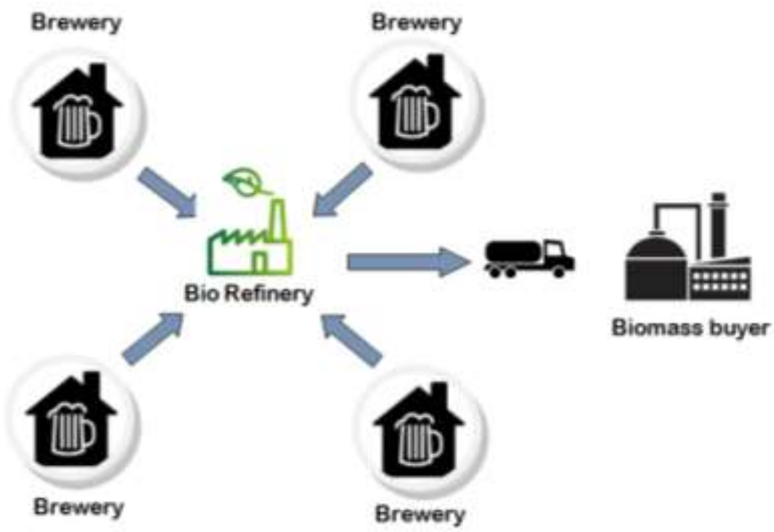


Figure 5 Industrial Symbiosis 'Hub & Spoke' BSG supply chain material flow (borrowed from Buffington,2004).

Micro-breweries located in the NPA region tend to rural based, producing small amounts of beer and hence small amounts of spent grain. There are too few cluster groups of breweries located throughout the NPA region to justify the existence of a bio-refinery facility to service the small amounts of waste volumes that these breweries produce. The NPA region is also spread out along the west & north of the country, making a geographically acceptable centralised location that little bit harder to establish. The large-scale breweries in Ireland tend to be located in urban environments in the east of the country, most notably Dublin and greater volumes of BSG occur in this region (outside the NPA). A justified centralised bio-refinery located to service breweries in the NPA region would necessitate a joint-up and/or a co-operative attitude to exist among the breweries operating in the region. This is however lacking at the moment as each brewery are working independent of each other when it comes to tackling their waste streams including BSG.

Currently, larger breweries such as Guinness and Heineken Ireland, whilst keen to achieve zero waste to landfill have yet to explore routes beyond traditional animal feedstock with any surplus grain considered not palatable to livestock being reprocessed at offsite-composting sites and sold as gardening compost.

Case descriptions

Case 1: Distillery

Established in 1784 in Northern Ireland. Their product is triple distilled from 100% malted barley with spent grain sent to local farms as animal feed. Animal feed with its high value end use was considered the best option for the company for by-product use, featuring high on the waste hierarchy – preventing the arising of waste and reducing the need for virgin resources to feed animals.

In order to improve efficiency, an onsite evaporator was installed to facilitate for greater transport efficiencies and increasing shelf life of grain before distribution.

The company have also carried out research along with Queens University Belfast (QUB), to investigate the feasibility of converting their BSG from a biological waste (lignocellulosic biomass) to synthesize activated carbon (AC) and carbon nanotubes (CNTs) for use in water remediation applications.

Case 2: Brewery

It is a microbrewery who have brought numerous beers to market and is a typical example of how some Irish microbreweries are finding niche markets for their waste streams. Equipped with a degree in chemistry, the company CEO qualified as Ireland' first female beer sommelier and was awarded the prestigious gold medal by The Institute of Brewing and Distilling in London. Over the past two years they have realised novel innovative approaches to the processing and reuse of their nutrient rich brewing waste that involves converting their spent grain and nutrient rich water from the brewing process into dog snacks, granola bars, and mediums for cultivating mushrooms by inoculating BSG with mushroom spores. The grain is then placed in a high humidity environment and the mushrooms yield in a month, particularly Oyster mushrooms which have witnesses significant growth yield.

Future opportunities for waste handling:

There are numerous alternative opportunities available for utilising organic matter generated from brewing and distilling processes in Ireland. Figure 6 illustrates potential utilisation of BSG based on Nigam (2017) and Buffington (2014). The majority are considered niche markets, or are only suitable for either very small volumes, or large joint aggregated collections. Regardless, downstream benefits exist from brewery waste stream products for the agricultural and other sectors.

The use of distillation and brewing by-products as animal feed has a long-established tradition between the alcohol and farm industries in Ireland, and which has evolved alongside each other specifically in rural regions resulting in an efficient and effective localised infrastructure with high value use of by-product generated. For brewery production in urban environments, the transport

distances to farms are significant.

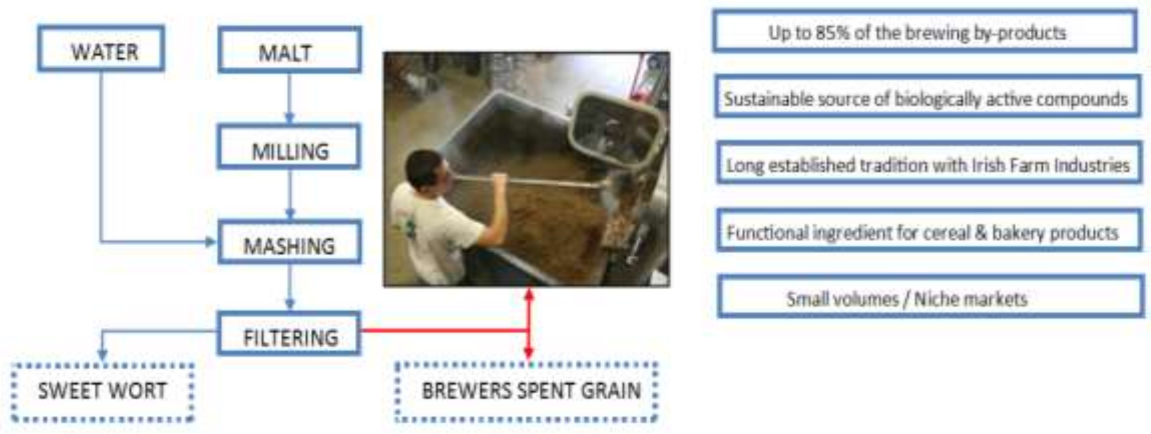


Figure 6 Brewery Spent Grain (BSG) potential overview based on Nigam (2017) and Buffington (2014).

Breweries with a particularly high-volume production on site are beginning to value higher risk/higher return by-products equally or more highly as feasible alternatives to animal feed. Biofuel production or anaerobic digestion are useful markets for by-product, with growth in AD facilities anticipated as being the main opportunity in coming years.

BioGas:

In light of the EU's 2020 goals for new sources of renewable energy. Brewer's spent grain (BSG) is an appealing waste product for conversion to biogas.

Composting:

Spent grain is nitrogen-rich and acts as a good composting material. Other organic arisings, where smaller volumes are being handled (for example, plant extracts from gin production), are very well suited to composting.

Absorption of heavy metals and pollutants:

The hydroxyl, carboxyl and amine groups present in spent grains have a high affinity for metal ions. This makes them a useful medium for use in treatment of wastewater high in these pollutants, such as textile and dye industries.

Cereal/Bakery Products:

The health benefits of dietary fibre and investigation into novel low-cost sources of fibre have highlighted the potential of BSG to enhance the nutritional value of cereal/bakery products. The Irish Department of Agriculture, Food and the Marine (DAFM) continue to research BSG potentials to increase the fibre content, decrease the calorific content and increase the protein content of food products.

Bottlenecks / challenges for efficient waste handling:

- The availability of brewers' grains is not always consistent due to a seasonal brewing practice exercised by some brewery companies. Prices during the winter months reflects the peak demand for the feed. During the summer period, brewery production generally reaches its peak while demand at farm level for fresh feeding is low. This results in a lower price and need for specialist storing. Long-term storage requires adding an absorbent. However due to its lower dry matter content, higher rates of the absorbent are needed to ensure that the product stacks correctly and to mitigate nutrient loss due to 'run-off'. Some farmers have reported grains dry matter as low as 16% moisture content ultimately impacting storage and feeding value leading them to seeking transparency on all feeds purchased. The low dry matter requirement thus leads to the need for large amounts of absorbents to stabilise it, consequently adding a higher cost to the product. Despite this, with a current delivered price of €35/ ton, brewers' grain represents good value for money on an energy and protein basis, provided dry matter content is kept above 22% (moisture content).

- Microbrewing is a much more labour-intensive activity than conventional large-scale brewing and is subject to substantial economies of scale and higher operational costs. As plant size increases, operational personnel do not necessarily increase in line. This situation can make it difficult for microbrewers to justify additional labour output into developing by-products from waste volumes that are small by comparison to macro breweries, preferring instead to use additional labour to increase beer production.

2.2 Potato processing

Potato is one of the most important agricultural crops for human consumption and high amount is produced worldwide every year. In particular, the EU produced about 60.7 million tons of potatoes (FAOSTAT, 2020). Potato peel is currently considered a zero-value or rather low value by-product, which occurs in largeg amounts after industrial potato processing and can range from 15 to 40% of initial product mass, depending on the various peeling or processing methods. Food waste utilization causes great concern in food industry in Europe and many scientific works and projects on this topic offer solutions and original approaches towards possible valorisation of potato peels (Sepelev and Galoburda, 2015).

Figure 7 represents a summary of the major wastes and by-products originating from the potatoes production and processing industry.

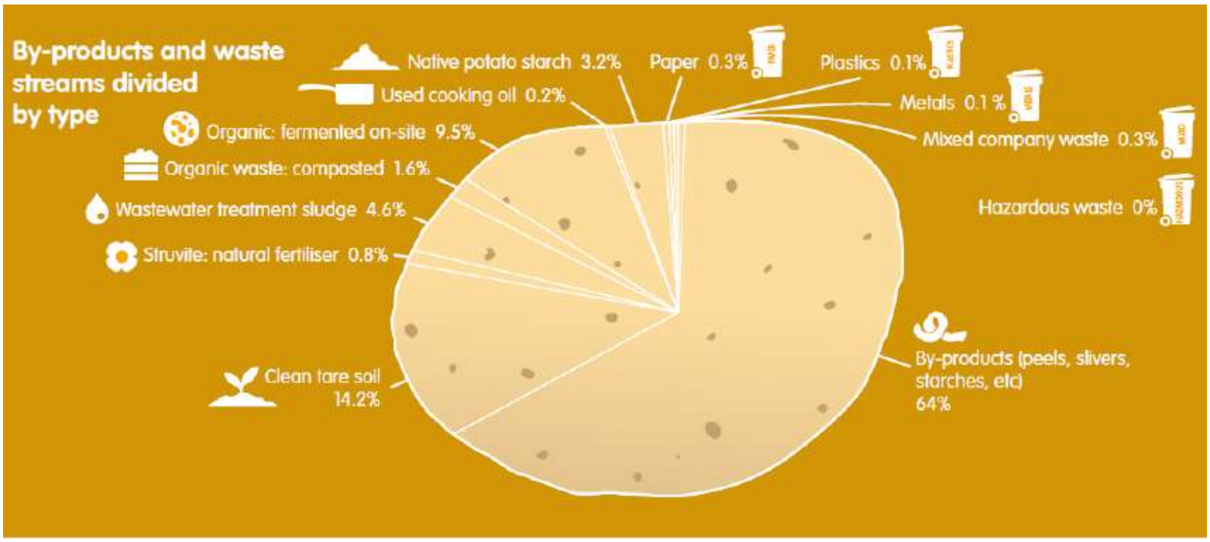


Figure 7 Schematic representation of the potato processing main wastes/by-products and the percentage composition of the different waste types (EUPPA, 2016).

Finland

In Finland, the total field area for growing potatoes in 2018 was 21 700 hectares (MTT, 2018):

- 9500 hectares was for growing potatoes for food consumption,
- 2950 hectares was for growing potatoes for potato industry and
- 6670 hectares was for growing starch potato.

In Finland Ostrobothnia and Northern Ostrobothnia (both are in NPA are) are main areas for growing potatoes: 3300 hectares in Northern Ostrobothnia and 5800 hectares in Ostrobothnia are reserved for growing potatoes (90 % of the total area reserved for growing potato in NPA area). Two thirds of the potatoes for food consumption and more than half of the potatoes for industrial use are grown in or near these areas. Also, about 70 % of the seed potatoes in Finland are grown in Northern Ostrobothnia (LUKE, 2020).

Most of the potato crops in Finland goes either to potato packing facilities (seed or food potato) or to potato industry (companies that peel and/or precook potatoes or manufactures different potato products). Main potato industrial processors in NPA area are presented in Figure 8 below.

In a 2012 report (Ahokas et.al, 2012), it was estimated that in Northern Ostrobothnia, side streams from potatoes packing facilities were 5300 tons, and from peeling facilities 1100 tons per annum. Since the area for growing potato in Ostrobothnia is almost twice the area in Northern Ostrobothnia one can cautiously estimate that side streams from packing facilities in Ostrobothnia are 10 000 tons and from peeling facilities 2000 ton per annum. Together these two areas produce as side streams approximately 15 000 tons of unprocessed potatoes, and 3000 tons of wet sludge of potato peels and greywater per annum.

POTATO PRODUCTS (snacks, starch etc.)	PRECOOKED AND/OR PEELED POTATOES	POTATO PACKAKING
Pohjolan Peruna	Pitkäsen Peruna Oy	HZPC keeps you growing
Evijärven Peruna Oy	Kotirannan Vihannesjaloste	Penttilän Perunatila
Oikia	Tervakankaan Peruna Oy	Hirvosen Peruna
Feelia	Hannulan Peruna	Liperin Juurespakkaamo

Figure 8 Potato processors in NPA area (Finland).

