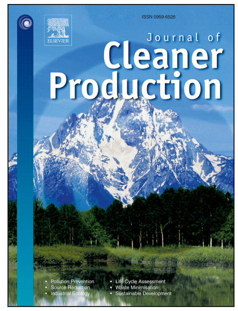

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Valorization of bio-residuals in the food and forestry sectors in support of a circular bioeconomy: A review

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Abstract

This literature review focuses on valorization of bio-residuals from the brewery, dairy, slaughterhouse and forestry sectors. Bio-residuals are organic wastes, side streams, or residues that remain at the end of the processing of a biological raw material. These under-utilized resources have the potential to support circular bioeconomies, given they can be valorized through viable value chains. To better understand this potential and gain insights in the opportunities for these resources, we analyzed 57 publications that contained findings related to value chains for bio-residuals valorization. The value chains were partitioned into the categories of resource procurement, transport and handling, transformation and processing, valorization and market, and end use. Additionally, the contextual drivers were analyzed, including policy and governance, business strategies, economics, demand, innovation, research, and development, and actors and networks. After summarizing the state of the art in research for bio-residuals valorization, the value chains were categorized for each sector. The push-pull factors were then identified, and how these influence bio-residual value chains. These analyses reveal that the dairy industry has a well-developed value chain for bio-residuals, with a myriad products from whey being pulled by market demand. With the knowledge and capabilities of the dairies, this creates a *modular value chain* for these products. The slaughterhouse industry resembles the dairy industry, but has greater barriers for valorization of animal by-products and so less market pull, leading to more conglomeration of rendering operations. Valorization of slaughterhouse residuals indicates a *captive value chain*. Contrarily, valorization of brewers spent grains (BSG) has been slow to develop, due mainly to low supplier capability, and the BSG value chain is dominated by the use of unprocessed BSG as animal feed. The forestry industry has been slow to invest in technological and market capabilities for valorizing residuals, due to weak market pull, high capital needs, and risk-adverse strategies among the few incumbent firms. As a result, the value chain for forest residues is still mainly *hierarchical* and rather undeveloped; yet with the recent entry of many new firms competing for biomass for a variety of end products, a shift towards a *relational value chain* serving a greener and more complex industrial symbiosis production model could be developing. Synthesizing across the sectors, we conclude that the materiality of the residuals, regulations, transformation technology, firm capabilities, actors, and the market are all important factors shaping the value chains for bio-residual products, with each sector having unique challenges and opportunities related to their value chains. As such, more research is needed not only in transformation and processing of residuals, but also regarding more downstream parts of the value chain, such as end-product markets, as well as cross-cutting issues such as governance and regulation. This would better promote valorization pathways, creating a market pull rather than just a technology push for bio-residuals.

Keywords

Circular bioeconomy; food processing waste; forest materials; bio-residuals; global value chain; valorization

1. Introduction

1.1. The Circular Bioeconomy

As part of the effort to support a transition to more sustainable resource use, the circular bioeconomy concept has emerged among academic, political and industrial circles (Bugge, et al., 2016). The circular bioeconomy links together concepts of the circular economy, the green economy (which includes both biological and non-biological renewable resources (Lewandowski, et al. (2018), and the bioeconomy (D'Amato, et al., 2017). In so doing, the circular bioeconomy aligns the throughput of different bio-industrial production processes such that the material outputs of a production process serve as inputs to other processes. This includes principles of sharing, reusing, reparation, remanufacturing, and recycling of material, cascading uses, utilization of residue streams, resource efficiency, and nutrient cycling (Carus and Dammer, 2018). The feasibility of cascading uses depends on the quantity, quality, lifetime and spatial allocation of the material resources resulting from producing particular products (Bezama, 2016). These parameters determine the technical and economic potential for valorization

(Bezama, 2016). In principle, the circular bioeconomy makes the greatest possible use of bio-resources, and therefore promotes greater economic and environmental efficiency. Moreover, as renewable resources by nature, bio-based materials are necessary for a truly circular economy (Sheridan, 2016), and the circular bioeconomy can contribute to the United Nations Sustainable Development Goals (Lokesh, et al., 2018). The European Commission has therefore included aspects of the bioeconomy into the Circular Economy Action Plan, namely, addressing food waste and efficient of bio-based resources at all steps in the value chain (European Commission, 2015).

Many studies exist on the issue of food waste and technologies and practices to reduce it, including strategies for improving efficiency and changing consumer behavior (e.g., Parfitt, et al., 2010). In our review, however, we build on Mirabella, et al. (2014) and focus specifically on the valorization of so-called "organic waste by-products" from industrialized food and forestry production processes. The food processing industry accounts for 39% of total materials loss in the food industry (Mirabella, et al., 2014). At the same time, future demand for bio-feedstocks is expected to grow 3–4% per year globally (Carus and Dammer, 2018). Often authors use the term "residue" which suggests "that which remains after something else has been removed." We however choose to adopt the term "residuals" to describe these products, referring to a remainder at the end of a process. While the difference is subtle, we prefer the latter as it emphasizes how innovation can drive changes in these processes, making residuals into valuable co-products. Moreover, beyond describing the emerging and potential uses for biomass residuals, we focus on the dynamics of technological innovation within the circular bioeconomy and the development of value chains for the residuals from the various production sectors.

The valorization of biomass residuals allows for a higher degree of closure in the biomass utilization loop and therefore, more efficient use of nutrients and resources, as in, for example, wastewater and lignocellulosic waste resource recovery (Guo, 2018). As such, Sheridan (2016) recommended that bio-based industries do more to promote biomaterials, which have large potential to attract investment. Likewise, Bezama, et al. (2018) see the bioeconomy as a guiding concept that can foster innovation in the waste management sector. For example, the processing of biomass for food and forest products produces residual feedstocks that can be valorized as chemicals and materials, food and feed, or bioenergy and biofuels (Carus and Dammer, 2018; Zabaniotou, 2018). Other research has focused on innovation within bio-based value chains: the process of harvesting raw materials, pre-treatment, manufacturing, packaging, consumption, waste management and recovery (Lokesh, et al. 2018). To illustrate this, they analyze five specific value chains: starch to bioplastics, starch to bio-mulch films, starch to frame material, cellulose to bio-based solvents, and vegetable fats/plant lipids to bio-based lubricants (Lokesh, et al. 2018).

