Cascading Norwegian Co-streams for Bioeconomic Transition

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Highlights

1 A bioeconomic transition to minimize food loss and waste calls for institutional and technical innovation.

2 Cascading options to avoid food losses occurring in chicken, fish, and fruits & vegetable industry, explored.

3 Contribution and novelty is the transdisciplinary investigation of concrete bioeconomic cascading and valorisation options in the case of three value chains in Norway.

4 A transdisciplinary approach and involvement of industrial actors collaborating with researchers is required to address societal challenges facing the bioeconomy.

Abstract

A circular bioeconomy has become a global aspiration for governments in Europe and around the globe. This article pursues research questions concerning concrete innovations aiming to create bioeconomic transition options in Norway and presents results from a transdisciplinary investigation of Norwegian food industry cases involving processing of fish, meat, fruit, and vegetable co-streams aiming to capture or even increase use and value of residues from processing. It shows that while objectives of avoiding food losses and transforming co-streams to new products of higher value characterizes the poultry industry case and part of the ´blue´ sector, challenges remain particularly in the ´whitefish´ area where - also at the global level - a high share of fish resources ends as rest raw materials, i.e. not fully utilised. The investigation targeted strategic cases of innovations enabling alternative uses of co-streams: automation and scanning technologies for fractioning raw materials and co-streams into different qualities, a collection system for fish rest raw materials at sea, enzymatic hydrolysis, use of second grade vegetables for smoothies and potato peels for biodegradable plastics in the vegetable (potato) processing industries. The article shows how these innovations enable cascading and valorization of co-streams and why an upcycling potential exist as well. Its main contribution is in demonstrating feasibility of transdisciplinary research and innovative options for bioeconomic transition towards sustainability.

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1. Introduction

1.1 Transition towards a bioeconomy is a global aspiration for policymakers and the science community has been called upon to build ´bridges´ to make the transition, boost innovation, and help society face planetary boundaries through increased resource efficiency and sustainable conversion of bio resources into food and feed (Ingrao et al. 2016, Blok et al. 2015). Consequently, an increasing number of research programs and researchers all over the world started to identify and document ways to accelerate the bioeconomic transition. The quest includes pinpointing ´hotspots´ in a life cycle perspective, with a view to reduce food losses and waste (FLW) (Serenella et al. 2017, HLPE 2014). At the same time, companies around the world continue aiming for business models combining market performance with eco-efficiency and reducing the environmental impact of food production (IISD 2017, Sidiropoulos 2013). The bioeconomic strategy implemented should be diverse, involve innovation support programmes and industrial stakeholders – and concrete options for valorisation of food losses occurring in food industries have to be identified (Mirabella et al. 2014).

1. 2 Consensus is yet to emerge on how to embed the evolving European Policy Framework in a more holistic scientific or ´meta´ discourse, more inclusive of social and environmental sciences focusing on circularity, thermodynamics, limits to substitutability between natural and man-made capitals, systems and planetary boundaries (Ramcilovic-Suominen and Pülzl 2017, Ghisellini et al 2016, Golembiewski et al. 2015 and Pülzl et al. 2014). Consensus, however, dominates the literature as far as the realities of food loss ´hotspots´ and FWL is concerned (Kosseva and Webb et al. 2013, Mena et al. 2011, Stuart 2009.): in the US 40% of the food supply is ´never eaten´ (Reich and Foley 2014), and this challenge is also European (OECD 2014, Vaqué 2015). The global relevance of researching bioeconomic transition is clear from worldwide trends beyond the OECD: Brazil, India and Russia experience a mixed pattern of considerable loss and waste problems.

1. 3. The bioeconomic literature is emerging when it comes to coverage of countries and sectors (Besi and McCormick 2015 and Golembiewski et al. 2015) and it has left a research gap which we aim to fill with transdisciplinary research on emerging technical innovations with potential to facilitate bioeconomic transition in three Norwegian bioeconomic food chains. We have accepted the premise on which many current bioeconomic research calls are based, explicitly or implicitly, namely that *ceteris paribus*; increasing the number of technical innovations will provide valorisation and reduction options of relevance to the major global societal challenge of bioeconomic transition, including reduction of FLW. Focusing on food losses in selected processing units within three Norwegian food chains, and using a 2013 baseline, we will show that while the objectives of avoiding food losses and transforming co-streams to new products of high(er) value has been reached to a high extent in the ´red´ (meat, poultry) industry case, at least in Norway, challenges remain in the white (fish) blue sector and ´green´ (fruits, vegetable) processing industries.

2. Methodology

2.1 Scientific paradigms compatible with the reality of human economies evolving in a highly globalized and yet finite material biogeophysical world on a single planet are becoming a sine qua none. Facilitation of bioeconomic transition is an example of a complex societal challenge, the understanding of which calls for interdisciplinarity: crossing existing boundaries and integration of disciplines. Calls for interdisciplinarity to address big societal challenges characterize some of the world's major research programs like as IPCC, IAASTD, MEA and EU´s Horizon 2020. UNESCO (2010: 189) spoke of a coming post-disciplinary age in which the social and natural sciences can integrate.

2.2 Case studies, semi-structured interviews, industrial site visits and triangulation characterizes our mixed methodological approach, along with an ´abductive´ dimension allowing us to pursue observations and leads emerging from ongoing investigation (Egelyng et al. 2015, Adler et al. 2014a). In our case studies, we focused on food losses happening in the processing stage of the food system and so like the WEF (2014), we identified bioeconomic ´leakage points´ or hotspots from a ´circular economy´ viewpoint. Interviews were conducted in the period June 2013–May 2016, and our baseline for ´current´ applications of technologies and destinations of co-streams has been 1st June 2013, unless other dates are mentioned. Publicly available data (annual reports, statistics) and calculations based on figures obtained from third parties have also been used. Estimations of national and regional levels are based on aggregation of processors by market share.