In the NPA area there are two larger industrial operators that manufacture potato products, e.g. potato chips and other food products. Side streams from the larger of the two operators was reported to be 15 000 tons per annum, most of which was potato peels (Ahokas et.al, 2012). All in all, one can roughly estimate that the amount of potato side streams in NPA area are 15 000 tons of unprocessed potatoes and 18 000 tons of potato peels and grey waters per annum.

Dry unprocessed potato side streams are utilized mainly in manufacturing industry. In Northern Ostrobothnia 85 % of the side streams from packing facilities (for Ostrobothnia figure is not known) is transported to one of the two larger industrial operators in the area to be used as raw material for potato flakes (Ahokas et.al, 2012). Wet sludges of potato peels and the grey water from the different facilities after reducing the water content, are either fed to the cattle or composted. Currently valuable components such as proteins, fibres etc. are not separated from the potato side streams. There are plans to establish biogas plant at one of the bigger facilities in the future.

Case descriptions

Case 1: Potato company

A company on a west coast of Northern Ostrobothnia grows potato, buys potatoes from the neighboring farmers and sells washed, peeled and readily cut potatoes. Their main customers are restaurants, institutional kitchens and wholesales. Last year company's revenue was over 1,2 million euros. By comparing industry revenues in the NPA area, company is quite small. Side streams from peeling and cutting potatoes is used as cattle feed or composted. On-site valorization of the side streams is not financially feasible.

Case 2: Potato company

Company is one of the two larger facilities in the area that uses potato to manufacture food products. Their customers are households and professional kitchens. Potato side streams from the company are the largest in the area. Most of the 15 000 tons of potato peels and other side streams per annum is fed to the cattle, company has plans for investments into biogas plant and increase energy self-sufficiency. Company's facilities are quite centrally located in the part of NPA area where most of the potatoes are grown. Currently 85 % of the unprocessed potato side streams from packing facilities located in Northern Ostrobothnia are transported and used by the company as raw material for potato flakes.

Future opportunities for waste handling:

- Currently, most of the potato peels and grey waters are utilized either as cattle feed or composted. Also, there are side streams of unprocessed potatoes from the packing facilities and possibly from retailers that are currently not well utilized. At the moment there are no operators that uses potato side streams as raw material for production of more valuable products, such as e.g. proteins, ethanol.

Bottlenecks / challenges for efficient waste handling:

- Northern Ostrobothnia and Ostrobothnia together is a large land area. Distances between different facilities that operate in the area are long. Most of the facilities that are involved in the potato industry are quite small. Therefore, investments in on-site valorization of the side streams are not justifiable. It will be a challenge to collect small side streams cost effectively from the facilities, that are spread over a wide land area.
- Selection of the location for the site of valorization is very important. Most of the dry unprocessed potato side streams in the area are used in manufacturing potato flakes. So, most abundantly available potato side streams are wet sludges of potato peels and grey waters. In order to reduce transportation costs most of the water from the side streams should most likely to be removed before transportation.

Norway

Statistics Norway estimates that there are approximately 1 575 potato farmers in Norway, cultivating a total of 11 572 hectares, and producing 332 000 tons (SSB- Statistics Norway: Production of potatoes and forage plants, 2019). The total production of potatoes in the NPA region in 2019 was 71800 tons (SSB, www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/jordbruksavling/aar).

In June 2017, the Norwegian Government and actors from the domestic food industry signed an agreement towards a 50 % reduction of food waste in Norway by 2030. The agreement is signed by five ministries and 12 industry organizations, including the Norwegian Farmers' Association and the Norwegian Farmers' and Small Farmers' Association. Starting 2020, Statistics Norway (SSB) will gather and process all data related to food waste.

An important program in Norway is the "Reutilization of out-sorted potatoes" (Avrensordningen for poteter) that is under the Norwegian Agriculture Agency (Landbruksdirektoratet), an agency under the Norwegian Ministry of Agriculture and Food. The purpose of the program is to ensure the efficient disposal of Norwegian-produced out-sorted potatoes. Today 26 companies nationwide are approved for selling their waste potatoes through this arrangement. Eight of these companies are located in the NPA region. The companies get into the arrangement through a three-year contract that stipulates the conditions for delivering waste potatoes. Yearly the contracted volume is about 45 000-50 000 tons waste, that includes waste potatoes, potato pieces, and starch water from potato processing. However, the waste volume fluctuates from year to year depending on the yield and climatic conditions. The price is negotiated annually in the Agricultural Negotiations that take place between the Norwegian Ministry of Agriculture and Food and the two farmers' associations. The price depends on the dry matter content/starch content of the potatoes and this year it was notably increased.

This case is a very good example of circular economy utilizing the full potential of the whole potatoes. From the waste potatoes, they produce starch and alcohol, where about 20 000 tons goes into the alcohol production. The overall process is completed through Hoff, an agricultural cooperative owned by more than 500 potato farmers throughout Norway and producer of a wide range of potato food products. All the waste potatoes are transported to Hoff industries for further processing.

The starch is produced through a process of shredding and cleaning to retrieve the starch and then proceeds to a drying process to potato flour (see example in). Potato flour is utilized in a range of different food products such as minced meat or fish. Some of the flour is further processed to extract the glucose that is utilized both in candy production, as well as in pharmaceutical industries. The alcohol is processed through a similar initial process, freeing the starch from the waste potatoes, and then distilling it to rectified alcohol (96%). This alcohol is sold to various alcohol producers that use it as a base to produce aquavit, gin, or vodka. The waste material from processing starch or alcohol is utilized either as feed or as soil improvements.

We have identified four main categories of streams from the potato production: potatoes that satisfy criteria for human consumption and therefore proceed through different routes in the value chain to consumers, out-sorted potatoes that fail to meet the criteria of the first category and are mainly used as side stream products, potato peel that is utilized in side-streams, and rotten potatoes with limited utilization (Figure 10).

Figure 9 Potatoe flour from Hoff. Photo Erling Fløystad, NIBIO.

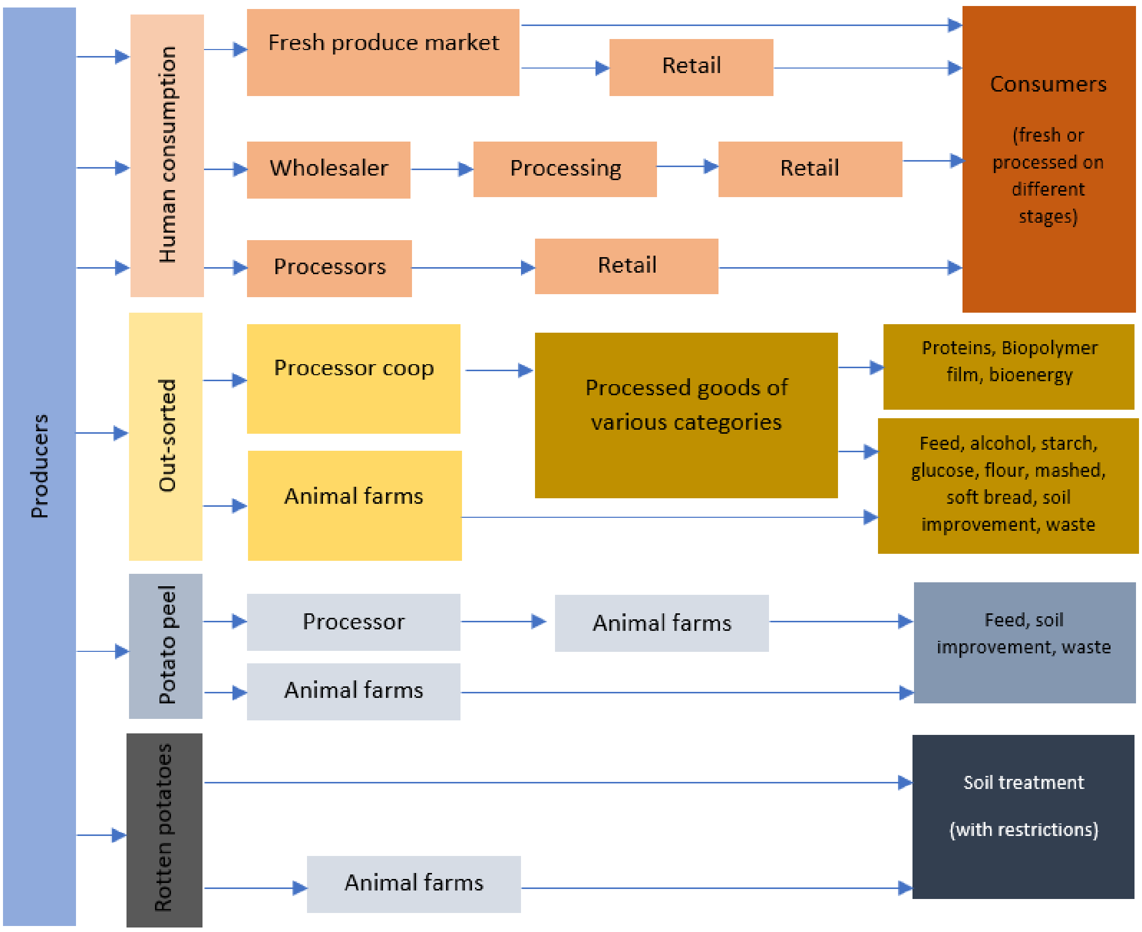


Figure 10 Value chain of potatoes in North Norway

Potatoes deemed for human consumption

Potatoes that satisfy the criteria for human consumption can either go to a wholesaler and then through processing, progress to retail and final consumption, or go for further processing before reaching the retail chains. In some cases, these potato volumes are sold directly from farmers in fresh produce markets ("farmers' markets"), mainly locally.

Out sorted potatoes

The category refers to potatoes that have the wrong size, shape, either on the peel or internally. Potatoes are harvested, transported and in some cases stored, before sorting/grading. Storage in temperatures ranging from 12°C at inset to 4°C which is optimal. Storage can also increase the amount of outsorted potatoes. Water and some nutrients can be extracted as well as whole and cut potato segments.

Potato peel

Potato peel comes from potatoes that after harvest is sorted/graded before going into storage again. Before peeling, the potatoes are washed. The potato peel has a very high moisture content.

Rotten potatoes

Rotten potatoes are usually identified after harvest during sorting/grading, but rot can also develop during storage. Some of this waste end as compost, although there are several restrictions to utilize such compost due to a dangerous soil-borne potato disease (*potato cyst nematodes*).

Along the value chain we can identify several functions and processes that relate to different stages (Figure 11). Inputs relate to the pre-production stages and involve both domestic and international actors, as well as government bodies working on agricultural research and extension services. The production stage can vary depending on the farm and the potato variety, as well as weather variations. Processing also varies from case to case, while the trading stage that follows will segregate the production for the different markets and applications.

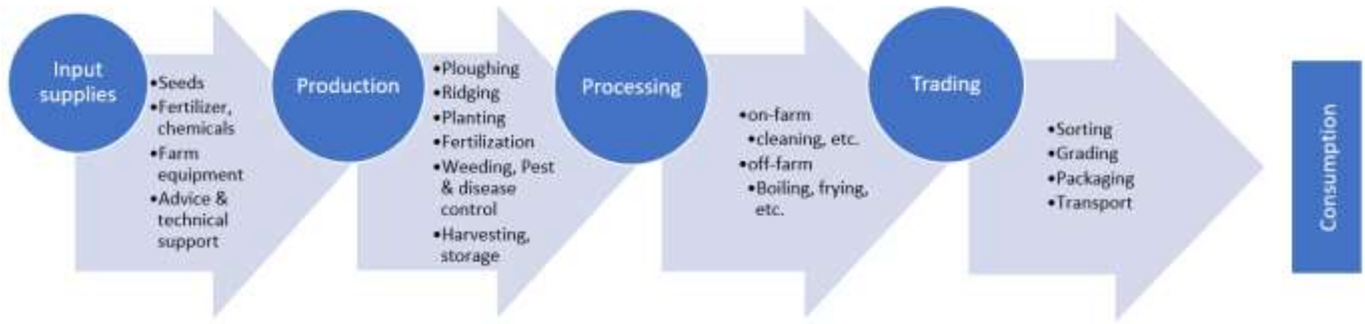


Figure 11 Functions and processes in the potato value chain.

Additionally, there are different actors that get involved on the various stages of the value chain, ranging from local producers to nation-wide cooperatives as summarised in Table 1.

Table 1 Main actors and functions in the potato value chain.

Function	***Actors***
Input supplies	- Cooperatives - Government institutions agriculture office (extension advise), research (seed), etc. - Farmers, farmers groups - Private companies
Production	- Smallholder farmers - Cooperatives
Processors	- Farmers - Wholesalers - Cooperatives
Grading	- Farmers - Collectors - Wholesale retailers
Consumption	- Locally - Retailers (supermarkets) - Institutional trade

Case descriptions

Case 1: Potato wholesaler in northern Norway

The company is relatively large and is a farmer-owned receiver, storage, and packing facility for potato (and vegetables). The company is co-located with a processing facility producing various sous-vide processed potato products. Today's potato waste is: damaged potatoes, wrong size, shape etc. about 25% of total amount received approximately 1 125 tons potato, and potato peel, about 30-40% of the potatoes that are peeled, approximately 500 tons a year (peel and water). Current waste utilization is alcohol (through the "avrensordningen"), cow feed, soil improvement, and waste-deposition. The potential for improved waste utilization is considered high, especially in collaboration with other actors in the food industry.

Case 2: Potato producer 1 in northern Norway

A farm producing potatoes on 10 hectares. In addition, they have their own processing facilities where they are sorting, grading, washing, peeling, and packing mainly their own potatoes. Today they have about 5-10 tons peel and cut potato as waste from processing, and these are used as feed for dairy cows. Some of this, as well as some damaged potatoes, are used as compost for soil improvement. Small potatoes are used as seed potatoes. They see their best opportunities for added value from waste through cooperation with other food industry actors (fisheries), to increase the amount of biological waste. For instance, to utilize it to produce bioenergy.