However, research has also shown there can be limitations to the circular bioeconomy (Carus and Dammer, 2018). Research and development in food wastes processing is costly and the benefits of reuse and recycling of food wastes need to be put in consideration of environmental impacts caused by new production processes (Mirabella, et al., 2014). For example, adherence to circular bioeconomy practices may not necessarily reduce greenhouse gas emissions, though there is usually an increase in resource efficiency from cascading (Carus and Dammer, 2018). Second, toxins or other unwanted substances can accumulate along the cascade, making further recycling or incineration problematic (Carus and Dammer, 2018). Third, there are regulatory barriers regarding the use of biomass, e.g., subsidies for waste incineration, which reduces incentives for valorization (Carus and Dammer, 2018). O'Reilly (2017) lists discusses the similarity between the challenges faced by the emerging bioeconomy and the typical challenges faced when introducing a new technologies, including: lack of demand, lack of consumer awareness and knowledge, high switching costs, absence of standards, and high initial costs. Because the issues faced are similar, there is evidence to suggest that public procurement and other incentives can accelerate the nascent bioeconomy.

Technological innovation is often seen the result of both technology-push and demand-pull factors, and in particular the interaction between the two factors, with an emphasis on the fundamental role of science and technology (push) and an acknowledgement of markets (pull) as steering innovation in the right economic and institutional direction (Di Stefano et al 2012). Historically, research and development as well as policy incentives have emphasized technology "push" over demand or market "pull", however, there has been a shift toward demand pull in recent years (Hoppmann, 2015). For mass-produced goods, pull policies tend to be more effective at achieve economies of scale (Huenteler, et al. 2016). Regarding the circular bioeconomy, there is also discussion concerning the mutual dependence of push and pull factors in driving innovation, where technological research focuses on the industry and market demands, in order to achieve a more balanced path that involves all parts of the value chain (Bezama, 2018). Shifting the emphasis in research is thought to drive more innovation through better understanding of market conditions and individual actors, creating a more "consensuated development path" (p. 553), i.e. a path created through the consensus of many actors across multiple sectors (Bezama, 2018). A paradigm shift allowing for mixing of waste streams from different food industries may also have certain advantages (Kosseva, et al., 2001). These dynamics and development paths influence the way value chains develop for residual valorization.

1.2. Analytical Framework

Global Value Chain (GVC) theory has been applied since the 1990s to conceptualize the dynamics of economic globalization and international trade (Gereffi and Fernandez-Stark, 2016). Three determinants useful for describing value chain governance and development are identified (Gereffi, et al., 2005):

1. Complexity of information and knowledge transfer;
2. How efficiently the information and knowledge can be transferred without specific investment from the parties; and
3. Capabilities of the supplier to meet the requirements of the transaction.

Using these determinants, Gereffi, et al. (2005) classify value chains into typologies based on increasing power asymmetry between chain actors and, simultaneously, degree of coordination within the chain:

1. Market (low complexity, high efficiency, and high supplier capability) creates linkages with low cost for switching to new parties;
2. Modular (high complexity, high efficiency, and high supplier capability), where suppliers deliver products according to customer specifications, so called “turn-key” relationships;
3. Relational (high complexity, low efficiency, and high supplier capability), with complex interaction and mutual dependence between buyers and sellers, and therefore, cost of switching parties is high;
4. Captive (high complexity, high efficiency, and low supplier capability), with small suppliers that are dependent on large buyers; and
5. Hierarchical (high complexity, low efficiency, and low supplier capability), with a large degree of vertical integration and managerial control, typically where a lead firm will supply needs in-house.

In this review, we employ the GVC framework to understand better the linkages between the subsequent parts (nodes) of the value chain: input supply, production, trade, and consumption or disposal. The GVC typology is relevant to the circular bioeconomy as it helps analyzing the firms that participate (potentially or actually) in the valorization of bio-residuals, either as input/technology providers, processors, buyers, or retailers. Hence, bio-residuals can be seen as a resource and a potential marketable product. By adapting the typology of Gereffi, et al. (2005) to this case, we can describe the structure of possible value chains that may emerge based on the material characteristics (materiality) of the bio-residual and the strategies and innovative capabilities of the firms. We adapt the typologies to bio-residual valorization regarding the three determinants mentioned: 'Complexity' refers to the materiality of the residual and how specific the end products are. 'Efficiency' is the flexibility of firms to produce a wide scope of different end products (also related to the materiality of the residual) and to adapt quickly to a changing market. Finally, 'Supplier capability' is understood as the in-house ability of a firm to collect, store, transform and valorize its residuals (both the business model and the regulatory landscape are factors in this). With respect to the technology-push and demand-pull factors mentioned earlier, our approach emphasizes the first factor and adds to this the role of materiality, while also considering market factors in terms of how they influence the demand for bio-residuals from firms in the downstream end of the value chain.

In terms of the long-term transition to a circular bioeconomy, Gereffi, et al., (2005) note that the governance patterns are dynamic and value chains can evolve as their determinants change, e.g. regarding technological innovation or market demand. As such, it is a useful framework for analyzing the activities and relationships along the value chain in a specific sector, to describe how the chain is developing, and to provide the industry context for the trends in bio-residual innovation and valorization.

1.3. *Purpose of Study*

The purpose of this study is to determine the state of knowledge in utilization and valorization of bio-residuals, and to identify where along the value chain current research is being focused. We therefore analyze the current state of knowledge regarding the utilization and valorization of organic residual biomass across food and forestry production sectors: forestry, beer brewing, slaughterhouse, and dairy. These sectors were chosen as they collectively represent the majority of industrial-scale bio-resource processing from a variety of different production systems (forestry, agricultural, and animal husbandry). This allows us to compare and contrast the development of the value chains and their drivers in the various sectors and the push-pull factors, thereby identifying strategies for future development of organic residual valorization and highlighting areas for future research.

2. Material and Methods

The review is based on the method outlined by Okoli and Schabram (2010): we determined the research purpose, developed a protocol, conducted a search, completed a practical screen, appraised the quality of the publications, and finally extracted data. Our goal was not to attain a comprehensive review of all publications in the literature, but rather a representative compendium of landmark publications within each sector. Therefore, we addressed each sector separately and strived for balance across all the various sectors.

2.1 Protocol and Training Set- Derivation of Keywords

To begin, we identified ten key representative publications (i.e., journal papers and scientific reports) for each sector. The publications were selected for their relevance to the issue of residual valorization from a value chain perspective. The abstract, title and keywords of these publications were aggregated by sector, and then we performed a textual analysis to tally the most commonly used words. Irrelevant words were removed. The top ten most commonly used words for each sector served as disjunctive (inclusive) search terms in Google Scholar (Table 1).