2.3 We pursued representativity of Norwegian food industry practices through our strategic selection of industry cases and partners: investigated food processing plants had significant market shares in Norway within fresh potatoes, lettuce, poultry meat and white and pelagic fish. Our interdisciplinary[1] cases illustrate potentials known by the concept of cascading. Cascading movements pushing rest raw materials forward in the value chain has been a central strategy for the animal byproduct sector for years (Egelyng et al. 2017). Instead of focusing on a single sector, we have had the opportunity to use data across sectors enabling analyses of problems observed, enabling potentials to be seen, and willingness and level of readiness of individual companies and whole sectors to seek cascading opportunities to be explored.

2.4 We have chosen a terminology alternating co-streams and rest raw materials, while avoiding the term of by-products, to denote our general object of research. This choice of terminology is based on the fact that EU regulation of animal by-products has largely ´conquered´ the common language meaning of by-products. By alternately using ´co-stream´ and the concept of ´rest raw material´, broadly, we wish to stress that the fate of the materials under study, remain up for discussion: depending on research outcomes such materials are not pre-conceived, and could theoretically still end up in human consumption, even if currently used for energy or fodder – or vice versa. So co-streams are materials within a production process which are not destined to be part of the ´main´ product(s) of that process and which may or may not end up as a secondary product other than a by-product.

2.5 Our analytical approach and framework (table 1) aimed to identify sectoral hotspots and leakage points, valorisation options and provide a basis for crudely estimating resulting monetary benefit options. The approach is well aligned with a standard approach in circular economy: the three R´s for reduce, reuse, recycle, and awareness about the additional principle of or option for reclassification. However, we adopted the cascading concept and further developed the theoretical term ´upcycling´ to denote innovation potential for

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[1] The (US) National Science Foundation defined interdisciplinary research as: ´a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge´ (NSF 2004).

applications enabling not only monetary valorisation, but reducing environmental impact relative to economic value, in other words a dual process of adding monetary value and lessening environmental impact per resource unit. We imported and adapted the upcycling concept from an industrial design context where it denotes a manufacturing stream dis-assembling a product with parts returning to the stream, without a loss of value to the ingredients (Mahoney 2005). Table 1 aims to be illustrating the extent to which introducing the innovations analyzed in our scenarios for innovations to cascade co-streams could make sense under the market conditions in which the blue, green and red - processing industries exist.

Table 1: Norwegian upcycling potential – a basis for estimating combined co-stream processing case values

Sector (I.P.)	Blue	Green	Red	Summary
Processing Industry Challenge (Cases)	Fish viscera, heads, bones, skin, tails, tongues, roe, oil, milt, bycatch and damaged fish at seagoing fishing vessels processing captures onboard, has low commercial value and is usually discarded at sea.	Second grade vegetable is a low value co-stream. Potato industry loses the value of co-harvested potato soil and face a cost (and society a waste) instead.	All co-streams are used and easily absorbed by the market, except blood and feather. Still, of course, the poultry industry aims for cascading co-streams up the value ladder.	Norwegian whitefish industry is facing major challenge in terms of improving values and use of co-streams/rest raw materials. The whitefish sector in other words constitutes a bioeconomic hotspot or leakage point.
Innovations Explored	Automated classification of fish intestines, algorithm and machine-vision based. Collector Vessel (institutional innovation). Enzymatic hydrolysis of cod heads collected (frozen).	Automated detection of fruit ripeness (CT scanning). Second grade vegetables to smoothies and other foods. Potato peels to biopolymer.	Detection of blood stains in chicken fillets via hyperspectral imaging. Hydrolysis, upgrade of poultry residues from export for mink feed to in-country use for pet-food, aquaculture feed, or [human] food grade ingredients.	Great variability with regard to the plausibility of the explored innovations in terms of adoption in the market and by industry, for upcycling.
Basis for monetary estimates	Quantities of current discards and non-use of rest raw materials, particularly in the whitefish sector.	Current use/disposal of 2nd grade vegetables, fruits and potatoes (feed, industrial alcohol) as well as costs associated with disposal of co-harvested soils.	Current use of co-streams in the highly competitive market for animal by-products.	Cascading options feasible in all three cases.
Export Options	Global situation adds up to a very significant potential for exporters of cascading equipment and know-how.	Low to moderate potential for exporters of cascading equipment and know-how.	Major potential for exporters of co-stream upcycling equipment and know-how.	Cascading know-how and technology export options significant in two of the three cases: the white-fish industry and the poultry by-products industry.

3. State of art and theory.

3.1. Transdisciplinarity is required to gain scientific knowledge on the bioeconomy in a global market context and applying it forms part of the quest to meet the global imperative of creating eco-efficient sustainable systems (Ayer et al. 2009). Transdisciplinarity allows for seemingly unrelated contributions to be part of the same field - or at least enable an easy connection to other disciplines through common themes. Clarification of implicit assumptions and theoretical fallacies marking standard (neoclassical) economic theory – as done by Daly and Cobb (1989) - is fundamental for any emerging bioeconomic paradigm to make scientific sense. Any bio-economic discipline aspiring for scientific validity does need conform to the [thermodynamic] laws of nature, and account – inter alia - for energy costs. Energy prices are important institutional framework components, co-determining whether a particular co-stream will be upcycled - or recycled, composted, incinerated or dumped in a landfill. In Norway, between 1960 and 1990, the energy use to catch a basically constant amount of fish, increased 6-fold (Andersen. 2002). Carbon performance of Norwegian seafood products vary highly both among species and within species, depending on management and processing (Ziegler et al. 2012). While the sustainability of Norway's fisheries sector is sensitive to energy prices, energy and resource use is thus no longer only a price matter for companies and industries.