Case 3: **Potato producer 2 in northern Norway**

A farm producing potatoes on 10 hectares. They have their own storage facility and a small-scale grading and packing facility. They are mainly selling all their yield, graded in bulk through a wholesaler. Currently all potato waste goes to compost and the farmer considers the potential for added value from the potato waste low. Small potatoes are used as seed potatoes. After shipping, the potato (and subsequent waste), is handled by the wholesaler.

Case 4: Potato producer 3 in northern Norway

A farm producing potatoes on 38 hectares. They have their own storage and grading facilities and are selling all the potatoes in bulk to a wholesaler. They estimate that they have about 240 tons of waste potato (in field and harvested). Current utilization is feed for own dairy cows or compost. Small potatoes are used as seed potatoes. The opportunity for added value is mainly through collaboration with other producers of biological waste to increase the volume.

Future opportunities for waste handling:

- Direct sales of fresh and stored potatoes; less affected by strict quality requirements from wholesalers.
- Soil treatment/compost (but restrictions due to potato disease).
- Processing to get potato flour or other food products for human consumption.
- "Avrensordningen for poteter" opens the possibility for increased volumes on several raw materials for potato liquor, potato flour, and glucose.
- Collaboration with other food producers to increase the volume of biological waste processing to food, feed, chemical compounds, or energy.

Bottlenecks / challenges for efficient waste handling:

- Several restrictions due to possible spread of potato cyst nematodes (PCN), 1-mm long roundworms belonging to the genus *Globodera*. May spread with soil and infected machinery and equipment.
- Little collaboration / few common projects; leads to small waste volumes on each farm that lowers the potential for added value.
- Logistics; shelf life of perishable biological material.

Sweden

In Sweden, discarded potatoes intended for human consumption contribute about 50 000 tons of waste, which to a large extent unavoidable, with high water content, but rich in starch. Except potato that is left unharvested, these quantities occur at packaging and sorting facilities in the southernmost part of the country, although about 10% of the national production takes place north of Stockholm. Currently, these quantities are used for biogas production and, to some extent, animal feed. Potato starch production results in two main by-products: potato pulp, most often used as fodder, and potato juice, used as fertilizer or for biogas production. Swedish potato starch production is located to two plants in the south region around Kristianstad, where about 100 000 tons (wet weight) of potato juice and about 3 000 tons (wet weight) of potato pulp are produced. Potato juice contains nitrogen, phosphorous and potassium, and some of the juice is processed to fodder protein. Some of the potato pulp is processed to potato fibers for use in bakeries and meat processing (Engdahl, et al., 2011 in Torén et al., 2019).

Figure 122 shows available waste generated from potato production at 1000 m resolution. The data includes harvesting losses and fraction that needs to be left on the ground to avoid negative impact on soil organic carbon (Torén et al., 2019). The black rectangle in **Error! Reference source not found.** i ndicates the waste from potatoes production in the Swedish NPA area which is in a range between 50-100 tons (average values for crop production from 2013-17).

One of the interviewed potato companies which cultivates potatoes in 100ha of land, for example, generates 5 tons of waste of peeled potato skin in a week from 5-tons harvested potatoes. For washing potatoes, the company uses around 4000 m^3 water in annually which is drained to the municipality sewage. Also, during the interview, the owner of the company mentioned that there is a need for more efficient way to handle potato peel rather than just dumping it on the field.

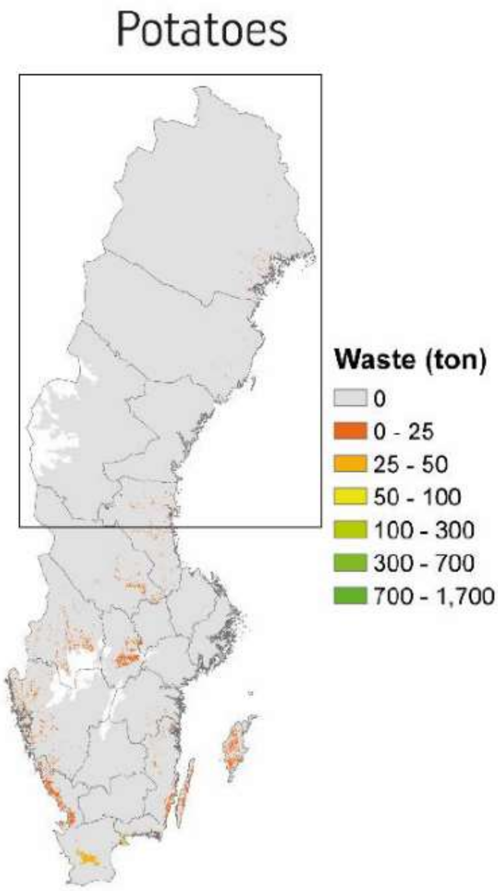


Figure 12 Estimates of waste generated from potatoes production (Torén et al., 2019

Case descriptions

Case 1: Potato company

A family business since 1950s that supplies the Swedish market with various types of potato products (fresh/washed/packed potatoes and sour creamy potatoes gratings). The company's four core values are tradition, innovation, quality, and authenticity. The company is located in a small town on the border between Sweden and Finland. The company buys fresh potatoes (with soil which is approximately 3% (w/w) from the local producers. The common way to utilizes the waste is by sending peeled skin to farmers. Usually the potato company is paid for logistics, which in overall lead to natural costs. The remaining soil is reuse by a neighbor company that offers soil.

Case 2: Potato company

A small local producer of potatoes with 6 employees. They take care of the whole production process starting with cultivation, harvesting, wash, peeling, packaging, and selling depending on the business models. Also, in different seasons and depending on their own cultivation process, the potato company buys from another potato wholesaler (which is located approx. 15 km from the potato company). The potato company has an agreement with local administration, nowadays they supply local schools, kindergarten and local restaurants and stores as well as sale to some companies that just pack potatoes and then sale further or produce readymade food. The most common way to handle the potato peeled skin (7-8 m^3/ week) is to leave on the own field (ditched/dumped on their field). This way of waste handling has a negative cost effect because of the workforce needed and the lacking fertilizing effect of the waste.

Future opportunities for waste handling:

- There is rather a good and tight relationship between different potatoes companies and wholesaler since there are a few of them in the NPA region. Owners usually keep personal contacts to solve /handle various aspects/problem/ lack of materials. A need for a local union/organisation that may help handling various aspects/problems as well as waste handling in more efficient manner.
- Potato peeled skin is not classified as waste but more of by-product.

Bottlenecks / challenges for efficient waste handling:

- Big challenge to keep and develop potato business in NPA region due to lack of interest for younger generation in such businesses. In the last 10 years around 10-15 potato farms were gone from the market.
- The owners of potato farms are rather old, lack of young and innovative drivers. The knowledge about potatoes cultivation is decreasing due to lack of knowledge exchange.
- Lack of a common vision and closer collaboration from the local potato businesses.
- Lack of partnership relations with local Biogas factory. It is costly for potato companies to deliver and leave by-products/waste to the factory.

Ireland

Potatoes are the world's fourth largest crop behind corn, rice, and wheat and is synonymous in Ireland as a stable food crop with an average annual potato consumption of 85kg per person, (2½ times higher than the world average).The Irish potato market comprises 540 potato growers and approximately 9,000 hectares and is valued at €195 million to the Irish economy. Potato yields can be variable depending on seasonal climate conditions with averages of approximately 40-45 T/HA reported by Irelands agriculture and food development authority An Teagasc.

Potatoes grown in Ireland can be broken down into four main growing types:

Early Potatoes: Harvested in June and supply the market until early September.

Main Crop Potatoes: 70% is sown to a variety called Rooster, has the greatest area and through refrigerated storage, can supply the market year-round.

Salad Potatoes: Smaller in size (quicker to cook) are supplied from August to December.

Seed Potatoes: Grown to supply the source of the majority of the next year crop.

The Irish Farmers Association (IFA) estimates that 50,000 tonnes of potatoes are commercially peeled in Ireland every year. In addition, they estimate that upwards of 30,000 tonnes of potatoes remain on Irish farms as waste each year, either as out-grades or surplus to market requirements. Predominantly, waste from Irish potato production and processing is generated as a result of screening, grading, peeling, trimming, slicing, blanching and disintegration processes. It is one of the main issues facing the industry and threatens expansion within the sector. Potato crop residues generated during primary production (on farm) can play a vital role in servicing the farm ecosystem. In this regard, potato waste is used as a 'closed loop' solution on Irish farms as waste can contain high levels of moisture leading to putrefaction in a short period which promotes antimicrobial activity and use as a dietary fibre source for animal stock such as pigs.

A typical potato processing plant can generate 6-10 % potato peel waste (PPW) from the peeling process as well as other wastes (15%) from other trimming and cutting processes which can create disposal, sanitation, and environmental problems for the industry. Potato peels possesses excellent nutritional characteristics which make it ideal to be utilised into bio-products due to it being rich in cytotoxic glycoalkaloids such as α-solanine and αchaconine, carbohydrates, high in starch (8-28%) and about 1-4% protein.

To realise higher value-added chains, the industry stipulates that the up-scaling of optimised techniques for the extraction of antioxidants and other bio-actives is necessary in order to utilize potato waste as a valuable by-product for use in functional foods. Currently, both solid-liquid and pressurized liquid extraction techniques for the extraction of antioxidants are employed (see Figure 133)

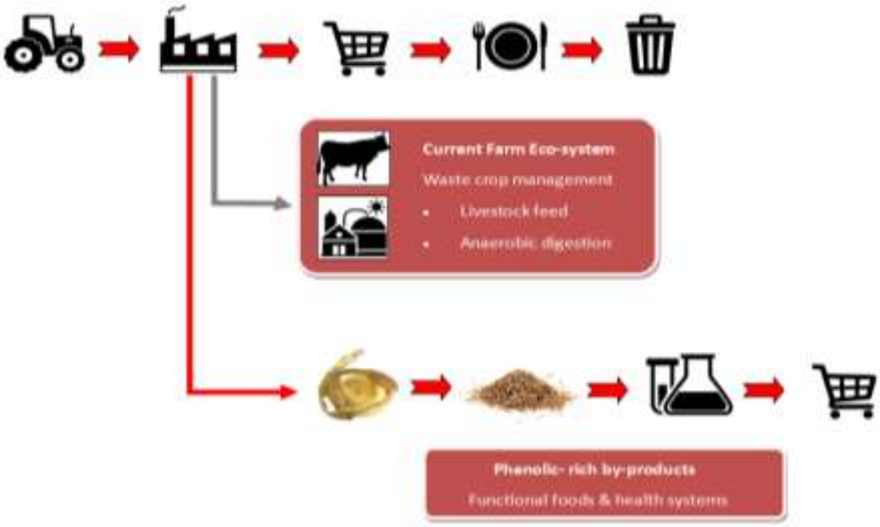


Figure 13 Valorisation of potato peel waste (PPW) into functional food ingredient.

Case descriptions

Case 1: Food company 1

The company produces a variety of vegetables and ingredients to the Irish wholesale and food manufacturing plants. All their produce is sourced from Bord Bia registered local farmers with the potato crop a prominent product comprising peeled, sliced, diced, wedges, jacket, baby and baker potato varieties. The company has been proactive in the application of intelligent processing to upgrade their products waste streams into new ***functional vegetable fibres*** for use as texture ingredients in food.

Reacting to market demand for '*less processed*' and '*more natural*' food ingredients, the company have realised a use from their repurposing waste vegetables into functional food fibres containing both soluble and insoluble fibre fractions that possess different textural and nutritional functionalities. They have achieved this in collaboration with the Irish Farmers Association, the Irish Environmental Protection Agency (EPA) and an independent product development group (CyberColloids Ltd) who specialise in hydrocolloids, focusing on food, nutrition and industrial applications.

Case 2: Potato company

This company is an Irish family farm business founded in 1982 and is one of Ireland's leading growers, packers and distributors of fresh produce to retailers nationwide. Their production facility comprises 1500 m2 of packing space and 5000 m2 of storage space.

The company operate a Zero Food Waste ethos within its facility thanks to measures taken for channelling visually impaired produce to food processing, community food banks and stock feed sources. Their advocacy work for food waste prevention has seen them being awarded (Repak Award 2016) for efforts to promote waste prevention in particular their collaboration with FoodCloud (a social enterprise initiative that connects businesses with surplus food to charities) to collect crops leftover after harvesting.

"*From a business point of view, it makes sense to use every resource we have at our disposal. Growing and selling potatoes and vegetables, we are in a high volume, low margin business. This means that investment in more efficient production methods and recovery of by-products is crucial and that we have to take decisions from a sustainable point of view*",

Eleanor Meade: Business Manager, Meade Potato Company

The company is also implementing plans to include operating a potato starch manufacturing facility for the extraction of starch from their potato peelings for use in the ingredients market.

Future opportunities for waste handling:

- **Extraction of Phenolic Compounds from Peel:** Potato peel waste (PPW) as a basis for phenol extraction, ethanol, lactic acid and enzyme (α-amylase and β-mannanase) production through fermentation, and edible film production.
- **Health benefits:** PPW extract has high antioxidant, antimicrobial and anticarcinogenic use potentials within health systems.
- **Functional foods:** Traditionally, texture in food (e.g. gelling in jams, thickening in dairy based drinks and desserts and water binding in meat products) has been provided using hydrocolloids. Hydrocolloids, also known as gums, are increasingly seen as “artificial” and food companies are looking for more natural alternatives. Food fibres are not additives but are food ingredients and thus offer a clean label alternative. Re-use of potato peel waste (PPW) into new textural functional fibres (e.g. superior water binding ability, viscosity and gelling behaviour) for use as texture ingredients in food exist.