*Table 1. List of keywords used for initial search in Google scholar. BSG = brewer's spent grain (the residual grain remaining after the beer-brewing process), and the abbreviation was used as a keyword. *The word "paper" was a common keyword in abstracts for all sectors (e.g. "In this paper,") and was deemed irrelevant for the search in all but the forestry sector. For this reason, an additional keyword was added to the search in the forestry sector, and the word "paper" is retained since it is a key forest product.*

Sector	Keyword ranking	Keyword	Frequency (n)	Frequency (%)	Sector	Keyword ranking	Keyword	Frequency (n)	Frequency (%)
Brewery	1	waste	19	0.8	Slaughterhouse	1	waste	33	1.9
	2	energy	16	0.7		2	food	29	1.7
	3	industry	15	0.7		3	products	22	1.3
	4	sustainability	13	0.6		4	processing	19	1.1
	5	BSG	12	0.5		5	meat	15	0.9
	6	brewery	11	0.5		6	extraction	12	0.7
	7	production	10	0.4		7	production	10	0.6
	8	spent	10	0.4		8	industry	10	0.6
	9	used	10	0.4		9	wastes	9	0.5
	10	potential	10	0.4		10	animal	8	0.5
Dairy	1	whey	33	1.4	Forestry	1	forest	52	1.8
	2	food	26	1.1		2	industrial	22	0.8
	3	waste	24	1		3	paper*	17	0.6

4	products	19	0.8	4	product	33	1.2
5	cheese	16	0.7	5	biorefinery	16	0.6
6	production	13	0.6	6	sustainability	15	0.5
7	used	11	0.5	7	industry	12	0.4
8	processing	11	0.5	8	policy	12	0.4
9	dairy	11	0.5	9	pulp	11	0.4
10	lactose	10	0.4	10	innovation	11	0.4
				11	firm	10	0.3

2.2. Literature Search

The top fifty most relevant references were collected for each sector. This list was augmented by any of the original 10 key publications that did not return in the search results, producing a list of candidate publications for each sector.

2.3 Practical Screen

The candidate publications for each sector were appraised using the following criteria:

- Is this one of the ten key publications sent used to generate the key words?
  - If yes, retain this publication
- Peer Review: Is the publication peer reviewed?
  - If not, remove this publication
- Timeliness: Was publication published in the year 2000 or after?
  - If not, remove this publication
- Relevance: Does the reference contain analysis on organic waste / residuals in the sector?
  - If not, then remove this publication
- Relevance: Does the reference contain some aspect of the value chain?
  - If not, then remove this publication
- Literature Review: Is the publication a literature review?
  - If yes, identify relevant publications that fit the above criteria.

Under the peer review criterion, we removed non-peer reviewed literature, such as books, student publications, or industry publications. With the timeliness criterion, we removed any publications before 2000 (publications up to 2019 were included). Using the relevance criteria, we included only publications that contained an analysis on organic waste / residuals and referenced some part of the value chain. Under the literature review criterion, we retained other literature reviews and denoted them as such. These references included in previous reviews were assessed and added to the candidate publications (i.e. backward search) by expert discretion.

2.4 Quality Appraisal

The publications were categorized by the methods used (literature-based study/review, case study/ interviews, observational study, experiment, etc.). The publications were further assessed by the following criteria:

- Quality of method: Is a method explicitly defined and applied; and is the method sound?
- Conclusions: Do the conclusions follow from the data, results, and/or analysis?
- Impact: Are the results meaningful / applicable on a larger scale?
- Other comments: Any other comments relevant to the quality of the publication? (optional)
- Recommendation: Do you recommend that this publication be included in the literature review? (Y/N)

Only publications that were assessed as “high quality” (those that met the five requirements above) were selected for data extraction.

2.5 Data extraction

Data were extracted on the value chain findings, the contextual findings (i.e., drivers), and the general findings, in the form of a concept table as described in Webster and Watson (2002). A matrix was constructed, and in each corresponding cell, we described how the publication addressed each part of the value chain and contextual aspects. We also noted which aspects were in focus within each publication.

- Value Chain findings
    - Resource procurement (characterization, description, potential)
    - Transport and handling (aggregation, pretreatment, storage)
    - Transformation and processing
    - Valorization and market
    - End use
- Contextual findings (drivers)
    - Policy and governance
    - Business strategies
    - Economics and costs
    - Demand sectors
    - Innovation and R&D
    - Actors and Networks
- General findings

3. Results

In total, 57 publications were included in the data extraction. The distribution of these papers by research methodology and sector is shown in Figure 1.Table 2 shows how the different aspects of the value chain are covered in the literature sample, by sector, and similarly, Table 3 shows the different contextual elements within the literature. A broad summary of the structure of the valorization value chains for bio-residuals from the four sectors considered in this study is depicted in Figure 2.