3.2 Without the consideration of basic economic principles, however, many a perceived scientific or technical ´solution´ to a perceived global or societal (say food loss) ´problem´ risk failing. Cost shifting, opportunity costs as well as trade-off´s and transaction costs are just a few of the many economic and social science concepts awaiting further application in analyses of bioeconomies. Bioeconomic circularity and transition, including reduction of food loss, thus may also be approached as a logistics problem and call for logistics theory and more ´intelligent´ logistics (Strandhagen 2011). Logistics issues such as careful handling and speed of handing are critical for all biological products since they affect product quality. The aspiration for bioeconomic transition gives rise to different logistical challenges than those seen in traditional forward logistics and requires design of customised supply chains and logistics solutions for key activities such as material forecasting and handling, storage, transport, packaging, transparency and traceability. (Romsdal 2014, Romsdal et al. 2014, Vlachos, 2014, Grant et al. 2013).

3.3 The point in the supply chain where a 'leakage' occurs impacts on the magnitude and cost of the loss the leakage represents. It is not only about the value of products, but also about all the resources their production has consumed and which has been incurred from cultivation, harvesting, processing, packing, transporting, storing and handling, all the way to final consumption. In this perspective, leakages occurring at later stages in the supply chain have bigger impact on the total sustainability of products, because more resources are wasted. In addition, the potential for upcycling such materials decrease and costs increase with the degree of processing and mixing, packaging, and consumption of shelf life. For biological products traditional models and mechanisms are unsuitable for planning and controlling operations in food supply chains with the aim of matching demand with exact supply. In addition, actors in food supply chains must not only handle demand uncertainty, but must also deal with issues of supply uncertainty, such as seasonal and annual variations in the volume, timing, quality and price of raw materials (Dreyer and Grønhaug, 2004, Hameri and Pálsson, 2003).

Research on planning and control of supply chain operations under the conditions of supply uncertainty is therefore still needed to identify and analyse effective coping mechanisms (Chaudhuri et al., 2014).

3.4 The reality of a fully globalized economy where the Norwegian seafood industry is part of the international value chain means that structural changes along this chain can open new opportunities for valorization and upgrading for human consumption of for instance fish species currently used purely for fish feed. It is already known that regulation and insufficient technical and logistical capacities add up to insufficient economic incentives preventing a higher degree of rest raw materials to be used. International standards exist for production and processing of wild fish (ISO 12875) and farmed fish (ISO 12877) and use of marine by-products are regulated by several public agencies (Agrifish and environment ministries) with rules relating to quality, disease regulation, and organic waste treatment. In Norway, the Food Law in particular, is perceived to have facilitated innovation through increased actor focus and knowledge of industrial handling and processing procedures, and deeper insights into production processes (Jakobsen and Aarset 2010). Thus, as much as innovations can provoke institutional change, regulatory reforms can transfer decision-making from the political-regulatory sphere to markets and create new markets for innovation[2].

4. Results

4.1. Norwegian Hotspot # 1 - Whitefish Rest Raw Materials.

While depletion of fishing stocks around the world increases the urgency of complete fish utilization, around 50 to 70 per cent of our extracted global fish resources - 80 million tonnes of fish processed worldwide - end up as rest raw materials not fully utilised (FAO 2014, Gestsson and Gudjónsson 2012, Rustad et al. 2011, Blanco et al. 2007). Major strategic research initiatives have addressed losses and waste from vessels and factories, at sea and land and Norway impacted the international community with its ´Norwegian approach to dealing with fish offal´ (www.fao.org/docrep/003/x9199e/x9199e04.htm). A more recent Norwegian strategic research analysis identified a continued challenge of finding innovative solutions on how best to exploit the between 180,000 and 820,000 tonnes of fish rest raw materials which is either ´currently not exploited at all´ or used for feedstuffs (Almås 2013; 47). Almost all co-streams from pelagic fish, but less than half of the white fish co-streams, are utilised. The annual Norwegian whitefish catch consist of several species and cod is only one. Yet, it is highly relevant as a hotspotted case based on the amount of heads of cod caught in Norwegian waters and thus amounts of rest raw material currently - or still - discarded in large volumes.

4.1.1 As a concrete option for co-stream based valorisation of food losses in the fishing sector we identified the option and propose concept for increasing the utilization of rest raw materials by establishing a collector vessel based co-stream supply chain. We believe a large untapped potential lies in onboard-generated processing residues. However, limited space and preservation possibilities onboard trawlers limit the amount of residues

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[2] Institutions sensu North (1995) is a concept inclusive of formal as well as informal rules of society and economy and a concept which should not be confused with organisations. Institutions are rules, regulations, policy instruments and social codes for patterns of behaviour and they form a web governing or institutional environment influencing behaviour of economic actors.

that can be kept and transported onshore for further processing. We therefore outlined the concept whereby a dedicated ship collects rest raw materials from several seagoing fishing vessels, and transports these materials to land for further processing and upgrading into valuable products (Figure 1). While the collector vessel in figure 1 is purely conceptual, the world´s first fish trawler, owned by the Norwegian ´Nordic Wildfish´ company, with an on-board hydrolisis facility producing fish oil and hydrolyzed fish protein powder, is now in operation (www.nrk.no).

Figure 1: The Collector Vessel Concept.