Bottlenecks / challenges for efficient waste handling:

- **Technological challenges:** Potato waste processing is complex and requires several efficient processing steps, equipment and techniques. The peeling process is a central part of production and an area that can be problematic. If mismanaged it can lead to excessive waste. Technological solutions that are reliable and adaptable to manage many potato varieties is necessary in order to mitigate against such losses. Downstream processing steps to reduce loss at the peeling stage requires a reduction in peeling time and the removal of aggressive post peel brushing.

- **Potato Starch:** An Teagasc (Irelands Agriculture & Food Development Authority) has highlighted that Irelands volume of starch and starch based products sold is not sufficient for the establishment of a starch production industry stating that with small volumes any production processing facility would have to be able to export competitively to the UK and EU destinations which could be hampered by higher freight cost. As starch potato growing and processing are interdependent, a careful and thorough feasibility study would be necessary to see if production would be viable against a background of international competition. Some private commissioned studies have been carried out indicating a challenging business case outlining that a commitment of all stake holders would be a prerequisite to achieving a potato starch industry.

2.3 Fish processing

Fisheries contribute immensely to global food and nutritional security. The Food and Agriculture Organization of the United Nations (FAO) estimates that fisheries and aquaculture provide livelihoods to over 10-12% of global population. About 75% of fish resources are used for human consumption globally. A substantial part of the fish produced is currently lost as fish waste discards and various other uses (over 25% rough estimate) (Prasad and Murugadas, 2019). The definition of "fish wastes" is quite broad and includes caught fish species having no or low commercial value, undersized or damaged commercial species as well as species of commercial value but not caught in sufficient amounts to warrant sale. Furthermore, under the umbrella of “fish wastes” there are more than 50% of fish tissues including fins, heads, skin, and viscera which are usually discarded. For example, the availability of fish skin and bones following the fish filleting process.

Finland

Fish catch in Finland annually is about 135 million kgs from marine fishing and 5,2 million kgs from inland fishing (Statistics database). In Finnish marine waters, Baltic herring is the most important catch, in terms of both volume and sales value. The most important species of catch in commercial inland water fishing is vendace, which is caught in open water through trawling and in the winter with seines. While marine fishing is declining, inland fishing is growing. Marine fishing of salmon is being replaced by fish farms of various types, located in both marine and inland water areas, and in recirculated aquaculture facilities, in which the water used in the farming is recycled and cleaned.

Fish catch is mainly used for food (sold as whole, filets, preservatives or other edible forms), feed (mostly for fish farms and for fur farms) and production of fish oil.

Finnish enterprises processed 79 million kgs of fish for food in 2017, where 51 million kgs were of a domestic origin and 28 million kgs were imported. Most of imported fish is salmon from Norway (81% of total salmon processes and sold). A total of 21 million kgs mostly of herring and sprat were frozen as a whole fish and exported. Also, 38 million kgs of domestic and imported fish was processed into fillets and other fresh products. The rest is used for highly processed products, such as smoked or salted fish, canned fish products, ready cooked foods, etc.

In particular, Baltic herring and sprat are produced into fish meal. At the moment there is only one facility in South Finland (Kasnäs) producing fish meal and fish oil. Annually 30–40 million kgs of fish are processed. The fishmeal plant using fish caught in the Baltic Sea employs several circular economy practices.

Fish farming becomes load-neutral, as fish are fed with fish fodder made from fish in the same sea. Nutrients are thereby no longer added to the Baltic Sea, but the sea’s nutrients are recycled. During the production of fishmeal and fish oil, foreign matter is removed. The fish is dried and boiled, oils are separated from the liquids, and dioxins and polychlorinated biphenyl (PCB) are removed from the resulting products (Prokala, 2018).

In 2017 there were 143 fish processing enterprises in Finland, of which 23 processed more than half a million kgs. These accounted for 93% of the total volume of processed fish.

Fish side streams/waste is generated along all the supply chain of fish from fishing to consumer.

In this report we focus on waste and side streams which are generated in fishing harbours, where fish is initially pre-treated, fish farms and in fish processing plants.

Fish farming, NPA area

There were 151 fish farms in Finland in 2018, 54 fish food farms in NPA region and they produced 2,6 million kgs of food fish, mostly rainbow trout (Figure 144) (Fish Farming, 2017). It is estimated that numbers of aquaculture facilities will increase in a near future, which will also increase need for fish food.

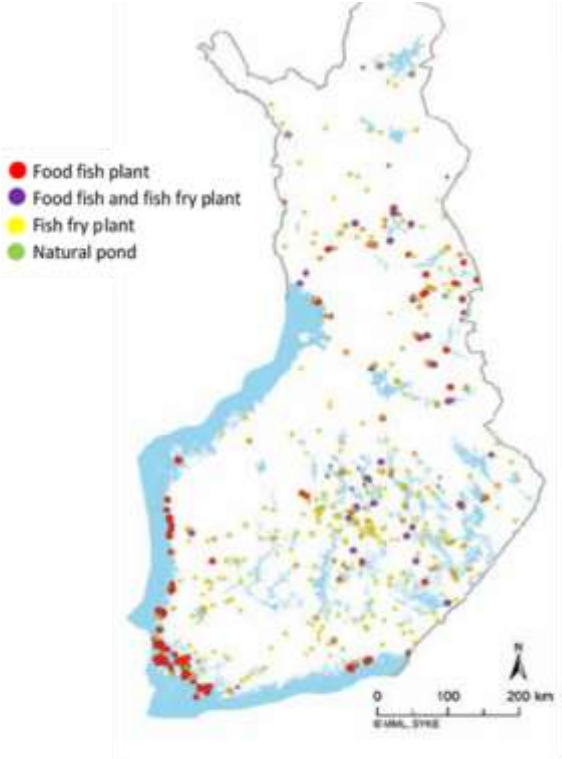


Figure 14 Aquaculture facilities in Finland

Case descriptions

Case 1: Farm in sea water (Lupapäätös, 2017) Annual production of fish is 1 million kg. Feed consumed by fish is 1,1 million kg.

Fish before transporting to processing plant is cleaned onsite. For cleaning 1 000 m^3 of sea water and 1 500 m^3 of clean drinking water is used. Fat is separated from the wastewater before discharging to municipal sewage. Slurry (some 14 m3) is collected into tanks, formic acid is added for preservation and full tanks are delivered to biogas plant. Fish cleaning process generates about 15% solid waste (viscera mostly), i.e. 150 000 kg annually.

Some 3000-6000 kgs of fish are dying and are not suitable for food. At the moment it is transported for biogas production. The most of fish is sold to fish processor, who is taking whole fish.

Case 2: Fish processor 1.

This fish processor in one of the biggest in NPA area of Finland, turnover is about 110 million euros and company employees almost 200 people. The company coverts 18 million kgs of fish into various fillet products. Salmon, whitefish are the main raw stock, also others in smaller amounts are processed.

Some 6 million kgs (33%) are by products which are not sold as a premium product. Fishing harbours very often have equipment for gutting big fish and therefore the company buys ready cleaned fish. The company has however also invested in small fish gutting machinery and can deal with supplied fish which is not cleaned.

Filleting waste is shared into various streams. Fish heads are frozen and sold to Asia, cut-offs suitable for food is separated from the stream and used in production of ready foods, and the rest is delivered to produce feed for fur animals.

Company tried to remove oil from this waste, but it was not economically feasible, oil yield remained a couple of per cent of the expected 20 per cent.

Case 3: Fish processor 2

Company's raw stock is mostly small fish like vendace form inland fishermans. 400 000 kg of fish. Companies turnover in 2019 was some 1,7 million euros. Raw stock fish is gutted in company and waste is taken by animal feed producer (production plant situated some 25 km away) and processed into feed for fur animals.

Fish harbours in NPA (Botnia Bay) area (marine fishing)

Marine fish processing in Botnia Bay covers anarea from Kokkola to Tornio (area 31 in Figure 155) and has some 40 fishing harbours (Nouseva Rannikoseutu, 2017). 17 of these have covered halls and is suitable for some type of initial processing. 12 of fish halls comply with Food Hygiene Act. Most of harbours are owned by municipalities and municipalities are responsible for maintenance, including waste handling.

The catch in Bothnia bay in 2018 was 3,2 million kg (2,4 % of all Finnish marine fishing catch), 1. 68% of all catch is sold to wholesales, with the rest sold directly to consumers or to grocery shops. About 30 % of catch is sold without any pre-treatment, 0,5% is cleaned and fileted, the rest is being cleaned by removing viscera.

The adjoining region, the Botnian Sea (seen as area 30 in Figure 15), has an estimated catch of 76 million kg and it is almost half of all Finnish marine fishing.

Figure 15 Sea fishing areas in west Finland.

Case 4: Trullevi fish harbour in Kokkola

The harbour is owned and managed by the City of Kokkola. City is responsible also for waste management. Harbour has hall and fish cleaning equipment, hall complies with Food Hygiene

Act and therefore almost all fish is cleaned (removed viscera) and washed. About 50% of cleaned fish is sold to retailer and the rest is sold in local supermarkets.

Waste is collected and kept in freezer before it is transported as biowaste. Biowaste from Kokkola region is produced to biogas and compost.

In Pietarsaari (about 35 km) there are few companies manufacturing feed for animals, also new fish farm in the see is planned. It is possible waste would be transported for feed production.

Kokkola city is responsible for waste management also in 4 more fishing harbours (all within 30 km distance).

Inland fishing, NPA

Inland commercial fishing in NPA region is 4,2million kg (80% of all Finnish inland commercial fishing) (calculated from Statistics database). Most of it in in South-Eastern part of Finland. If marine fishing catch for food was more big size fish, such as salmon and whitefish, inland fishing catch is mostly composed of small sized fish, vendace in particular. Marine fishing harbours are often equipped with big fish cleaning equipment, when inland harbours often lack any equipment. Processing industry often purchases from fisherman not cleaned fish, which means that there is more waste than in case of marine fish processing industry.

Majority of common utilisation of by products is for feed, especially for fur animals. Growing fur animals in Finland is however reducing, and it is expected it will be forbidden as has happened with most other European countries. The fish industry therefore needs to find new outlets to be able to utilise by products cost efficiently.

Future opportunities for waste handling:

- Production of fish oil for human consumption (Hiidenhovi, 2017)
- Production of fish oil for diesel
- Production of fish oil for cosmetics industry
- Feed for animals or fish instead of biogas (it is higher in waste hierarchy) Fish proteins for human diets

Bottlenecks/challenges for efficient waste handling:

- Fish processing waste has clear use and it is even imported (e.g. cut-off from fillets) or as ready products, e.g. fishmeal for fur animals and artificial fish aqua culturing (Kalamarkkinakatsaus, 2017). Waste handling at the moment does not seem to be an issue, however higher value products would be useful. This set though pressure on feed producers, if fish waste is not available it should be replaced with other sources.

- As most valuable products would be fish oil for human consumption. Fish oil production for human consumption requires fresh raw materials. It is possible to achieve if the processing plant is big and waste stream is continuous. In case of small-scale processing, waste needs to be preserved, e.g. by fast freezing.
- Technically, fish oil could be converted to biodiesel. Several reports though indicate that economically this it is less feasible.
- Biogas production from fish waste also seems to be not that economically attractive

Norway

According to Statistics Norway, Norwegian fishing vessels caught a total of 2.5 million tons of fish in 2019. In 2018 there was 6 018 registered Norwegian fishing vessels, 11 219 registered fishermen, and out of these, 9 514 persons had fisheries as their main occupation. In aquaculture, an estimated 1.35 million tons of seafood were sold (mainly salmon). 2 423 346 tons seafood was exported in 2019.

SINTEF made a thorough report on the waste material available from Norwegian fisheries and aquaculture production, and how this material is utilized (Richardsen et al., 2017). The report shows that in 2016 there was in total approximately 914 000 tons waste available from fish and shellfish, and that about 75% of this volume, 689 000 tons, was utilized.

We identified five main categories of streams from the Norwegian fisheries: seafood that is suitable for human consumption, waste from pelagic fish, waste from white fish, waste from aquaculture, and waste from shellfish (Figure 16).

Seafood for human consumption

The category includes all forms of fish that meet the criteria for human consumption. These volumes can either be transported to a wholesaler and then through further processing, progress to retail and final consumption, or go for other forms of processing before reaching the retail chains. In some cases, some of these volumes can be directly delivered to fresh produce markets, mostly locally.

Waste from pelagic fish

Richardsen et al. (2017) estimate that waste from pelagic fish (herring, mackerel, blue whiting, capelin, etc.) accounted to approximately 178 000 tons. Other smaller species, such as for example sandeels or Norway pout, are fully utilized in the flour/oil production and because of this, leave no waste material. The main part of the waste material from pelagic fish comes from fileting herring.

Waste from white fish

Richardsen et al. (2017) estimate that the total landed quantity of white fish (cod, haddock, pollock, Greenland halibut, ling, cusk, redfish, catfish) in Norway in 2016 was approximately 925 000 tons. Waste material is produced when the fish are gutted or processed. Waste and co-product components (heads, backbones, and guts) are estimated to 319 000 tons. From this volume, they estimate that 140 500 tons was utilized.

CYCLE (2018) made its own estimation where," The Norwegian fisheries produces around 300 000 tons of whitefish co-products (heads, backbones and guts) each year. In 2015, approximately 166 000 tons of the co-products were discarded and not utilized, resulting in a significant loss in potential value creation".

Waste in aquaculture

Richardsen et al. (2017) estimate that a total of 1 255 700 tons of the species salmon and trout were slaughtered in 2016 in Norway. Waste material from these processes was approximately 401 000 tons, and about 91% was utilized.

Waste in shellfish

Richardsen et al. (2017) estimate a total of 49 200 tons of shrimps and crabs in 2016 in Norway. From this amount, 16 300 tons of waste was generated. Only 4 700 tons of this waste is currently utilized, which is about 29% of the total waste material.