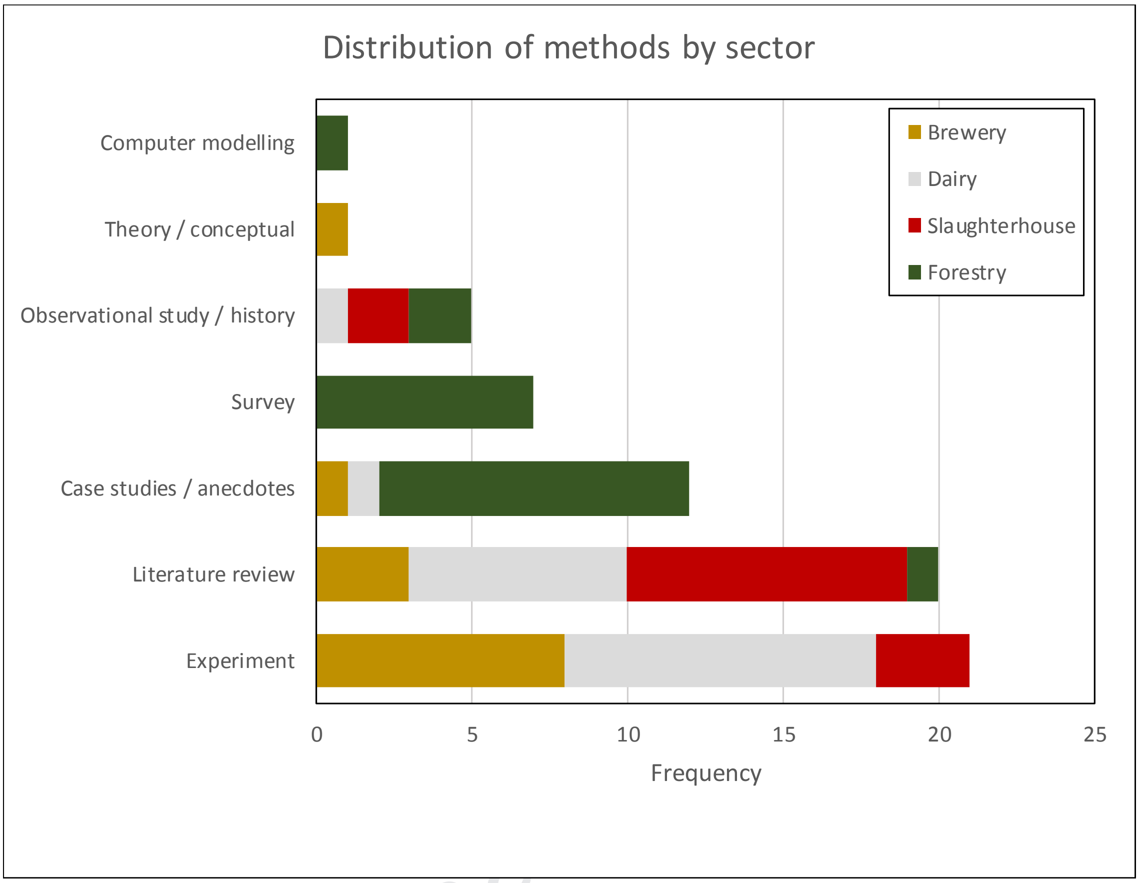

Figure 1. Distribution of the research methods used, by sector, in the sample of papers included in the analysis.

Table 2. Aspects of the value chain covered in the literature sample. Publications may be represented in more than one category.

Value chain	Resource procurement	Transport and handling	Transformation and processing	Valorization and market	End use
Brewery	6	6	8	9	5
Dairy	13	7	18	3	9
Slaughterhouse	7	7	13	5	12
Forestry	10	5	3	9	6

Table 3. Contextual findings covered in the literature sample. Publications may be represented in more than one category.

Drivers	Policy and governance	Business strategies	Economics and costs	Demand sectors	Innovation and R&D	Actors and Networks
Brewery	1	3	6	4	11	2
Dairy	6	1	7	8	12	1
Slaughterhouse	4	3	10	3	8	1
Forestry	8	10	7	6	8	6

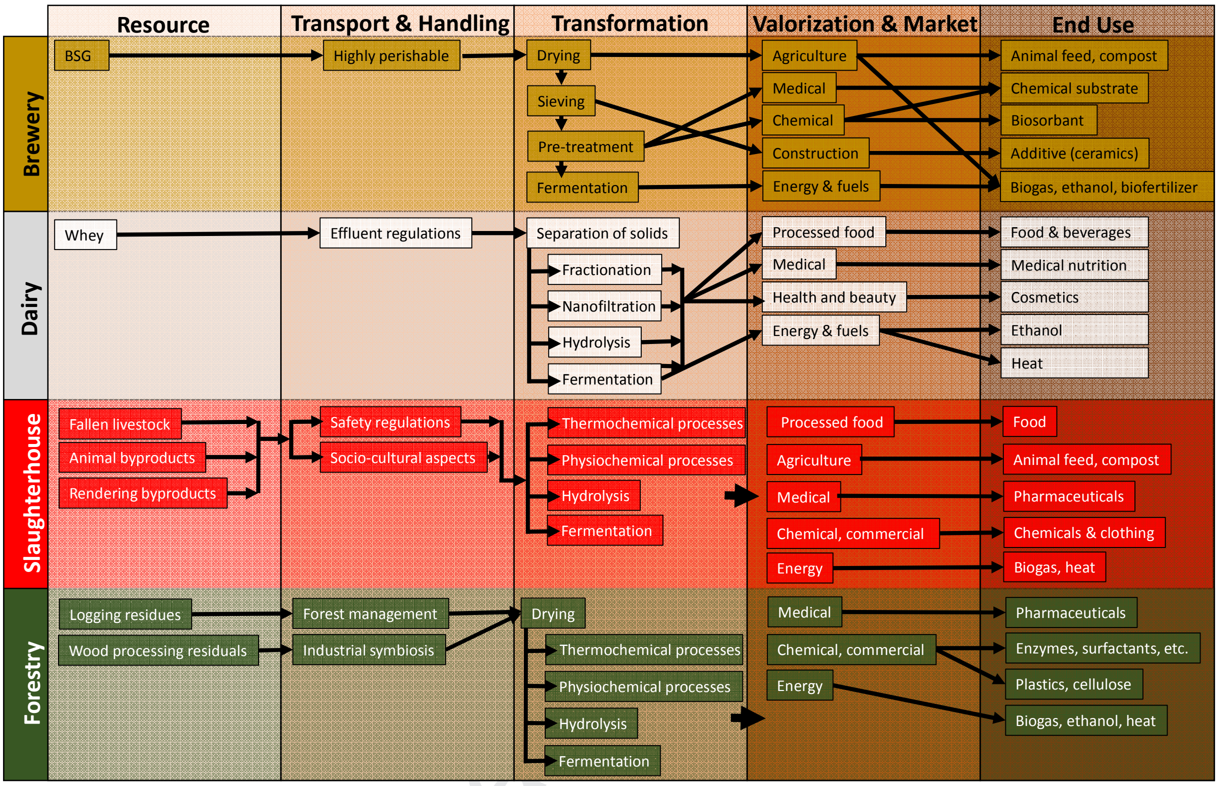

Figure 2. Summary of the value chain structure in the valorization of bio-residuals from breweries, dairies, slaughterhouses and forestry sectors.

3.1 Brewery

The most abundant form of organic residuals in the brewery sector is brewer's spent grain (BSG). BSG consists primarily of lignocellulosic material (cellulose, lignin, and hemicellulose) consisting of fibers, proteins, lipids, ashes, and others (Mussatto, et al., 2006; Panjičko, et al., 2015; Ferraz, et al., 2012; Aliyu and Bala, 2011). BSG is nearly 80% carbohydrates (Aliyu and Baya, 2011). Currently, much of the BSG is used for animal feed, especially for cattle. This use is a convenient and low-cost solution to breweries, which are restricted by food safety and hygiene regulations to store the BSG for more than three days, due to its quick perishability. However, such a limited scope can be a challenge for breweries because demand can decrease for BSG when farmers have access to other animal feed (Ferraz, et al., 2012).