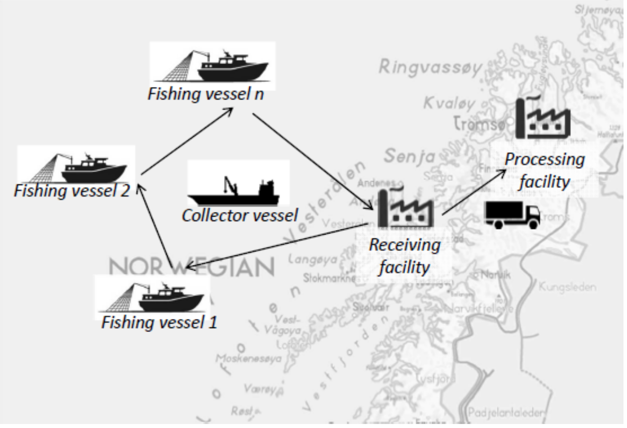

Figure 1 illustrates how co-stream valorisation options currently wasted at sea may be used by way of a collector vessel, transporting co-streams (such as fish heads currently thrown at sea) to a receiving and processing facility. Establishing such a collection system would give rise to a completely new supply chain for the co-streams. However, institutional and logistical issues would of course need to be addressed before this purely theoretical concept can be realised in practice, including development of practical solutions for storing and transfering the materials at sea that meet product quality and safety requirements. A new supply chain for fish co-streams could then be based on collecting and processing rest raw materials from fishing vessels. A firm foundation exists, since the range of current uses and options for valorization of fish industry co-streams is already impressive, with applications including animal feed, energy (biodiesel, biogas), natural pigments (carotenoids), cosmetics (collagen from bone, skin and fins), fish oil and gelatin, - and even in agriculture, as fertilizers or attractants for pest management products (Rustad et al. 2011).

4.1.2 An indication of how different national and regional institutional environments impact the capacity of producers to add more or less value to the same 5 kg fish is illustrated by the ´European´ cod (at USD 15 total value), the ´Icelandic cod´ (at USD 20) and the bioeconomically ´ideal´ cod with a potential market value of USD 80 when optimally processed, given known demands and theoretical product options in terms of the high diversity of products that can be made from cod, (Iceland Ocean Cluster. 2014). Based on these actual and hypothetical figures, respectively, table 2 provides an estimation of the upcycling potential of Norwegian cod[3].

Table 2 Cascading potential for Norwegian cod.

Degree of valorisation (Export price of products from ´average´ model-cod weighing 5 kg).	Norwegian Cod quota 2016 (Barents Sea): 401,240 metric tonnes divided by 5 kg = 80,248,000 pieces of ´model´ cod weighing 5 kg.	226,000 tonnes of whitefish rest raw currently ´not used at all´ (Paluchowski et al. 2016) valorized at between USD 5 and 60 per 5 kg.	Our Crude Estimate
15 USD (European Level).	1.2 billion USD (80,248,000 pieces of ´model´ cod x 15 USD)	0.23 – 2.7 billion USD.	1.6 billion USD.
20 USD (Icelandic Level)	1.6 billion USD		
80 USD (Ideal or bioeconomic optimum).	6.4 billion USD		

Major market demand for cod heads exist in South-East Asia and Africa (Nigeria). In a high labor cost country like Norway, cost of removing blood and gills reduces export options. Upcycling potential for cod head as a co-stream was selected for our study: From heads of wild cod (*Gadus Morhua*) we produced fish protein hydrolysates (FPH), using enzymes, and showed that freezing and thawing of cod head only lead to small changes in composition of the resulting FPH. While further research is of course needed on optimizations required for the hydrolysis process and matching of different quality requirements, FPH has further potential in the food industries (e.g. bakery products, appetizers, cookies and soups) as protein supplement with good nutritional value, well defined chemical composition, quick intestinal absorption in the body, flavor enhancing, functional, anti-oxidative and bioactive properties. Enzymatic hydrolization of cod heads is therefore one of several technologies developed enabling upcycling of fish rest raw materials.

Figure 2: Ranges of valorisation options for Norwegian Cod.

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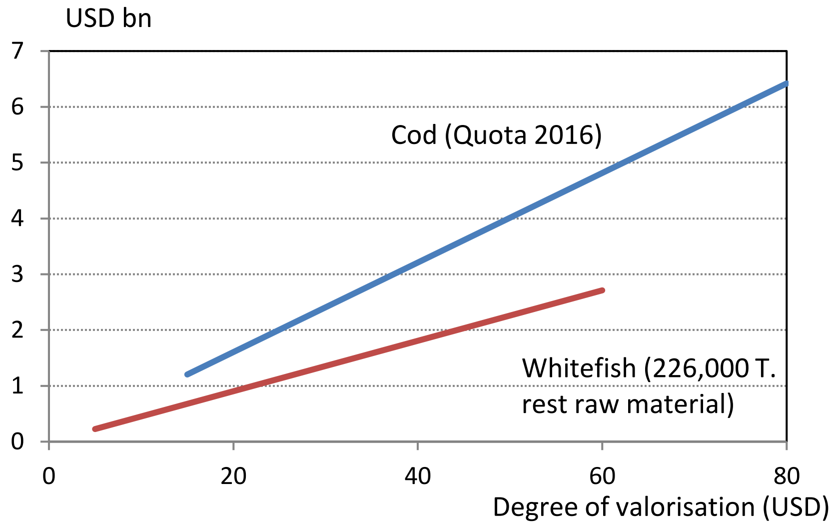
[3] The estimates in table 2 were produced by comparing the export value of a 5 kg cod in this way: 1. Typical European Cod - $15, based on export prices of cod products in Norway and other European countries, 2. Typical Icelandic Cod, based on export prices of traditional cod products in Iceland (H&G, fillets, salted, dried, heads, liver, oil), and 3. Optimally Processed Cod based on computing the possible export value if one 5 kg cod should go into the most valuable product categories that currently exist in Iceland, including products like fresh fillets, liver pate, roe and various medical products, cosmetics and supplements and keeping in mind that some of the most valuable products are being produced on a limited scale from a small percentage of the available raw material. (Personal correspondence with Haukur Mar Gestsson, Iceland Ocean Cluster).