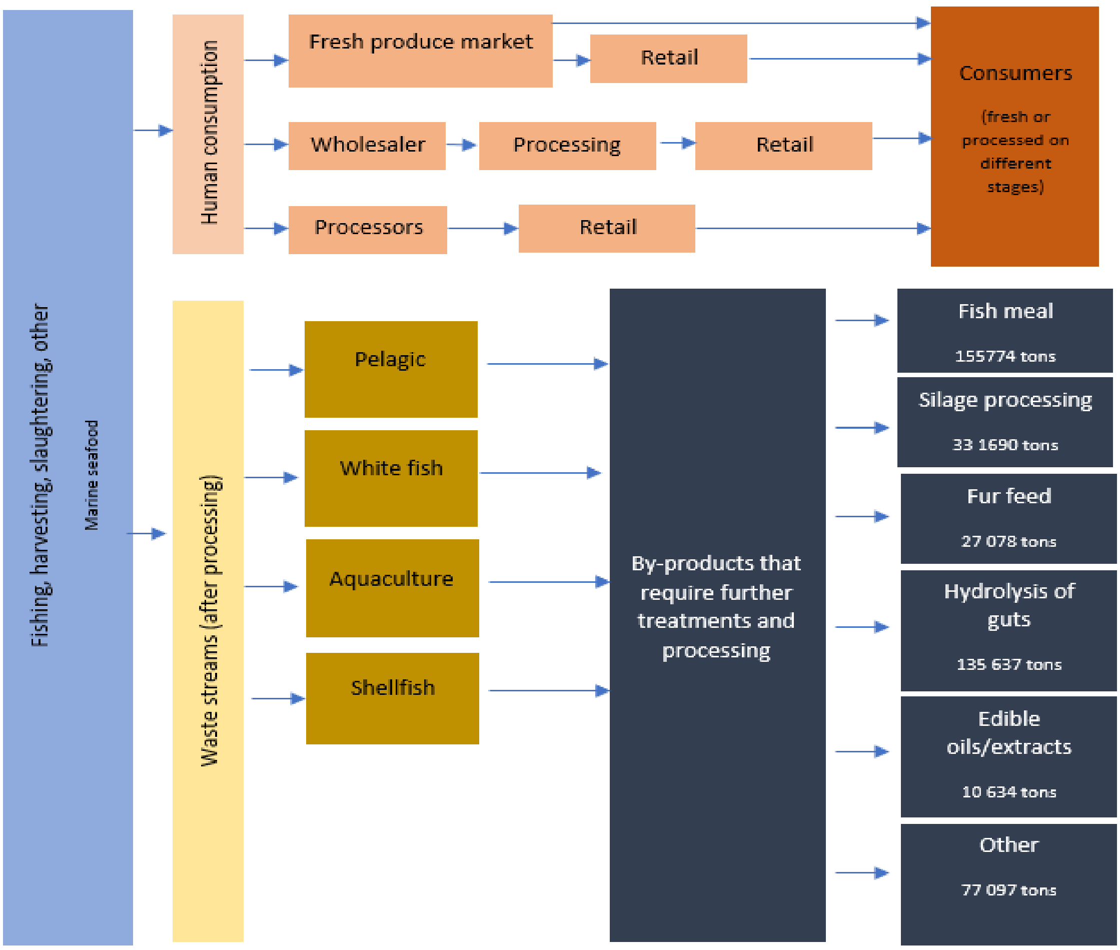


Figure 16:Value chain for fisheries in North Norway.

Utilization of the waste today

Figure 17 shows utilization of by-products in Norway in 2017 (numbers from Richardsen et al., 2017). 21 % is utilized in traditional flour and oil production, 46 % processed through silage, 20 % in oil and protein-production (this derives from aquaculture waste), 4 % goes to fur feed, and 9 % is utilized for human consumption (where 6 % as seafood products, and 3 % as oil and extracts). It is worth noting that according to Vestlandsforskning (Andersen et al., 2017): "*Fishmeal, which makes up a large part of the protein source for farmed fish, is produced by fish caught in the sea. It cannot be used as feed for the same species*". In addition, the same report highlights that "*Waste water from fish slaughterhouse has […] potential as a growth medium for macroalgae*".

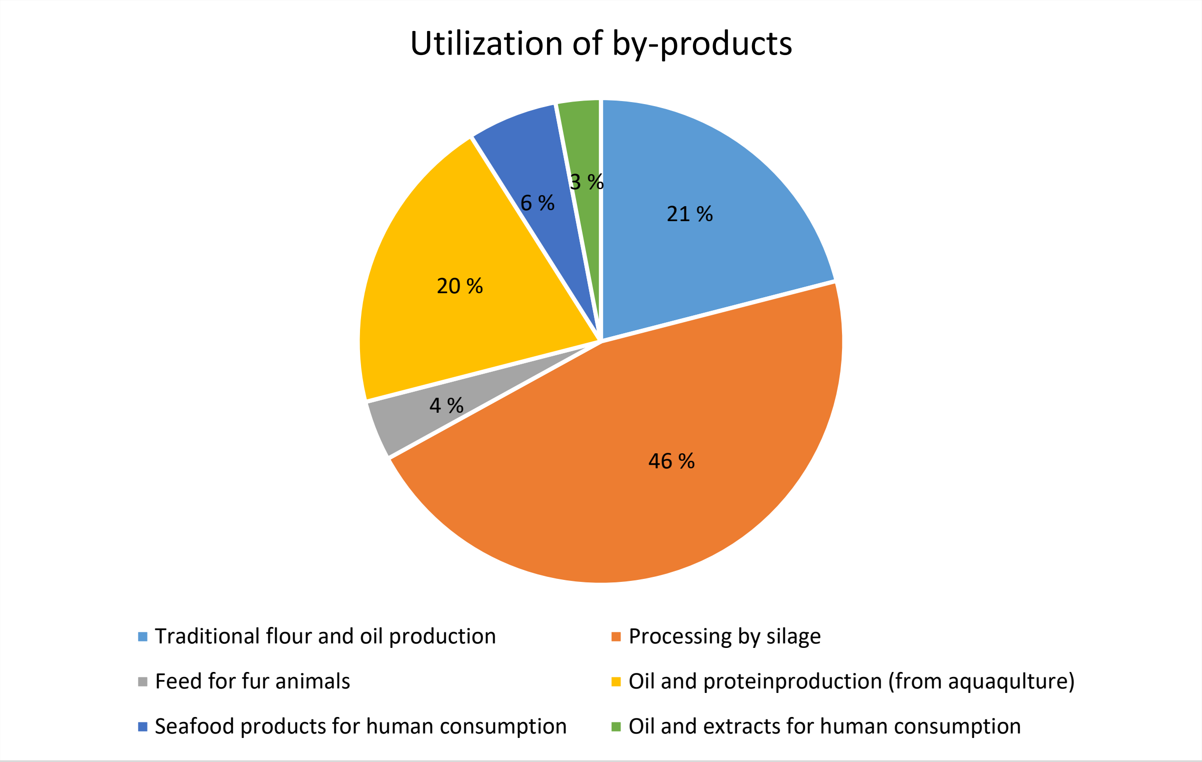


Figure 17: Utilization of by-products (based on Richardsen et al., 2017).

Case descriptions

Case 1: Seafood processor in northern Norway

The seafood processor is a relatively small actor in the seafood market, producing a large variety of seafood products for the retail market, HORECA and wholesalers. They buy mainly fileted fish or round fish without head/gut, and any remaining waste components are mainly cut-offs that account to about 90 tons a year. Current waste utilization is towards mink feed, and dried fish for human consumption. They see a potential for added value to their waste by handling the processing of dried fish themselves and increasing the utilization for human consumption. Their main challenge is logistics, since the company is located far away from the large fish processing plants that have the necessary infrastructure and systems for waste handling and processing (for example, processing to oil/extracts, etc.).

Future opportunities for waste handling:

- Feed products such as, fish feed/fishmeal, animal feed, and pet food.
- Oil/extracts.
- Bioenergy.
- The wastewater from fish slaughterhouse has the potential to be used as a growth medium for macroalgae.

Bottlenecks / challenges for efficient waste handling:

- Fishmeal cannot be used as feed for the same species.
- No collaboration /common projects.
- Logistics; shelf life of perishable biological material.

Sweden

Bergman (2015) has presented the study which showed that around 30,000 tons of seafood co-products are generated each year in the Swedish seafood processing industry based on interviews with processors. Following the report from Bergman (2015), the main waste utilization route was as feed for minks and production of fish meal and oil for animal feeds. Discard of fish at sea is another source of fish that could be used for human consumption or for other purposes. Guts that are discarded could potentially be used more. It was reported that cod catches, which have their guts removed and discarded at sea in the Swedish fishery sector, could be landed ungutted without decreasing the quality of the fish or the co-products as long as it was gutted within 12 hours after the catch (Akse et al., 2002 in Bergman 2015). Fish and crustaceans smaller than the minimum allowable size that are mandatory to land should however not be included in the efforts to find valuable uses but should instead not be caught at all if not intended to be landed. The aim of the landing obligation (Regulation (EU) No 1380/2013 of the European Parliament and of the Council) is to encourage the utilization of more selective fishing gear that catches only the target species of allowable size, and therefore it should not be profitable to land fish of unallowable sizes. Precise data on the amounts and types of seafood co-products that arise in the Swedish processing industry is lacking today. A complete picture of the present utilization of co-products is unknown as well (Bergman, 2015).

Case descriptions

Case 1: Fish company 1

The history of the company begins in 1992 by two fishermen fishing together. Now it is an SME with 17 employees, an ambitious vision, and innovative technologies. The most common caught fishes are herring in the spring and pike in the summer, vendace in autumn starting in the middle of September, and lasts for four to five weeks. The vendace season is short and very intensive. From vendance comes the production of Kalix vendace caviar. Herring is caught mainly for producing the Swedish specialty “surströmming”, fermented herring.

The most common ways to handle generated fisheries by-products are sending it for dog food production (dryfood), export as mink food to Finland as well as production of fish steaks for human consumption.

Case 2: Fish Company 2

This company is one of Norrbotten's oldest companies formed on the Gulf of Bothnia over 90 years ago. As early as 1928, two professional fishermen joined forces to form a fish sales association with the aim of selling members' products and at the same time developing the geographical market in Norrbotten. The company in its most recent incorporated form was founded in 1990 and is now owned by professional fishermen in Norrbotten. Today the company conducts its operations with head office, production, warehousing, and sales in Luleå and production in Nyborg. The company has about 22 full-time employees, sales of about SEK 100 million per year and produces about 900 tonnes of fish. Their market is divided into two main segments: restaurant and large kitchen and Grocery.

The most common ways of handling fisheries wastes are by sending it to a dog food producer (wet food, fresh sausages), bio-gas, and some of organic waste goes to the combustible waste.

Case 3: Fish Company 3

A small fish company with 3 employees. They fish herring, salmon, whitefish during summer in the High Coast which is a part of the coast of Sweden on the Gulf of Bothnia, and during autumn they fish vendace. In numbers, annually they usually fish around 20 tons of herring, 18 tons of salmon and vendace around 40 tons. This year (2020) it has been allowed to fish vendace just for 12 days.

Commonly, the company exports fish waste for a mink food production in Finland, or transports to a local dog food producer (wet food, fresh sausages). However, they expect that that mink farming in Finland will reduce significantly in a near future and new ways of waste handling will be needed.

Future opportunities for waste handling:

- More food production for human consumption
- Fish oil as dietary supplement
- Biogas production

Bottlenecks / challenges for efficient waste handling:

- In case of further food production for human consumption, there is a lack of social acceptance of eating various sort of fish
- Lack of business supporting opportunities /projects
- Tough requirements for fish products lead to high prices on the market
- Lack of innovative ways for keeping fish fresh after catching since some sorts could very sensitive and lose its quality.

Ireland

The clean, unpolluted waters around Irelands 7,500 km coastline contain some of the most productive fishing grounds and biologically sensitive areas in the EU. In 2018, the overall fishing opportunities (i.e. Total Allowable Catches (TACs) species) for stocks to which the Irish fleet has access to, were reported to be 1.3 million tonnes of fish, with an estimated landed value of €1.37 billion. Ireland’s total share of these TAC’s (2018) amounted to 215,511 tonnes with a value of € 222 million. In its *Food Harvest 2020* report, the Irish Government outlined plans to double the value of Ireland's ocean wealth from all marine commodities to 2.4% of GDP by 2030 and increase the turnover from its ocean economy to exceed €6.4 billion by 2020.

The main activities in the Irish seafood industry are:

Fishing – Eight out of eleven of its finfish fishing ports are in Ireland’s NPA region including Irelands top fishing ports Killybegs, Castletownbere and Dingle.

Fish farming – Aquaculture activity includes growing finfish, such as salmon and trout and shellfish farming, including the cultivation of mussels, oysters and scallops. Currently, 27 of its 32 aquaculture sites are located in Ireland’s NPA region.

Processing – Seafood companies produce high-value products from salmon, whitefish, shellfish and pelagic fish species (e.g., herring, mackerel and horse mackerel) all of which generate substantial export earnings to the sector.

The industry is broadly divided into two main classifications:

Finfish: Comprising *Demersal* fish which live on or near the seabed (e.g. cod, haddock, hake, plaice) and *Pelagic* fish found in mid waters or near the surface (e.g. mackerel, herring, salmon).

Shellfish: Broadly divided into *Molluscs* (eg. mussels, oysters, scallops) and Crustaceans (e.g. prawn, shrimp, crab and lobster).

The ‘Functional Foods’ sector, through the development of new high added-value products using fish as a carrier for pro-biotics or health supplements has facilitated the establishment of niche markets and ancillary income from by-products that exist beyond the purely nutritional content of the fish.