BSG can also serve as a feedstock for biogas (biomethane) and biofertilizer production (Martin and Parsapour, 2012; Panjičko, et al., 2015). For biogas production, pretreatment includes sieving residuals away to get clean material (Pires, et al., 2011). Separating the hydrolytic and methanogenic steps is a necessary pretreatment for the anaerobic fermentation of BSG (Panjičko, et al., 2015). This application requires consideration of the local conditions of the brewery and surrounding systems: existing storage tanks, for example, are necessary (Muster-Slawitsch, et al., 2011). Second, BSG have potential as inexpensive biosorbents (Liguori, et al., 2015), used to remove industrial dyes (Liguori, et al., 2015; Contreras, et al., 2012) and metal contaminants from aqueous solutions (Li, et al., 2009) or even natural water bodies (Contreras, et al., 2012). In some instances, such as dye removal, BSG is a more attractive substance than activated carbon (Djukić-Vuković, et al., 2016). Third, because the solids are already food-grade, BSG can be used for lignocellulosic yeast carriers for continuous beer fermentation (Pires, et al. 2012) or low-cost substrates for lactic acid production for chemical and pharmaceutical applications (Ali, et al., 2009; Djukić-Vuković, et al., 2016). Fourth, due to the high fiber and low ash content, BSG is also suitable for producing bricks (Aliyu and Bala, 2011; Ferraz, et al., 2012). In brick production, biochemical processes can be used to decrease the thermal conductivity of the BSG-based ceramic paste without significant losses of mechanical strength of the final product (Ferraz, et al., 2012). In addition, the ceramic bricks based on the BSG paste have the advantage over normal bricks by enhancing the open porosity in the brick material (Ferraz, et al., 2012). BSG can furthermore replace synthetic pore-forming material, and thus prevent legal concerns related to gaseous emissions (Ferraz, et al., 2012).

As an energy source, BSG can be used for biogas production. When considering the market, fluctuations in the price of conventional fuels and fertilizers affect the price of biogas as well as the costs of the feedstock. Pre-treatment of BSG for biogas production is the most costly step in the process. If around half the processing costs of the BSG could be reduced, an 80 % increase in profit from biogas can be reached (Martin and Parsapour, 2012). Cost savings can be achieved by using the washing step in the pretreatment process (Pires, et al., 2012). To this end, various chemical treatments can be used, and the resulting material can be stored after drying at room temperature (Pires, et al., 2012). Removing the fat and protein before chemical treatment can add more value to the process and the resulting end products (Pires, et al., 2012). Pretreatment and second stage anaerobic fermentation is recommended (Panjičko, et al., 2015). Research into recycling BSG into ceramic paste for building bricks has identified a number of advantages, including: 1) Waste disposal costs are decreased, 2) the “life” of landfill sites is prolonged which may indirectly lead to 3) the preservation of rural areas, and 4) environmental conservation. The 'green brewery concept' can improve thermal energy efficiency and reduce emissions by providing a set of guidelines (Muster-Slawitsch, et al., 2011). Economic benefits also include savings on landfill taxes (Ferraz, et al., 2012). Within the green brewery concept (Muster-Slawitsch, et al., 2011), if the BSG is used on-site, the methane yield has a potential to replace a maximum of 50% of the natural gas that is needed to produce beer (Panjičko, et al., 2015). Hot water management is an important consideration for beer brewing in general, and heat integration and BSG storage can be integrated in an intelligent way (Muster-Slawitsch, et al., 2011). The green brewery concept has other side benefits, potentially saving around 5,000 t/y in fossil carbon dioxide (CO_2) emissions (Muster-Slawitsch, et al., 2011).

3.2 Dairy

Whey, the main organic residual from the dairy industry, are chemically modified liquids with high organic load, considerable variations in pH, and a relatively large load of suspended solids. There are also large variations in supply. There are two types of whey, sweet and acid. Sweet whey is a by-product from white hard cheese production, for example Cheddar or Swiss cheese, and is by the most common type. Acid whey (or sour whey) is a by-product from cottage/cream cheese, skyr, or Greek yogurt production. Compared to sweet whey, acid whey has less protein, is more acidic, and has a more distinct (sour) taste, making it more difficult to valorize. Casein whey is derived from the production of calcium caseinate and has properties similar to acid whey, with a pH between that of acid whey and sweet whey. In this paper, the term ‘whey’ is used to refer to sweet whey unless otherwise specified. Details on the use of acid whey can be found in Bolwig, et al. (2019).

Every kg of cheese requires 10 kg of milk to produce, resulting in 9 kg of whey (Prazeres, et al., 2012). Whey has historically been considered a waste product (Marshall, 2004). It is the most contaminated effluent generated from cheese production (Prazeres, 2012) and may contain proteins, salts, fatty substances, lactose and various kinds of cleaning chemicals (Kosseva, et al., 2003). Without expensive sewage treatments, whey is a major source of environmental pollution (Koutinas, et al., 2009; Guimarães, et al., 2010). While effluent regulations have generally become stricter over the last 25 years (Smithers, 2008), whey is still poorly processed in some areas, (e.g. in Serbian dairies, 78% of whey is wasted (Ostojić, 2005)), and when discharged into riparian systems it can create algae blooms and a loss of dissolved oxygen. In this respect, Kosseva (2009) recommends even more stringent environmental regulations for the disposal or utilization of dairy by-products and wastes, concerning land spraying with agro-industrial wastes, landfill operations, and requirements for hygienic production.

Yet, whey is an effluent with high organic content and nutritional value, from which compounds such as lactic acid, peptides, proteins, substrates, lactulose, etc., can be extracted (Mirabella, et al., 2014; Prazeres, et al., 2012). The lactose carbohydrate reservoir of whey and the presence of other nutrients essential for microbial growth make whey a potential raw material for the production of various bio-products through biotechnological means (Koutinas, et al., 2009). Whey products can be reformulated in the production of: 1) alcoholic beverages, including whey wines, low alcohol content drinks and distilled drinks (Guimarães, et al., 2010); 2) processed food and flavorings (Mirabella, et al., 2014; Smithers, 2008; Ostojić, et al., 2005; Guimarães, et al., 2010) in dairy products or sweet syrup for use in other products (Nguyen, et al., 2003); and 3) health and functional foods (Smithers, 2008; Kosseva 2009), e.g., by applying lactose and a complex of minerals to dietic foodstuff for diabetics and hypertensic patients (Ostojić, et al., 2005). Moreover, the addition of yeasts and bacteria that facilitate whole formation in cheese extends shelf life without the addition of chemical preservatives (Koutinas, et al., 2009). Marshall (2004) lists a number of examples of the possible health benefits of whey products. Some of the demonstrated effects of whey protein substrates include activating natural killer cells and neutrophils, inducing colony-stimulating factor activity, and enhancing macrophage cytotoxicity (Marshall, 2004). Whey's anti-inflammatory properties make it useful as an exercise treatment as whey protein supplements. It can also be used in pharmaceutical (Ostojić, et al., 2005) (Guimarães, et al., 2010) (Mirabella, et al., 2014) and cosmetic products (Guimarães, et al., 2010).