Due to substitution effects and limits to the absorption capacity of the world market our estimate is that while the theoretical market potential for ´total utilisation´ of the Norwegian cod – shown in figure 2 above - is perhaps not realistic to seize in the near future, adoption of on-board enzymatic hydrolysis should enable the Norwegian bioeconomy perform to the ´20 USD´ mark and so add at least 400 million USD to reach a future cascaded total value of 1.6 billion USD/year.

4.2 A Case of Green Norwegian Co-streams

4.2.1 In the green food system of Norway, a wider range of co-streams was identified as having potential for upgrading (Løes et al. 2015, Adler et al. 2014a). This part of the food system employs five thousand people full time and adds USD 330 million to the Norwegian economy (Pettersen, Nebell and Prestvik, 2014). One concrete potential identified was use of new algorithm based optical scanning technologies enabling fruit and vegetable production lines to ´see through´ the fresh products and identify any inner decay, rot, deformation or insufficient maturity. An important strategy to reduce the volume of the less valuable co-streams is to use rapid on-line and non-destructive techniques to differentiate the high value raw materials to different uses.

4.2.2 In the Norwegian potato processing industry, especially the frying and sous-vide industries, a large part of the contribution to co-streams is made up from end products of non-satisfactory quality. One case addressed is the differentiation of whole potatoes according to dry matter. The dry matter content in potatoes is an important quality parameter frequently used to determine the cost of the raw material and more important; the choice of process settings such as frying and cooking time. A poor match between dry matter content and process settings results in significant waste of raw material end energy, which leads to economic losses. Dry matter is presently measured on a spot check basis only (typically on a 5 kg sample), and the obtained value is rarely representative for the actual variation in the much larger batch to be processed. Studies in Norway show that dry matter can be measured in every single potato by near-infrared spectroscopy, and the potatoes can then be sorted continuously into batches of uniform quality (Helgerud et al. 2015). The batches of known dry matter content can then be processed optimally ensuring high end quality and a minimum of waste/co-streams. The use of process analytical technology (PAT) as described above is supposed to be an important future strategy to optimize processes and reduce waste in the food industry.

4.2.3 In the vegetable and potato industries second-class products and peelings are co-streams currently used for production of starch or industrial alcohol, as animal feed or for biogas. To some extent the co-stream of second class produce, e.g. potatoes with visual quality issues, is sold to other food companies using it as raw material in food processing. Depending on the type, vegetable co-streams can be rich in carbohydrates like sugars, starch and fibers, and many of them contain also high-value components like flavonoids and carotenoids. Second class vegetables, now mostly ending up for feed use, consist of vegetables with wrong size, shape, color, other visual defects and small rot spots. The major part of these is highly nutritious and edible. Increased utilization of second class vegetables in food products would decrease food loss. However, more sophisticated identification, quality differentiation and sorting procedures would be needed to direct the co-streams efficiently to food uses (Paluchowski, Misimi, and Randeberg 2015).

4.2.4 Our research included experiments aiming to increase nutritional quality of vegetable co-stream-based smoothies and other products through fermenting with health-promoting probiotic bacteria. Research was undertaken to show that carrot, lettuce, Swedish turnip, red beets and spinach are useful raw materials for production of co-stream based smoothies, i.e. with raw extracts to be consumed fresh or fermented. Fresh smoothie mixtures were evaluated in 2014 by consumer panel which found the best mixtures very pleasant. The vegetable extracts scored highest in preference when combined with melon or other fruit extracts in smoothies as evaluated by a local consumer panel (Løes et al. 2015).

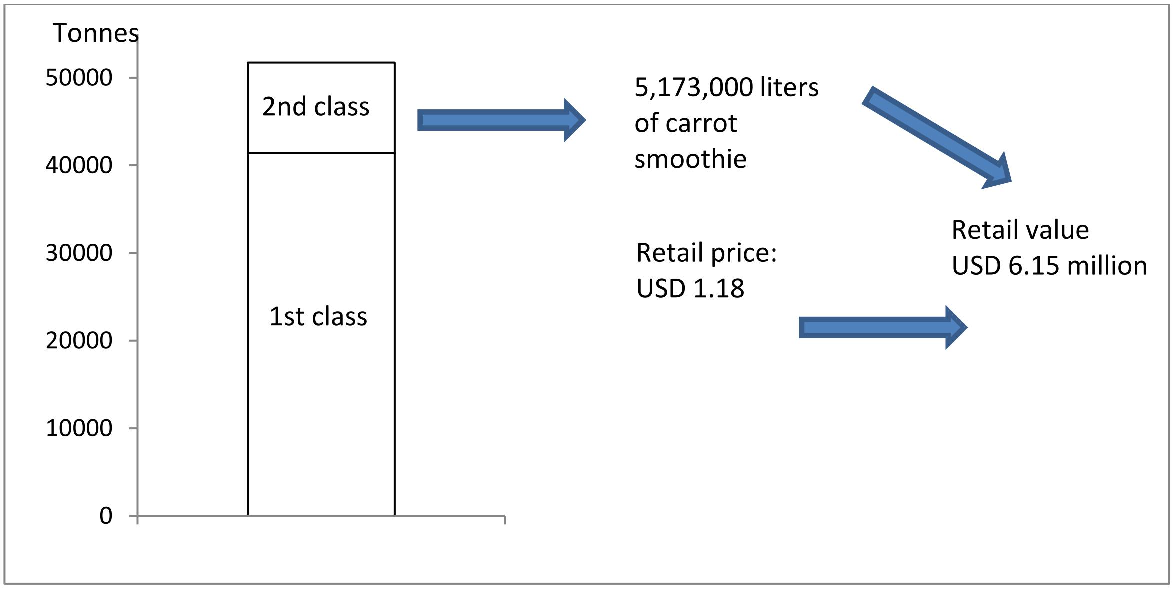


Figure 3. Cascading option for 2nd class carrots in Norway.