Most animal by-products of fish origin in Ireland are classified as Category 3 under the Animal By-product (ABP) regulation which includes:

- Fish material that is not destined for human consumption
- Finfish by-products arising from processing activities (excluding mortalities)
- Shellfish that have been previously fit for human consumption but have now passed their shelf life

Additionally, many seaweed species grown in Irish waters which were commercially used as a raw material in the production of high-volume, low-value commodities (animal feed and raw material for alginate production) has witnessed an increased acceptance as a fast growing mineral-rich sea crop that can produce high-quality, high-value products for use in the cosmetic, pharmaceutical and human nutrition industries including Vitamin B12, omega-3 fatty acids and trace minerals.

Despite the excitement about seaweed's commercial potential as the next big thing in Irish food production, plans to develop a sizeable seaweed industry has been slow to become reality due to a variety of factors, most notably changes to licencing laws and constraints in technology.

The issue of marine plastics is particularly pertinent to Ireland. The fisheries sector is heavily reliant on plastic (for fishing gear, aquaculture equipment, fish crates, packaging, etc.). Due to its rot-proof nature, plastic have proved extremely effective in the marine environment. However, it is also a non-biodegradable material, made from fossil fuels, that can wreak havoc on marine ecosystems. A circular Economy approach to introducing better end-of-use systems by recycling plastics for gear such as fishing nets has witnessed up-cycling and net re-working enterprises cropping up around the country as a means to creating additional revenue streams in coastal communities. This has included the development of different types of biodegradable-compostable nets, obtained by extrusion melt spinning process (one-step process), for shellfish harvesting and packaging products.

Expanded Polystyrene (EPS), a closed-cell single-polymer foam used for both packaging and insulation purposes is widely used in the fish processing industry as it has proven to be the most cost-effective and efficient way of transporting fish over long distances. The Irish state agency tasked with the responsibility for developing the Irish marine fishing and aquaculture industries, Board Iascaigh Mhara (BIM)- Ireland's Seafood Development Agency has been working with primary producers, co-ops and processors to address major waste streams stemming from both marine plastics and EPS by conducting national research into the area of fish box EPS usage and disposal in Ireland, and to devise EPS recycle business models to encourage the development of alternative sustainable fish packaging solutions.

Likewise, many shellfish farmers are implementing strategies that will see them realise by-product opportunities as a result of the chemical composition of their waste shell accumulations. Value proposition exists in the potential for the Oyster's principle chemical component calcium carbonate ($CaCO_3$), (96%) to be repurposed into by-products for use across multiple sectors including eg. Bio-filtration & agricultural products for eutrophication control of soil pH to counteract calcium deficiencies, chicken feed, landscaping products, to hydroxyapatite synthesis (high value) potentials such as nutritional/health supplements and reagents to produce thermoplastic elastomer (TPE). What makes it innovative is its ability to produce the highest purity by comparison to mined limestone powder of other types of shells with less acid insoluble material and a more superior texture perception (see also Figure 1819).

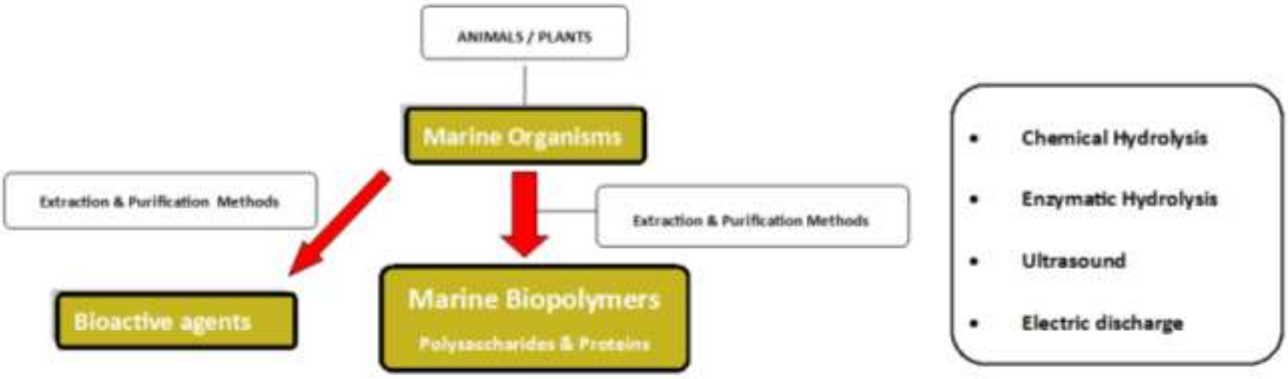


Figure 19: Valorisation of Marine Biomass

Case descriptions:

Case 1: Fish company

This company started as a national strategic research programme (spanning 2008-2015), which integrated Irish marine science and food science expertise and capabilities from 6 institutions throughout the island of Ireland to develop synergies for marine bioresources. The partnership provided the capability to establish and develop a coordinated approach for the exploitation of Irish marine resources to realise functional food and health by-product applications.

In 2017, the company became a 100% Irish owned and operated blue biotechnology company, located on the south-west coast of Ireland's NPA region. A leader in the blue revolution, it focuses on harnessing and extracting a range of highly bioactive ingredients from a variety of seaweed species to develop next generation phytochemical formulations.

Their flagship product is PureCoidan™, a high-purity, organically certified fucoidan powder for use as an ingredient in food, cosmetics and supplement products with benefits to immunomodulation, anti-oxidant, anti-microbial and anti-cancer effects. Their Alga-fibre product has anti-inflammatory properties and benefits for gut and digestive health.

Case 2: Fish company

The company are in the North-West region of Irelands NPA and have grown over a twenty-year period to become one of Irelands biggest exporters of the Crassostrea Gigas (Pacific Oyster) species. Oyster production in their region accounts for 16M to the local Donegal economy, €11M in terms of GVA and approximately 249 regional jobs created either directly or indirectly.

In Ireland, the Dept of Agriculture, Food and Marine policy states that the shellfish sector "must be responsive and adaptable to consumer demands and sustainable opportunities" (see also Figure 200). They report an additional €40M outcome from simple value-added activities (of which 80% has export potential) because it is an already established natural resource base activity, has very small associated import costs placing it "on the positive side of the trade balance. The company is seeking to implement a Circular and Bioeconomy strategy for the CaCo3 (Calcium Carbonate) rich Oyster shell waste which has not yet been exploited by the industry. Nationally, Oyster Shell waste accumulations report average stock mortalities of 20-30% per annuum. A more fundamental challenge exists with the threat to the biological security of the sector resulting from pathogens (eg. Ostreid Herpes virus-1 (OsHV-1) which can occur in 3-5 yearly cycles leading to mass stock mortalities of between 60-80% mortalities resulting in a significant waste issue for the industry. Legislation safeguarding the sustainable disposal of waste accumulations in accordance

with EU landfill directives has placed pressure, cost & onus on the industry to reduce organic waste volumes sent to landfill.

Currently, the vast majority of the world's calcium carbonate ($CaCo_3$) comes from ecologically harmful and unsustainable limestone mining. The $CaCo_3$ composition of crushed oyster shell is approximately 96%. Reusing shell waste is a perfect example of a circular economy, particularly as shells are a valuable biomaterial that can improve the sustainability of the aquaculture industry moving forward. An opportunity exists for secondary economic benefits to be realised by the company through the establishment of an ancillary waste shell processing facility to develop multiple opportunities comprising low risk/low return (e.g. chicken feed, fertiliser products, landscaping) Medium risk / medium return (e.g. use as an absorbent for volatile organic compounds (VOC's) and sustainable bio-filtration products). High risk/high return (e.g. 'Functional Food & natural health supplements) products.

Ensure waste is minimized and by-products recycled into alternative value-added products.	> Investigate or adapt technology for better fish waste management > Continue efforts to identify options for extraction of novel products from fish and shellfish waste	> Improved management practice and reduced waste tonnage to landfill > Series of new products developed based on by-products of fish processing lines

Figure 20:Leverage Irelands natural resources. Target outputs for the Seafood Processing Sector: Ref: Department of Enterprise, Business & Innovation: Future Jobs Ireland publication:2019

Future opportunities for waste handling:

The majority of fish and shellfish processing operations in Ireland are carried out in shore-based processing facilities. The amount of waste produced during processing varies according to the species, type of raw material supplied, and the type of product being produced.

The component parts of demersal fish produce are broken down into specific ratios with edible product yields of 50% accomplished. The remaining 50% is discarded as waste material in the form of heads, viscera, frames, lugs, flaps and skin. Waste products from shellfish processing include shell and viscera with the shell ratios typically comprising 70-80% of full product weight.

Future fish waste potentials exist in the development of valuable oils, minerals, enzymes, pigments and flavours that have many alternatives uses in food, pharmaceutical, agricultural and industrial applications. In addition to fishmeal and oil production, there is potential in silage production, fertiliser, composting, fish protein hydrolysate and fish protein concentrate. Non-nutritional uses include chitin and chitosan, carotenoid pigments, enzyme extraction, leather, glue, pharmaceuticals, cosmetics, fine chemicals, collagen, gelatin and pearl essence.

Barriers/challenges for efficient waste handling:

- **Licensing:** Transition through to added value chains within the seafood sector is happening gradually as the industry in its current state is quite focused on primary raw materials and products that require minimal processing. Future potential for the sector lies in higher value-added products such as functional ingredients and foods but is continually hampered by licensing and governance issues as well as a perceived lack of cooperation within the sector. This has caused a loss of confidence in the sector amongst financial lending institutions which in turn has starved the industry of investment. Delays of up to seven years in sourcing licenses are not uncommon and involve stringent and expensive environmental risk assessments which take time and money for companies to administrate.
- **Regulation:** The use of fish by–product material for human consumption, is subject to extensive food safety legislation, as are all fishery products for human consumption. Governed by strict EU regulations, seafood by-products are considered collectively with those from other animal sources. By-products are required to be treated according to risk and to a range of prescribed methods, from rendering and incineration to composting and anaerobic digestion. A Feasibility Report on the 'Use of Anaerobic Digestion within the Irish Seafood Processing Industry' reports that the uptake of anaerobic digestion in Ireland is a treatment option with great growth potential but is encumbered by regulatory and financial hurdles preventing industry uptake.
- **Capacity building:** Technological bottlenecks exist particularly for micro-enterprise to realise new products from their waste streams. The justification for expenditure on technical solutions to overcome identified technological barriers is influenced by potential revenue outcomes anticipated-V's -waste volumes experienced-V's -anticipated specialist equipment installation and running costs. This can be problematic if by-products identified turn out to be of low volume / low value. For example: In the case of waste biomass (seaweed) a compromise between drying speed, efficiency and nutrient degradation needs to be reached. Technological solutions and post processing techniques adopted may need to be compatible with specific by-product value chains involving ie. food grade and feedstock sodium alginates, plant nutrition, pigments / fine chemicals and fermentation products. This may call for expensive direct (combustion) and indirect (heat exchanger) heating / drying techniques that use purpose built and/or modified chambers that need to work simultaneously with existing

in-house processing operations, all of which can place a financial strain on existing operating costs and overheads for particularly micro sized SME's.

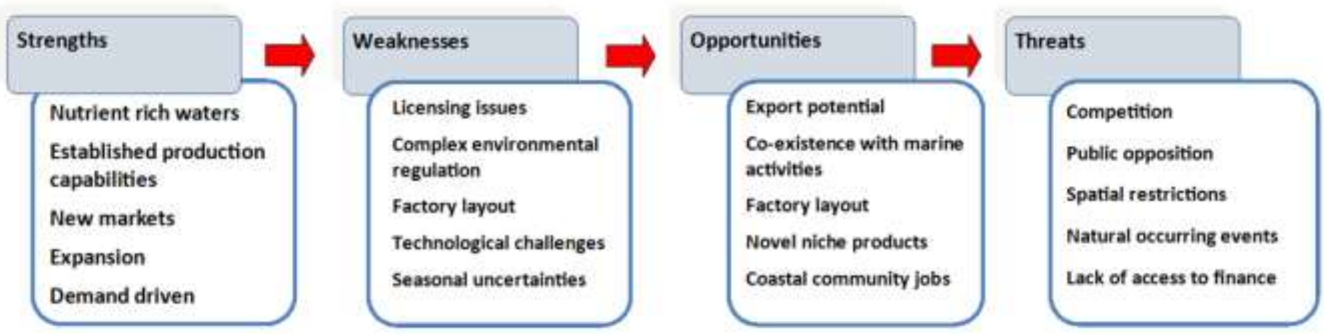


Figure 21: SWOT Analysis review for industrial symbiosis uptake within the fishing & Aquaculture sector.

3.0 Conclusions from analysis of existing circular business models in the NPA region

The individual descriptions above show a lot of similarities in the existing circular business models in the NPA region. But, especially the differences, open up for valuable cross-border learning. This section summarises opportunities and challenges per industry from all four countries as well as draws general conclusions on the findings. The general conclusions show that challenges and opportunities are not only industry specific and that cross-industry learning is important.

3.1 Brewery and distillery production

Traditionally, waste streams from the breweries and distilleries are used as animal feed or discarded. One of the main findings is however, that there is a strong interest in the brewery and beverage industry in the NPA region to create more value from their waste and by-products. Due to the significant amount produced annually, environmental awareness and the recognition that BSG may represent a nutritionally valuable co-product, efforts should be focused on its valorisation. Although microbreweries may have a rather low production, and a consequent low waste amount, many of them have on-going attempts to find sustainable and circular solutions to support their businesses.

Figure 22 is the schematic representation of the routes for potential valorisation of waste and by-products from breweries. The waste and by-products are highlighted in grey and potential valorised products are highlighted in orange. The processes which the waste or by-products must undertake to be valorised are highlighted in blue.