Bioenergy is a relatively low-value use for whey (Kosseva 2009; Prazeres, et al., 2012) by either converting whey lactose into fuel ethanol (Guimarães, et al., 2010) or for as a substrate for biohydrogen production (Venetsaneas, et al., 2009; Azbar, et al., 2009; Davila-Vazquez, et al., 2009; Castelló, et al., 2009; Yang, et al., 2007; Antonopoulou, et al., 2008). Being a by-product, whey has an advantage over food-related fermentation feedstock, such as corn, for ethanol production (Guimarães, 2010). Some countries such as Ireland, United States, New Zealand, Denmark and Germany currently produce ethanol from whey (Guimarães, et al., 2010), although only acid whey is used for this purpose in Denmark due to the lack of higher-value alternatives. Salt depleted lactose concentrate derived from whey can also be a raw material to pharmaceutical or paper industry (Minhalma, et al., 2007; Mirabella, et al., 2014).

Key to processing and thus valorization of dairy residuals is the ability to separate solids from whey (Smithers, 2008). Different approaches have been developed for storing whey before processing. Wastewater can be refrigerated and replenishing when there were signs of acidification (Antonopoulou, et al., 2008). Alternatively, anaerobic seed sludge used for fermentation and fresh raw cheese whey is kept at 4 °C until used (Azbar et al, 2009; Yang, et al., 2007; Castelló, et al., 2009). Finally, the wastewater can be stored at −20 °C and thawed before use (Venetsaneas, et al., 2009). Likewise, a number of different transformation and processing techniques are currently in practice, and continuing developments in high tech processing have allowed for more applications for whey and economies of scale for whey processing (Smithers, 2008). The conversion process of dairy residuals includes concentration and fractionation, fermentation, nanofiltration technology, membrane filtration technology, anaerobic digestion, hydrolysis, fermentation, microbial fuel cells, precipitation, and membrane separation (Mirabella, et al., 2014; Prazeres, et al., 2012). Whey-to-ethanol bioprocesses work through alcoholic fermentation technology by using wild-lactose fermenting yeasts. The fermentation should be fast to maximize the ethanol productivity of the process (Guimarães, et al., 2010). Due to the environmental impacts of untreated whey, post-treatment may be necessary. Thermophilic aerobic treatment is a process technology for treating organic residual streams. This technology combines the advantages of low biomass yields and rapid kinetics associated with high temperature operation and stable process control of aerobic systems. Kosseva, et al. (2003) recommend a thermophilic strategy for bioremediation due to higher reductions in chemical oxygen demand (COD), lactose, and protein. Kosseva, et al. (2001) found that thermophilic aerobic treatment led to nearly a 100% decrease of soluble COD, a 100% lactose consumption, and a 90% decrease of soluble protein in batch cultures.

The relative value of whey has increased substantially since the 1950s (Smithers, 2008). The need for cheap and largely available substrates will likely boost industrial interest in whey (Guimarães, 2010). New developments in processing and advanced liquid handling techniques have improved cost effectiveness and allow for whey processing at a larger scale (Smithers, 2008). Advancement in microbial biotechnology and strain engineering promote further exploitation of whey lactose to produce value-added products (Guimarães, 2010). In particular, this will be driven by the functional food revolution, e.g. demand for health foods and infant nutrition (Smithers, 2008; Ostojić, 2005; Mirabella, et al., 2014; Kosseva 2009). Whey's potential for producing preventative medicine for muscular atrophy prevention, weight management, improved cardiovascular health, anti-cancer effects, wound treatment, infection treatment, and healthy aging is also driving demand (Smithers, 2008; Mirabella, et al., 2014; Kosseva 2009).

Using biocatalyst immobilized cell and enzyme technology can improve the economics of whey conversion processes to produce valuable whey-based products (Kosseva 2009). The conversion of whey into whey protein concentrates creates a larger stream of lactose permeate. The price of edible lactose has a bigger economic influence in comparison with the price of whey protein. Finally, the economic value and costs entailed to the post-treatment process (post valorization) must be considered in the treatment line (Prazeres, 2012).

The conversion of whey lactose into an ethanol fuel is not economical in comparison with currently established processes and alternative uses of whey. However, the biofuel market is growing, and it presents an advantage for dairy firms by providing diverse options for whey bioremediation (Guimarães, 2010). An enhancement in volumetric hydrogen production rate (VHPR) is significant because this is a critical parameter in the practical application of fermentation technologies. The higher the VHPR, the smaller the size and consequently the cost of the reactor needed for sustainable and clean energy generation from biohydrogen (Davila-Vazquez, 2009). Costs can be further reduced by using unsterilized cheese whey, but it is not yet clear if there are negative effect on hydrogen production from this practice (Castelló, 2009).

3.3 Slaughterhouse

Slaughterhouse by-products are the residuals from slaughtering and processing animals. These include organs, blood and plasma, hides and skins, meat trimmings, bones and horns, tallow, lard and other fatty tissues, slaughterhouse wastewater and fish residuals in various forms (Jayathilakan, et al., 2012; Kosseva 2009; Toldrá, et al., 2016; Salminen and Rintala, 2002; Okoro, et al., 2017; Bujak, 2015; Bustillo-Lecompte and Mehrvar, 2017). Additionally, recovered biomolecules from animal byproducts may be utilized (Baiano, 2014). The meat industry is a high waste generating industry, and integration of biomass technologies are particularly relevant here (Clark, et al., 2012; Okoro, 2017).

Animal by-products (ABP) for human or animal consumption are created from residuals that are fresh, frozen, refrigerated, pickled or smoked, e.g. sausages from organ meat, fat for cooking applications, livestock feed (e.g. blood meal) and pet food (Jayathilakan, et al., 2012; Toldrá, et al., 2016; Salminen and Rintala, 2002) and as flavor enhancers (Mirabella, et al., 2014). Preparation includes washing after which the items are sliced, ground or kept uncut (Ockerman and Hansen, 2000). National boards of agriculture and food safety regulate health and food safety issues. For instance, Denmark maintains a 2% threshold of mentioning the amount of mechanically separated red meat on the label (Jayathilakan, et al., 2012). Extra control related to meat products arose at the beginning of the century due to food safety issues such as bovine spongiform encephalopathy (BSE). European examples of legislation and policy include the Regulation (EC) 1069/2009 on health rules and regulation (EC) 142/2011 implementing regulations (Toldrá, et al., 2012; Toldrá, et al., 2016). In addition, socio-cultural aspects (traditions, culture and religion) are often important when a meat by product is being utilized for food (Jayathilakan, et al., 2012).