Figure 3 shows how the valorisation potential from cascading 2nd class carrots, currently donated to cattle feed, into smoothie can be estimated as follows: According to Statistics Norway (2016) and FAO (2015) Norwegian production of carrots in 2015 was about 51,727 tonnes. Typically 20 % of this raw material consists of misshaped, small or mechanically damaged carrots available for cascading from fodder use to a higher value product such as a smoothie (see above). Given a yield ratio of 500 liter of carrot smoothie per one ton of carrots and a retail price of smoothie products above USD 1.18 per liter (5,172,000 liters of USD 1.18 each) the valorisation potential of this fraction is about USD 6.15 million, including value added through the value chain all the way through to the final consumer (total societal value).

4.2.5 As another example, potato peels are an abundant no-value industrial co-stream which can be processed into biopolymer with a simple process (Rommi et al. 2015). However, better washing of potatoes would be needed if the peelings are to be used for edible biopolymer production to ensure hygienic quality of the bioplastic. The low price of pure potato starch will probably hinder use of potato co-streams in edible film production. In applications where very low price is needed, e.g. in mulch films, unfractionated potato peel mass may serve as a feasible raw material. The Norwegian potato industry has shown interest in the innovation oriented research reported above as well as research aiming to sanitize soil from potato processing[4]. Research identifying costs involved in potato industry soil co-harvest/co-stream, along with research identifying alternative use options, contributed to expand the number of soil waste management options available to companies and regulators (Egelyng and Hansen 2015).

4.3 A Case of Co-streams from Poultry.

4.3.1 Computer vision has entered the poultry industry (Chao et al. 2013) where the world market for residues from the slaughtering of cattle, pigs and poultry is highly developed. In this ´red´ meat food system, the degree of valorization of rest raw material is generally already advanced (Hansen et al. 2015). However, the global situation concerning poultry processing in contemporary food industries, aiming to avoid food loss, involves continuums from situations in the global south where waste from poultry slaughtering amounts to environmental and health threats, as well as resource loss, to cases where the challenge is beyond recycling rest raw materials. Identification of cascading options or upcycling potential therefore adds itself to an existing competitive imperative for food industries, in casu the chicken meat industry, to ensure using all by-products[5]. In Norwegian companies this has for instance led to development of production systems providing options for chicken rest raw materials processing, upcycled through different technologies (Egelyng et al. 2017). Residues after production of chicken mechanical deboned meat (MDM) contain oils, protein, and minerals. This residue can be enzymatically hydrolyzed. Enzymatic hydrolysis experiments of the residues after mechanical deboning of chicken resulted in good taste of hydrolysates, high yields of protein (72.8 – 85.4%) and desirable amino acid compositions, indicating enzymatic hydrolysis of chicken co-streams is well suited for applications in human nutrition. (Carvajal 2014).

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[4] Representatives expressing this interest included Research Director Jens Strøm (BAMA) and Thor-Eirik Albrektsen (Produsentpakkeriet Trøndelag AS).

[5] Personal conversation with Heidi Alvestrand (Business Development, Norilia AS).

4.3.2 Norwegian research also pursued improving digestibility of feather meal, providing protein rich ingredient from materials often considered low value, if not waste, and simultaneously decreasing production costs in the process (Adler et al. 2014b). Chicken feathers consist of more than 90% protein, however, and due to disulfide bridges, hydrogen bonds and hydrophobic interactions feather keratin is insoluble and has a low digestibility. Different approaches to improve the digestibility of chicken feather have been compared to the current industrial standard of pressure boiling which is known to be energy intensive and has negative effect on amino acid composition. Traditionally used in fertilizer production, feathers are approved for fur animals and standard ingredients in mink feed kitchens. Feather hydrolysates with improved digestibility have the potential to substitute other animal proteins in animal feed. At an average price of USD 320 per ton of feather meal, a current European production of 175,000 tonnes and an estimated availability of 2.4 million tonnes poultry feathers in the world market per year, the potential market is large (Adler et al. 2014c).