Figure 23 is the schematic representation of the potential valorisation of waste and by-products from whisky production. The colour indications are like the Figure 23 where the waste and by-products are highlighted in grey, potential products are highlighted in orange. The processes which the waste or by-products must undertake to be valorised are highlighted in blue.

Referring further to the Figure 22 and Figure 24, in the NPA region some of the valorisation processes are currently being implemented, like for biogas or animal feed production, however, they are not providing added value. In best case they are cost neutral as waste handling costs are spared.

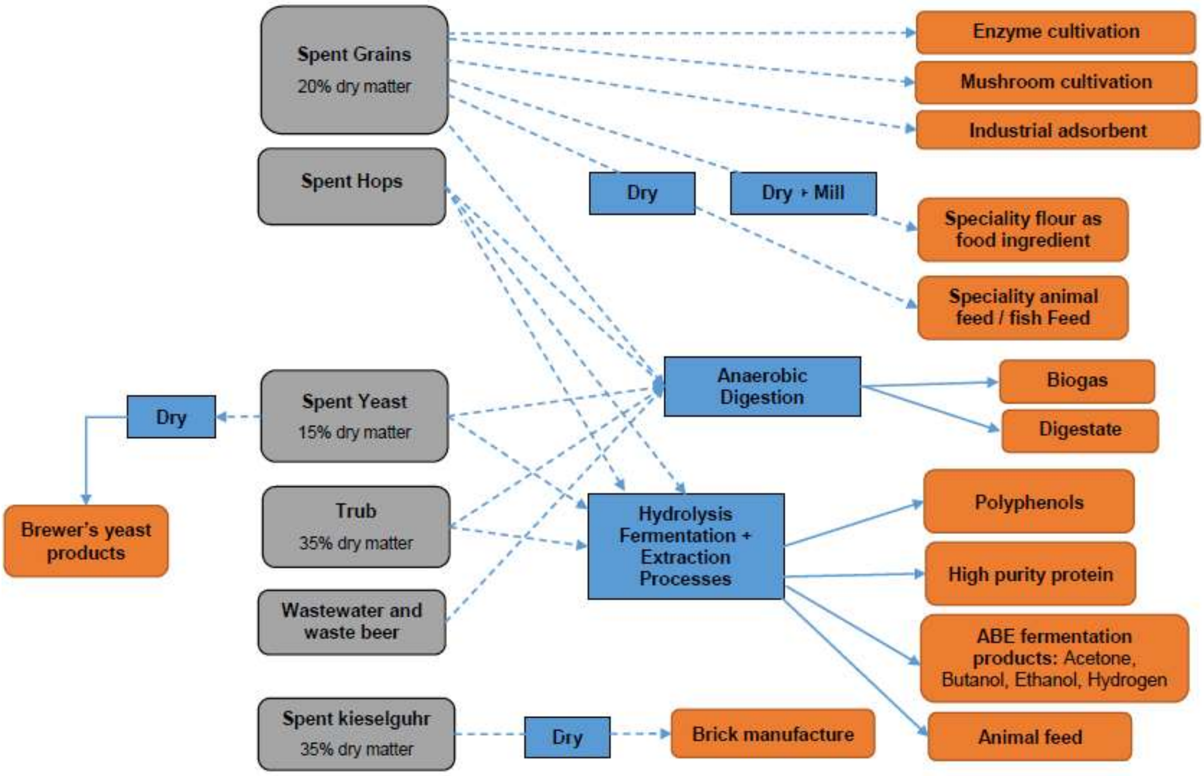


Figure 22: Current and potential uses of brewery wastes and by-products.

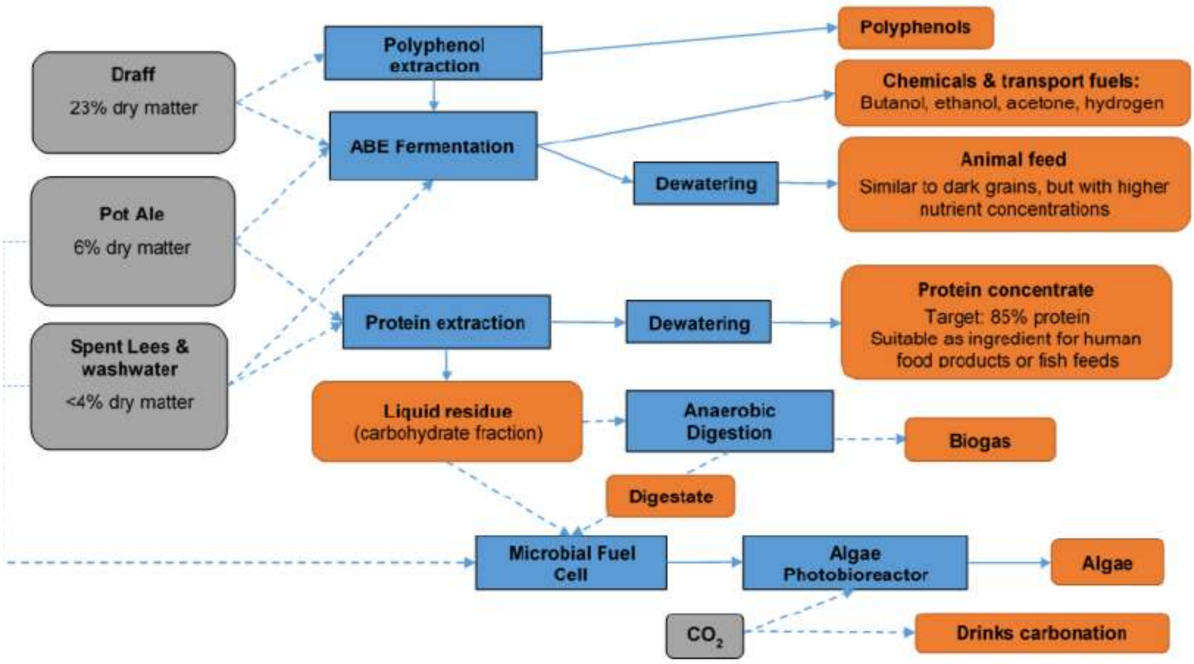


Figure 23 Current and potential uses of whisky distillery wastes and by-products.

Aggregated challenges and opportunities for valorisation of by-products and waste from alcoholic beverage production in the NPA areas of Finland, Sweden, Norway, and Ireland are summarised in Table 2.

Table 2 Opportunities and challenges from beverage production from four countries

Challenges	Opportunities
- Logistics: distance, small volumes, shelf life - Exiting solutions are “easy way out”, more value adding solutions need more effort in creating value chain and/or investments into new technology - Not enough knowledge and time to gain it as it is not the main business of beverage producer - Regulations/ restrictions	-Underutilized waste streams -Collaboration with new actors -Positive effect on cost or revenue -CO_2 and energy recovery

Logistics is the common challenge, that has been highlighted. The companies interviewed and presented in this report are in the NPA areas with rather low production waste volumes, which are located further away from the central part of country or/and far from other breweries which could be possible collaborators in creating more value from the production wastes and by-products. Also an additional concern is the shelf life of by-products as they mould in a short if no presentation means are taken into consideration, e.g. drying or freezing. Preservation of by-products though might increase costs of by-products.

Another common challenge is that the most companies don't focus on new solutions, but rather rely on existing solutions as they are "the easy way out" to handle production waste. The most common solution- animal feed in local farms does not require additional effort or investment. The companies would benefit from getting better support from government or local administration agencies in exploring other innovative solutions to address such issues. Lastly, a significant common challenge is the legal restrictions which unfortunately do not support the development of businesses towards implementing more circular philosophy in their business models.

Despite the above-mentioned challenges several opportunities were also identified. A lot of companies have highlighted that they are aware of their underutilized waste streams. They are very open for further discussions and looking into opportunities to transfer their current business models into circular business models, thus generate positive effect on economy, society, and environment. Especially new collaborations can lead to new circular business models. Public business support and industry branch organizations can play an important role in this establishment.

3.2 Potato processing

The NPA region of the partner countries offers rather good conditions for potato farming and further production of potato products. The utilization of by-products and waste streams from potato production, and with it the existing business models, vary a lot from country to country. Some examples of the current and potential uses of potato by-products and waste are illustrated in Figure 24. The waste and by-products are highlighted in grey, potential products are highlighted in orange. The processes which the waste or by-products must undertake to be valorised are highlighted in blue.

Norway has established a centralized system to take care of unusable potatoes, Finland has some well-established valorisation routes (e.g. production of potato flakes) and Sweden is rarely utilizing the waste streams. Overall, logistics issues, small waste volumes and short shelf life of waste and by-products are common challenges in the potato industry. In addition, the potato industry is highly regulated, thus the unique challenge is restrictions due to potato diseases which may spread with soil and infected machinery and equipment.

As in the beverage indusrty, the potato processors share an awareness of underutilized streams, and show a willingness to explore and establish collaborations with other companies and govermental institutes as well as municipalitites. Centralized support and regulations have shown great success in certain areas. More actions are required from all partner countries to drive the development towards circular busienss models.

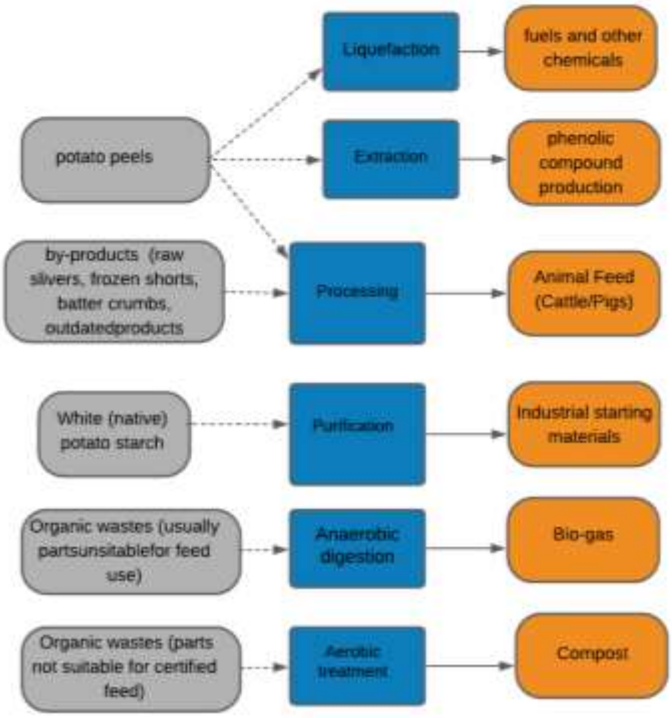


Figure 24 Schematic representation of current and potential uses of potato wastes and by-products

Table 3 Challenges and opportunities in potato industry

Challenges	Opportunities
-Logistics: High water content, shelf life, long distance, small volumes -Restrictions due to potato diseases, waste classification -Need for additional technology	-Utilization of valuable side streams, extraction, potato starch -On-side valorisation -Collaboration with other partners -Collaboration with municipality

3.3 Fish processing

Several processes have been identified that could offer valorisation opportunities for fish industry waste and by-products (Figure 25). The waste and by-products are highlighted in grey, the undertaken process for valorisation are in blue and the potential product are highlighted in orange.

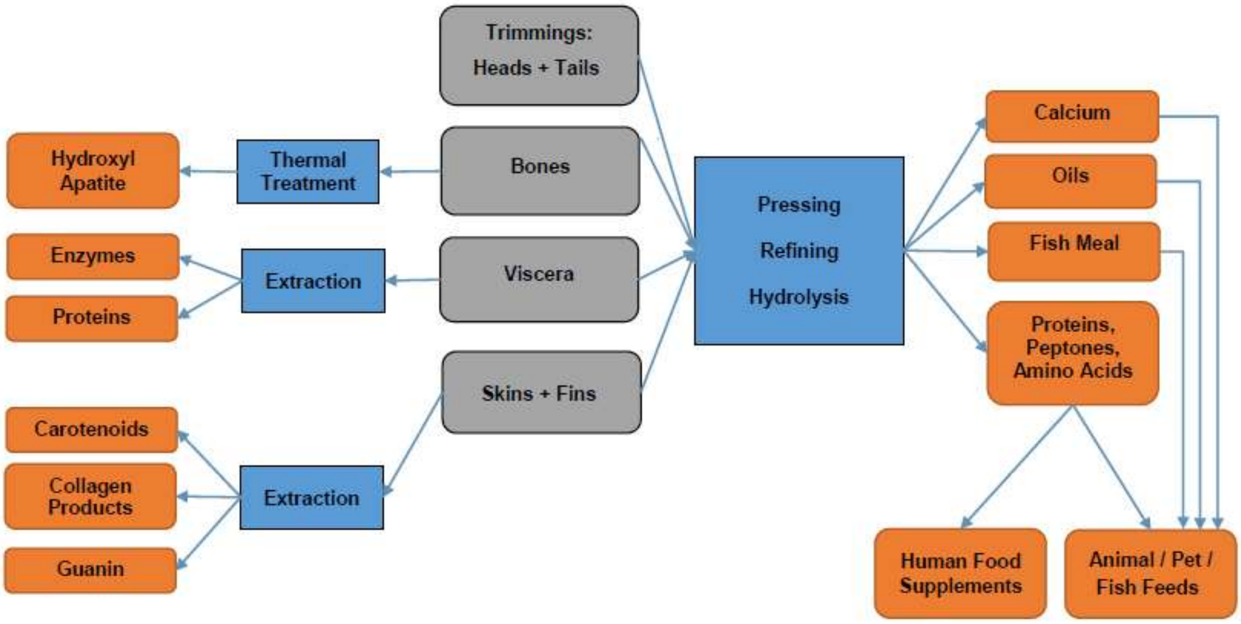


Figure 25 Potential uses of fish industry wastes and by-products

In line with the potential valorisation process certain challenges and opportunities have been identified by the fish companies in the NPA regions as well and aggregated in Table 4.