For non-food, non-feed applications, ABP can be used for a range of other products. The main slaughterhouse by-products are gelatin, protein, collagen, enzymes, phosphates and other ingredients (Mirabella, et al., 2014). Non-edible products include pharmaceuticals (Jayathilakan, et al., 2012; Toldrá, et al., 2016), meat derivatives such as leather, biodegradable packaging, edible meat product casings, and seafood derivatives such as glucosamine, gelatin, and marine peptone (Kosseva 2009). It can also be used as fertilizer (Bujak, 2015; Mirabella, et al. 2014; Salminen and Rintala, 2002), as an eco-phosphate from ashes (Bujak, 2015), as a soil additive (Mirabella, et al., 2014), as compost, and as a digestate (Chan, et al., 2009; Okoro, et al., 2017). Furthermore, ABP are used in research and technology (Jayathilakan, et al., 2012), particularly in agrotech and biotech (Toldrá, et al., (2016). Finally, it can be used for energy production through incineration (Bujak, 2015) or through anaerobic digestion to biogas and production of biofuels. (Jayathilakan, et al., 2012; Salminen and Rintala 2002; Bujak, 2015; Bustillo-Lecompte and Mehrvar, 2017; Toldrá, et al., 2016; Okoro, et al., 2017).

For non-edible rendering, there are both wet and dry processes. Fish by-product processing includes heat treatment, filtration pretreatment or collagen isolation (Jayathilakan, et al., 2012). Poultry residuals and wastewater are anaerobically digested for energy use (DeBaere, 2000) (Salminen and Rintala, 2002). Other processing means for poultry residuals include composting, rendering, autoclaving and acid treatment (Salminen and Rintala, 2002).

Fat can undergo hydrolysis for the creation of enzymes (Mora, et al., 2015), or hydro-oxy generation and hydro isomerization for energy production (Toldrá, et al., 2016). Anaerobic digestion requires pretreatment (Bustillo-Lecompte and Mehrvar, 2017). Chemical solutions such as gasoline, light petroleum, ethylene or acetone can be used in fat elimination of some by-products (e.g. glands) (Jayathilakan, et al., 2012). Pyrolysis is another method, and pretreatments include biomass particle size reduction, dewatering biochemicals, physiochemical and thermochemical processes (Okoro, et al., 2017). Thermochemical technologies include incineration, direct combustion, gasification, hydrothermal conversions, biologically-induced chemical transformations, and digestion (anaerobic, aerobic and alcoholic fermentation can also be used) (Okoro, et al., 2017). Other processing techniques are drying and/or mixing with solutions. Response surface methodology helps in process optimization, maximizes biogas yield and removes total organic carbon and total nitrogen while minimizing the total suspended solids. Rendering and vacuum drying can decrease water excess, while 'winterization', a process where a solvent is used to separate lipids and other compounds from waxes, can lower grease levels of animal fat (Banković-Ilić, et al., 2014; Toldrá, et al., 2016).

Currently, ABP are low value, because of historically decreasing consumer demand for blood, entrails, and muscle tissue, particularly by those in poverty (Mirabella, et al., 2014). Treatment of ABP is costly, but the added value can potentially make up for these costs (Toldrá, et al., 2016). ABP consist of valuable ingredients, such as amino acids, minerals and vitamins (Toldrá, et al., 2016). Toldrá, et al. (2016) find that when by-products are used efficiently, the gross income of beef and pork could be elevated to 11.4% and 7.5% respectively. Different processing plants maintain various approaches, which has an impact on management (Okoro, 2017). Integrated plants close to the processing facilities could render ABP, however, there is often poor economic performance of 'stand-alone' systems, and the payback time for an energy facility for meat processing residuals was found to be around 4.3 years using a net present value (NPV) to calculate the discounted cost effectiveness (Bujak, 2015). Independent rendering plants source the byproducts from a number of firms, such as butcher shops, supermarkets, restaurants, fast food chains, poultry processors, slaughterhouses, farms, ranches, feedlots and animal shelters (Jayathilakan, et al., 2012). However, the number of rendering operations have decreased globally (Okoro, et al., 2017). A gross profit margin might be reached if there was more integration and intensification of processes to minimize processing costs (Bozell, 2008; Okoro, 2017). For energy applications, EU grants are available for projects on energy from organic by-products (Bujak, 2015). The increased public acceptance of sustainability issues has led to an increased use of slaughterhouse by-products for energy conversion (Okoro, 2017). As compared to incineration, the combined anaerobic-aerobic treatment can reduce production costs and anaerobic processes are more economically attractive because of the low energy requirement (Bustillo-Lecompte and Mehrvar, 2017).

3.4 Forestry

Forestry represents cascading uses of biomass: wood is used and reused in different processes based on its quality (Scarlat, et al., 2015). However, availability of biomass and the competition between alternative uses of biomass are transforming the bioeconomy (Scarlat, et al., 2015). Traditionally, the focus for forest residuals has been on energy production from biorefineries, especially biofuels. Forestry residuals are still considered the largest and most important wood-based biomass source for biofuel production in the future (Näyhä and Pesonen, 2014). In addition to high-volume bulk products, like biofuels, various low-volume, high value bioproducts are becoming increasingly important to the industry (Näyhä and Pesonen, 2014). The current market share of bio-plastic is 5-10%, yet has the potential to increase up to 70-85% by 2050 (Scarlat, et al., 2015). The end products include bio-lubricants (640 million € by 2020), bio-solvents (400 million € in 2020), biosurfactants (1.3 billion € in 2030), enzymes (global market 8 billion $ in 2020), and biopharmaceuticals (52-50 billion € by 2020) (Scarlat, et al., 2015).

In the Nordic countries, Finland in particular, wood-based biofuel and chemical production is regarded as an important business opportunity for the forestry sector (Hämäläinen, et al., 2011).

The product portfolio is driven by global trends and the market prices of the various end products (Näyhä and Pesonen, 2014). For example, increased demand for bioenergy and biofuels has elevated prices for biomass feedstock and substitution of paper-based media by electronic media has led to an absolute decrease in demand for printing paper (Coenen, et al., 2015). In the U.S., national security of fuel supply and the competitiveness of the forestry sector are highlighted as drivers (Hämäläinen, 2011). Despite the 2008 oil price peak, which was a boon for forest biorefineries in Scandinavia, North America and South America, industry experts generally see poor cost efficiency in biofuels (Pätäri, 2010). Indeed, the global recession and related drop in oil price were seen as temporary negative factors for the development of biorefineries and lignocellulosic biofuels (Näyhä and Pesonen, 2012). Moreover, because of growing competition from Asia and South America, the prices of forestry products are expected to continue decreasing (Hämäläinen, et al. 2011). Nevertheless, traditional forestry products still play an important role in the forest industry, such as long-fiber cellulose used for high-quality papers, which expectedly remain almost at its current level over the next decades (Näyhä and Pesonen, 2014). Moreover, biomass and wood are increasingly demanded as feedstock for a growing set of advanced biomaterial processing, construction, and manufacturing industries (Novotny and Laestadius, 2014).