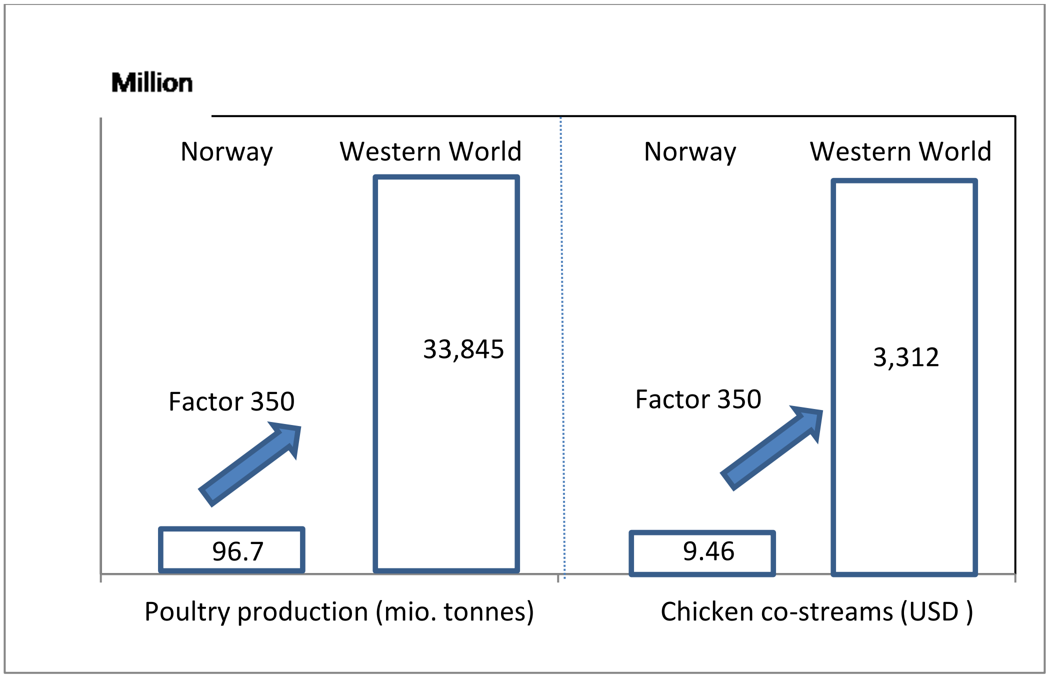

Figure 4. Cascading option for Norwegian chicken co-streams

Figure 4 illustrates an estimation of a valorisation option for Norwegian chicken co-streams, based on the fact that Norway accounts for about 0.1 per cent of world total poultry production (96.7 million tonnes see above) and 0.3 per cent of total poultry production in Western countries. The global economic gain from cascading existing Norwegian chicken co-streams worth about USD 9 million, would translate into a figure for the western/OECD world in the order of USD 3.31 billion (Egelyng et al. 2017 forthcoming).

4.4 Consumers have a role in transition towards sustainable consumption (Vittersø and Tangeland 2015). Consumer´s add to the bioeconomic transition challenge in the form of food waste, and therefore we briefly present results of a pilot study of consumer practices, and literature confirming food loss and food waste each amounts to at least half of the FLW problem. As amounts and character of the food wasted is mapped, and reasons identified on why food is wasted, efforts are in the making to find sustainable solutions to reduce the waste. Consumer surveys and ethnographic studies in Norway have shown that the food products most often wasted are fresh fruits and vegetables, fresh bakery products and left overs (Hanssen and Møller 2013). Surveys show that the main reasons for discarding food are that use/ best before date has expired, the food was forgotten in the fridge, the food had lost original quality, portions/ quantities bought were too large, and left-overs always thrown away (Ibid. Hanssen and Møller 2013). Particularly the differentiated labelling of expiry dates such as “use by” and “best before” confuses consumers enough to cause food waste. A main conclusion within most of the projects searching for waste reducing strategies is to better communication and education of the consumer regarding food preservation and labelling. Much attention is given to consumer attitudes and lack of knowledge as the main “problem” causing food waste in the households. Another approach is advocated by the design community. By combining insights from behavioural theories from social science (e.g. Shove, Pantzar, & Watson, 2012) with design thinking new solutions are being developed that might nudge people into reducing their food waste (e.g. Ganglbauer & Fitzpatrick, 2013). The solutions are targeted at the reasons identified by surveys and ethnography for why people waste food. These solutions are not solely focusing on educating the consumer, but to provide them with tools and an environment that makes it easy to reduce food waste in everyday life. Thus there are two important aspects of behaviour change that could be addressed simultaneously in order to achieve a reduction of food waste on the consumer level: the attitude/knowledge aspect and the practical aspect.

4.5 Implications of theory and results

4.5.1 The current order of institutional environments translates into economic (dis)incentives for the Norwegian fish industry to upcycle 226,000 tonnes of rest raw materials. African costumers appreciate dried and salted fish-heads, in some European countries tongues and cheeks are priced as fillets and freshly frozen fish stomachs sell in Asian markets. Yet half the body weight of the Norwegian caught cod is typically thrown overboard as a valueless rest raw material. This means that the Norwegian industry misses opportunities for value adding cod towards the USD 80 goal. It sends whole frozen cod to low cost countries for further processing and either re-import or re-export. A crucial difference could be made by institutional or either technical (such as enzymatic hydrolysis) or logistical innovations (collector vessels, live catch). Availability of rest raw materials for future upcycling will differ significantly depending on the future trajectory of the Norwegian fisheries as it stands at a crossroad between green consumerism, liberalism and specialty foods. The sector faces many choices, including about how large a role capture-based aquaculture (CBA) should hold, also for whitefish species such as cod. Production of farmed cod is already increasing[6]. Just south of the Norwegian border, a liberalization scenario has become reality, closing ports and rapidly concentrating ownership of the fishing fleet in very few hands. This is perhaps an illustration of a fate Norway can avoid by developing higher-value exploitation of wild fish resources.

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[6] Cod fishermen increased the value of their cod quotas by 35% through live catch (2006) for CBA. CBA accounts for 20% of farmed fish globally, and is expected to expand its share of Norwegian fish supply (Personal conversations with Tommy Torvanger (CEO, Nergård) and Kjell Midling (Nofima), Tromsø, 19. February 2014 and Herland (2009).

4.5.2 Edible co-streams in the vegetable industry, like wrong-shaped carrots and the outer leaves of lettuce, can be fluently separated from the ones not suitable for human consumption, and be used as raw materials in food production, in-stead of ending up into animal feeds. Smaller proportions of second grade vegetable ingredients can be used in many kinds of ready-to-eat foods, provided pre-processing and the logistics of the ingredients, can be made financially profitable.