Issues regarding the logistics, shelf life and small volumes are concerns for the fish industry as well. In addition, fishing is heavily depending on seasons and therefore availability of waste streams is fluctuating. Fish industry by-products might be valuable source for human consumption, for example fish oil or proteins, however due to extensive food legislation not always is viable route. In spite of that there are numerous R&D activities ongoing to facilitate better utilisation of fish industry by-products.

Table 4 Common challenges and opportunities in the fishery industry

Challenges	Opportunities
-Current utilization can become unavailable -Logistics: waste streams are not continuous, short shelf life, small volumes -Economically unattractive solutions -Regulations	-Utilization of fish oil and other extracts -Use in higher waste hierarchy -Intention for better utilization and integration in human food or animal feed products

3.4 Lessons learned

This study has shown that there are good examples of industrial cases, where companies follow innovations and have high ambition in attempt to balance business challenges and business opportunities to shift towards circular business models. It is of importance to highlight that local value chains and collaboration are main trends to support transformation to circular business models in remote and sparsely populated areas.

Table 5 summarises the common challenges and opportunities across the industries and countries considered in this study.

Table 5. Common overall challenges and opportunities in brewery, potato and fishery.

Challenges	Opportunities
-Logistics: small and not continuous volumes, long distances, short shelf life -Regulations -Economic feasibility -Established way of waste handling	-Underutilized waste streams -Collaborations with other/new actors -Extraction of valuable components -Trend of sustainable, locally produced food

It is essential for companies in the NPA area to continue to be open and innovative to prosper and contribute to sustainable development. During data collection and data analysis it became evident that there is a lack of publicly available aggregated data of available underutilised by-products and waste streams in various industries in different/all part of the countries. Symbioma project will further seek to gather database of by-product and waste volumes in NPA region.

References

This section provides a list of all sources that were used to write this report. The sources are divided in three main categories: 1) journal and conference publications/books; 2) websites/public statistics databases; 3) online reports.

Journal and conference publications/books:

1. Arvanitoyannis IS, Kassaveti A. 2008. Fish industry waste: treatments, environmental impacts, current and potential uses. International Journal of Food Science Technology 43: 726-745.
2. Barros, M. C., Bello, P. M., Bao, M., & Torrado, J. J. (2009). From waste to commodity: transforming shells into high purity calcium carbonate. Journal of Cleaner Production, 17(3), 400-407.
3. Bertella G., Halland H., Martin P. and Reykdal Ó., (in press), Book Chapter: Sustainable value: the perspective of microbreweries in peripheral northern areas.
4. Caruso G. 2016. Fishery Wastes and By-products: A Resource to Be Valorised. Journal of Fisheries Sciences 10: 12-15
5. Fărcaş AC, Socaci SA, Mudura E, Dulf EV, Vodnar DC, Tofană M, Salanță LC. 2017. Exploitation of Brewing Industry Wastes to Produce Functional Ingredients . Brewing Technology, Chapter 7: 137-156. http://dx.doi.org/10.5772/intechopen.69231
6. Farcas AC, Socaci SA, Tofana M, Dulf FV, Mudura E, Diaconeasa Z. 2015. Volatile profile, fatty acids composition and total phenolic content of brewers' spent grain by-product with potential use in the development of new functional foods. Journal of Cereal Science 64:34-42. DOI: 10.1016/j.jcs.2015.04.003
7. Halland H., Thomsen M and Dalmannsdottir S. (2018) Dyrking og bruk av korn I Nord-Norge. Kunnskap fra det Nord-Atlantiske prosjektet Northern Cereals 2015-2018. NIBIO rapport, Vol. 4, Nr. 86.
8. Huige NJ. 2006. Brewery by-products and effluents. In: Priest FG, Stewart GG, editors. Handbook of Brewing, 2nd ed. London, UK: CRC Press; DOI: 0.1201/9781420015171.ch18
9. Kato, S., Kunisawa, N., Kojima, T. & Murakami, S. (2004). Evaluation of ozone treated fish waste oil as a fuel for transportation. Journal of Chemical Engineering of Japan 37: 863–870
10. Kim S-K, Mendis E. 2006. Bioactive compounds from marine processing by-products- a review. Food Research International 39: 383-393.
11. Lee, C. W., Kwon, H. B., Jeon, H. P., & Koopman, B. (2009). A new recycling material for removing phosphorus from water. Journal of Cleaner Production, 17(7), 683-687.
12. Lindberg D., Aaby K., Borge G. I. A., Haugen J-E., Nilsson A., Rødbotten R and Sahlstrøm S., Kartlegging av restråstoff fra jordbruket, Nofima, Rapport 67/2016.
13. Linko M, Haikara A, Ritala A, Penttila M. 1998. Recent advances in the malting and brewing industry. Journal of Biotechnology 65:85-98. DOI: 10.1016/S0168-1656(98)00135-7
14. Mathias TR, de Mello PM, Sérvulo EF. 2014. Solid wastes in brewing process: A review. Journal of Brewing and Distilling. 5:1-9.

15. Mahro B. Timm M. 2007. Potential of biowaste from the food industry as a biomass resource. Engin in Life Sci 7: 457−468.
16. Mohan SV, Nikhil GN, Chiranjeevi P, Reddy CN, Rohit MV, Kumar AN, Sarkar O. 2016. Waste biorefinery models towards sustainable circular bioeconomy: critical review and future perspectives, Bioresource Technology 215: 2–12.
17. Mussatto, S. I.; Dragone, G.; Roberto, I. C., Brewers' spent grain: generation, characteristics and potential applications. Journal of Cereal Science 2006, 43, 1-14.
18. Pawelczyk A. 2005. EU policy and legislation on recycling of organic wastes to agriculture. ISAH 2005, 1: 64–71.
19. Robertson JA, I'Anson KJA, Treimo J, Faulds CB, Brocklehurst TF, Eijsink VGH, Waldron KW. 2010. Profiling brewers' spent grain for composition and microbial ecology at the site of production. LWT-Food Science and Technology 43:890-896.DOI:10.1016/j.lwt.2010.01.019.
20. Rustad T. 2003. Utilization of marine by-products. Electr J Environ, Agricult and Food Chem 2: 458−463.
21. Santos M, Jiménez JJ, Bartolomé B, Gómez-Cordovés C, del Nozal MJ. Variability of brewer's spent grain within a brewery. Food Chemistry. 2003;80(1):17-21. DOI: 10.1016/S0308-8146(02)00229-7
22. Shahidi F, Metusalach G, Brown JA. 1998. Carotenoid pigments in seafoods and aquaculture. Critical Reviews in Food Science: 38, 1–67.
23. Study of municipal wastewater treatment with oyster shell as biological aerated filter medium :Yao-Xing Liu, Tong Ou Yang ⁎, Dong-Xing Yuan, Xiao-Yun Wu
24. Recycling waste oyster shells for eutrophication control. Resources, Kwon HB, Lee CW, Weon SY, Koopman B. Conservation and Recycling 2004
25. Sepelev, I., & Galoburda, R. (2015). Industrial potato peel waste application in food production: a review. Research for Rural Development, 1, 130-136.
26. Prasad, M. M., & Murugadas, V. (2019). Microbial quality and safety of fish and fishery waste. ICAR-Central Institute of Fisheries Technology.
27. Torén, J., Lorentzon, K., & Cintas, O. (2019). Food waste as a resource for bio-based chemicals and materials in Sweden.
28. Bergman, K. (2015). Co-products in the Swedish Seafood Processing Industry.

Websites/ public statistics databases:

1. Avfall Sverige /The Swedish Waste Management Association Link: https://www.avfallsverige.se/
2. Biodegradable mesh netting alternative in Irish Aquaculture Industry: Link: http://www.bim.ie/our-work/projects/innovative-mussel-farming-technology%20-%20new-zealand/
3. Bryggeri og drikkevareforeningen, www.drikkeglede.no
4. EUPPA. 2016. Industry initiatives to reduce food waste- Progress towards zero waste in the EU potato processing supply chains. European Potato Processing Authority. FUSIONS European Platform Meeting. Brussels, 19 May 2016.

5. SSB-Statistics Norway: Production of potatoes and forage plants. Available online at https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/jordbruksavling
6. SSB-Statistics Norway data on fish. Fisheries: https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/fiskeri
7. SSB-Statistics Norway data on fishing vessels: https://www.ssb.no/statbank/table/07842/tableViewLayout1/
8. SSB-Statistics Norway data on fishermen: https://www.ssb.no/statbank/table/07811/tableViewLayout1 /
9. SSB-Statistics Norway data on aquaculture: https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/fiskeoppdrett
10. Pienpanimoliitto Ry website https://pienpanimoliitto.fi/
11. The Net Map Project: Exploring Opportunities to Create Value from Waste Fishing Nets in Ireland: Green Enterprise: www.netmap.ie

Reports:

1. Ahokas M, et al. Perunnan ja vihannesten sivuvirtojen arvokomponenttien hyötykäyttö. MTT raportti 67. 2012. http://urn.fi/URN:ISBN:978-952-487-410-6
2. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance) *OJ L 312, 22.11.2008, p. 3–30* (read from https://eur-lex.europa.eu/eli/dir/2008/98/oj)
3. Circular Ocean Project: ERDF Interreg VB NPA funded project (2015-2018) focused on diversion of marine plastic waste away from oceaans and landfills for reuse, recycling and new product development: Link: http://www.circularocean.eu/
4. CYCLE 2018 - Total utilization of raw materials in the supply chain for food with a bio-economical perspective, 2013-2017. Final report 2018, https://www.sintef.no/globalassets/cycle_finalreport_2017trykket.pdf
5. EU. 2010. Preparatory Study on Food Waste across EU 27. 2010. Available online: http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf (accessed on 07 January 2020).
6. EU, 2014. S.I. No 187/2014 – European Union (Animal By-Products) Regulations 2014. http://www.irishstatutebook.ie/eli/2014/si/187/made/en/print . Accessed on 9/01/2019.
7. FAOSTAT 2020. FAOSTAT Crops. Available online: http://www.fao.org/faostat/en/#home (accessed on 9 January 2020).
8. Fish Farming in Finland, 2017 https://www.kalankasvatus.fi/wp-content/uploads/2017/08/Fish_farming.pdf
9. Fish-box EPS in Ireland: Sept 2013: Link: http://www.bim.ie/media/bim/content/downloads/EPS,Report,Fish,Box,EPS,Usage,and,Disposal.pdf.
10. Hiidenhovi Jaakko et al, Kalan elintarvikejalostuksen sivutuotevirtojen jalostaminen kalaöljyksi. Luonnonvara- ja biotalouden tutkimus 51/2017. https://jukuri.luke.fi/bitstream/handle/10024/540233/luke-luobio_51_2017.pdf?sequence=1&isAllowed=y

11. Independent Craft Beer and Independent Micro-breweries in Ireland Oct 2018: A report for Board Bia and Independent Craft Brewers of Ireland.Link: http://icbi.ie/economic-impact-reports/
12. Kalamarkkinakatsaus-2017. https://www.luke.fi/wp-content/uploads/2019/03/Kalamarkkinakatsaus-2017.pdf
13. LUKE article, 2020. https://www.luke.fi/ruokafakta/en/field-crops/high-quality-seed-potato-production-area / , Accessed 15.3.2020
14. Lupapäätös Nro 32/2017/1 Dnro PSAVI/1977/2016 Annettu julkipanon jälkeen 10.5.2017. Extracted from https://tietopalvelu.ahtp.fi/Lupa/Lisatiedot.aspx?Asia_ID=1315590
15. MTT article: perunan ja sokerijuurikkaan tuotanto, 4.12.2018. https://www.mtk.fi/-/muu-kasvituotanto-1 . Accessed 15.3.2020
16. Nouseva rannikkoseutu ry, Perämeren rannikon kalasatamat nykytila – kehittämistarpeet, 2017. https://merijakalatalous.fi/wp-content/documents/Nouseva_rannikkoseutu_ry_-
17. Olvi Corporate responsibility report, 2019. https://www.olvigroup.fi/app/uploads/sites/2/2020/04/8.-Olvi_Corporate_responsibility_report_2019.pdf
18. Peetu Pesonen, Raimo Hämäläinen, Teemu Ukkola, Nuutti Siira (2018), Iso-Kallan Panimo Oy, Seminaarityö. http://materiaalivirrat.fi/download.php?id=102 . Accessed 17.3.2020
19. Prokala report: Finlands Fisheries Industry, 2018 https://www.prokala.fi/wp-content/uploads/2018/04/Vedest%c3%a4-ruokap%c3%b6yt%c3%a4%c3%a4n-2018-engl.-kevytversio-FINAL.pdf
20. Review of the application of shellfish by-products to land: The Seafish Industry Authority: August 2006: ADAS UK Ltd.
21. Richardsen R., Nystøyl R., Strandheim G., Marthinussen A., (2017). Analyse marint restråstoff, 2016 - Tilgang og anvendelse av marint restråstoff i Norge, SINTEF Ocean report; OC2017 A-095, https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2446152
22. Scottish Government. 2015. Sector Study on Beer, Whisky and Fish. Final Report
23. State Key Laboratory of Marine Environmental Science, Environmental Science Research Center, Xiamen University, Xiamen
24. Shell Waste in Aggregates Project Report For: Sea Fish Industry Authority: March 2007
25. Statistics database, http://statdb.luke.fi/PXWeb/pxweb/fi/LUKE/?rxid=001bc7da-70f4-47c4-a6c2-c9100d8b50db
26. The Pro Fish Association https://www.prokala.fi/wp-content/uploads/2018/04/Vedest%C3%A4-ruokap%C3%B6yt%C3%A4%C3%A4n-2018-engl.-kevytversio-FINAL.pdf Accessed 15.3.2020