4.5.3 A cascading potential in the Norwegian chicken co-streams annually worth about USD 9.46 million can be realized through innovations and industrial upscaling based on enabling research in fields such as enzymatic hydrolysis. Should this potential be upscaled to a global level, cascading value could be counted in the order of USD 3.312 billion per anno. The world market for residues from the slaughtering of cattle, pigs and poultry is highly developed and in Norway´s ´red´ meat food system the degree of valorization of rest raw material is generally already advanced. However, the global situation concerning poultry processing in contemporary food industries, aiming to avoid food loss, involves continuums from situations in the global south where waste from poultry slaughtering amounts to environmental threats, as well as resource loss, to cases where the challenge is cascading and upcycling of bio-co-streams (Egelyng et al. 2017).

5. Discussion

5.1 This article has demonstrated ongoing innovation and transdisciplinary knowledge production is part of a knowledge base for transition in the Norwegian bioeconomy: in food processing, through logistical improvements by retailers and through consumer awareness and even behavioral change. Through investment in research programs charged to improve circularity of our ´bioeconomy´, societies extend efforts to expand the availability of options for food producers and processers as well as retailers and consumers to avoid ´losses´ and ´waste´ in the food system. This is pursued through technically transforming rest raw materials of our ´bioeconomy´ to higher economic value and a mix of institutional and technical solutions for consumers and retail systems to minimize waste of food. The contribution and novelty of this article is in demonstrating feasibility of transdisciplinary research and apply this across sectors and costreams that are currently not cascaded further valorized or even ‘upcycled’ for a variety of reasons. It has focused on several supply chain stages and involved industrial actors within a multidisciplinary research approach.

5.2 In the global spectrum of nations Norway, is known to have capacity to ´act´ in both economic and political spheres and with regard to providing enabling institutional environments fostering a given desired developmental pathway. Norway imports most of the proteins going into its farm animals and pets, to a significantly larger extant than exploiting in-country protein sources. Consequently, doing empirical research in this field in Norway and subsequently abstracting away the concrete cases and national context with a view to generalization (table 1) makes sense. In Norway, major strategic research initiatives have already quite a history of addressing all kinds of losses and waste, from vessels and factories, at sea and land. This is a clear indication how different institutional environments impact the capacity of producers to add more or less value to different fish species and highlights a continued challenge for the blue food system to develop a regionally scoped, globally relevant, model, for increasing the utilization of rest raw materials.

5.3 Highly integrated in the global economy through the European Economic Area agreement and consequently under imperative to conform to international trade standards, Norway work as a strategic case for the article. The research activities reported contributed to strengthening interdisciplinary collaboration, allowing researchers and industry professionals of very different backgrounds come together in cooperative learning and pursuit of common language of sciences aiming to jointly pursue bioeconomic valorisation options. Automation, robotics and scanning enabling fractionation into different qualities is one cross-cutting theme in the cascading and potential upcycling processes analysed above (Mimisi et al. 2015). Another common technological theme across all three sectors is research on use of enzymes. While it is also clear from our results that enzymatic hydrolysis of costreams holds monetary valorization promise it is too early to quantify potential energy savings (convential hydrolysis is energy intensive).

6. Conclusion

6.1 Our study of strategically selected co-streams in Norwegian food processing industries identified a range of emerging innovations of direct relevance to a bioeconomic and valorisation potential amounting to an estimated national figure of up to USD 415 million (a chicken co-stream case of USD 9.55 million, a vegetable co-stream to carrot smoothie case of USD 6.21 million and a cod rest raw material case of 400 million USD) annually. Aiming edible co-streams for human consumption rather than allowing the co-streams to become by-products does not always make economic sense, given current market conditions. Our results, nevertheless, confirms how investing in innovation enabling bioeconomic research can trigger exploitation of major existing potentials for further valorisation of food industry co-streams through cascading and possibly upcycling with positive impacts on both national bioeconomies and global environments. Conversions of co-streams currently sold off to the fodder industry and other classical uses where competition for (rest) raw materials have intensified, have resulted in high prices for rest raw materials. Alternative uses of the same material for use as human food is therefore not automatically competitive in a market where quality requirements for certain labels of pet food may be higher than for human food in general.

6.2 Our transdisciplinary approach to investigating bioeconomic transition opened up different logistical challenges than traditional forward logistics: it is not only about the value of products, but about the totality of resources which production of the products has consumed, including e.g. greenhouse gas (GHG) emissions incurred from cultivation, and all the way to consumption. Yet, closing material energy and flow cycles of food systems is both desirable and at least partially realistic in terms of upcycling costreams within given blue, green or red food ´chains´ or systems. We have yet to see holistic transdisciplinary analyses comprising entire food systems measured on all the ´counts´ and criteria that a state of art transdisciplinary paradigm such as ecological economics would identify as comprehensive. Therefore, we may not be able to plausibly detail how our research result in the above analyses contributed to global sustainability. We believe that ceteris paribus some did and that we may have contributed to outlining future research agendas with an even stronger role for transdisciplinarity, across natural, technical and social science, and in the maturing field of research on the global bioeconomy.

6.3 As regard the emerging theoretical foundation for bioeconomic research, ecological economics (EE) is one example of a scientific discipline coming close to meet the criteria of inter- or trans disciplinarity: EE draws on natural sciences, social sciences as well as the humanities, uniquely combining insights in nature's cycles and processes', thermodynamics and ecosystem services, with material flows accounting and different languages of valuation, respecting irreversibility/non-substitutability of capitals (Martinez-Alier and Røpke 2008, Røpke 2005 and 2004, Daly and Cobb 1989). EE approaches map throughput of biosphere energy and materials, and so includes material passing processing industries of the human economy, circulating from cradle through grave to cradle, as important to underpin a deeper understanding of bioeconomic transition challenges. In this regard environmental impact assessment and life cycle analysis form part of ecological economics, quantifying factual and counterfactual scenarios with flows of energy and material in streams, along commodity or production chains.

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