Market potential for new types of products are driven, in part, by changing regulations, in, for example, biofuels and bioplastics (Coenen, et al., 2015). Indeed, an unpredictable and inconsistent policy landscape is a major barrier for the deployment of biorefinery technology (Hämäläinen, et al., 2011). Stronger regulation of pollution and energy efficiency has led to process innovation for improving the environmental and economic performance of production (Coenen, et al., 2015). Incentives to avoid waste have led to processes where residuals have been valorized into tradable or intermediary products. Coenen, et al., (2015) recognize a need for changed regulations to create a better market for biorefineries. Environmental sustainability plays a significant role indirectly through political factors (Näyhä and Horn, 2012). The general awareness of energy-related costs has grown due to the impact of the EU emission trading system (EU-ETS) on industrial CO_2 emissions, including emissions in the paper and pulp industry (Posch, et al., 2015). The image of being environmentally sustainable can be a competitive advantage for forestry firms (Näyhä and Horn, 2012).

As a result, two biorefining trajectories are emerging: (1) gasification of biomass and biofuel production, and (2) separation of products with high added value (Karltorp and Sandén, 2012). Biofuel products with the greatest market potential are Fischer-Tropsch-diesel and ethanol for fuel (Hämäläinen, et al., 2011). Regarding biochemicals, polymers currently have the greatest market potential (Hämäläinen, et al., 2011). Innovations are expected particularly in new extraction methods of hemicellulose or lignin, and in the development of new enzymes (Hämäläinen, et al., 2011). The developing polymer and niche chemical markets are important for sustaining the forestry industry, as revenues yielded solely from biofuel production are considered inadequate (Näyhä and Pesonen, 2012).

The industry currently sees an opportunity to develop further symbiotic operation (industrial symbiosis) or eco-industrial parks. In eco-industrial parks, firms can reduce costs by cascading energy and utilizing the by-products of other actors and gain an advantage in by-product exchange, by avoiding transport costs and buying goods below market prices (Lehtoranta, et al., 2011). The most important strategic competencies of the forest industry are knowledge of raw material acquisition and knowledge of logistics (Näyhä and Pesonen, 2014). Firms can obtain knowledge through patents and other immaterial rights or they can acquire companies with the relevant competitive knowledge and technologies (Näyhä and Pesonen, 2014). These companies can also come from outside the traditional forest sector such as energy companies and the chemical industry (Näyhä and Pesonen, 2014), and these industries have become interested in biorefineries (Karltorp and Sandén, 2012). While Scandinavian forestry firms tend to pursue network creation, the industry in the US has a more negative stance towards collaboration (Hämäläinen, et al., 2011). Collaboration has yielded benefits for both the pulp and paper industry and energy industries (Pätäri, 2010) and vertical linkages between forest industry and other types of industry (chemical industry, car manufacturing, furniture etc.) has created new research communities (Novotny and Laestadius, 2014).

Some firms are expanding their ownership to a larger part of the value chain, as a strategy to reduce vulnerability to increased feedstock prices and limited supply but also to gain access to high value downstream markets (Karltorp and Sandén, 2012). Stakeholders (from nine Scandinavian firms in the forestry sector) argue that transporting bulky, low-density biomass is not cost effective (Björkdahl and Börjesson, 2011). However, other stakeholders found that the major economic factor to be labor costs, and thus export biomass for processing to countries where labor costs are lower (Björkdahl and Börjesson, 2011). The production model of the biorefinery and the end products will depend on local feedstock availability and a firm's facility (Näyhä and Pesonen, et al., 2014). As such, Näyhä and Pesonen, et al., (2014) recommend that firms consider their roles and tasks in the biorefinery value chain. Transformation of the pulp and paper industry is challenging due to the large capital investments required (Pätäri, 2010), and poor returns to shareholders have reduced willingness to invest in innovation in the long-term (Björkdahl and Börjesson, 2011). Nevertheless, Hämäläinen, et al. (2011) expect more commercialization of biorefinery technologies in the near future.

However, the current lack of resources for investing in innovation has been a challenge for the forest industry. Many firms' business strategies and future development paths are heavily influenced by their institutional legacies. Some have argued that the forest industry has not been proactive enough and concentrates more on optimization of existing business operations rather than investing in new biorefineries (Hämäläinen, et al., 2012). Incremental improvements of efficiency of the pulp and paper industry have occurred over the last decades, and this is expected to continue (Karltorp and Sandén, 2012). This often takes the form of minor developments related to papermaking technologies, where firms have focused on incrementally more efficient resource use and decreased emissions (Lehtoranta, et al., 2011) and for solving problems related to achieving economies of scale (Novotny and Laestadius, 2014). Other innovation has largely focused on improvement of traditional effective and efficient harvesting and sawing of logs and decreased waste production, while less focus has been placed on the development of new types of products (Krigstin, et al., 2012). Accordingly, forest biorefineries require a different set of skills, which could be a challenge for the industry to manage (Näyhä and Pesonen, 2014). There is also a need for innovation strategies, as top managers from pulp and paper industry are often risk adverse and reluctant to sponsor uncertain projects (Björkdahl and Börjesson, 2011).

4. Discussion

Much of the available literature on the organic residuals are literature reviews, and here we find a need for more primary research of residuals valorization. While there are many similarities between the valorization strategies and emerging value chains of the sectors discussed above, we also note important differences in the current knowledge and research foci, trends, and push-pull factors. This has led to the formation of different types of value chains, and presents an opportunity for research and for lessons from one sector to be applied to another.

4.1 Brewery

In terms of the value chain for BSG, much of the current research focus is on the transformation, valorization and applications of BSG. Martin and Parsapour (2012) see the potential of using organic residuals from brewing beer to reduce the "consumption rate of nature's capital," alluding to a circular bioeconomy ideal. They promote valorization of BSG as a way to raise further awareness among governmental institutions on the sustainable management of organic residuals and thus prevent landfilling (Martin and Parsapour, 2012). As such, this research focuses on innovation and technology development, particularly on experiments to develop the feedstock and pretreatment processes for the different potential applications. Attention is placed on upgrading BSG and similar residuals to higher value products (Martin and Parsapour, 2012).

Though recent research has focused on processing technologies that may potentially expand the scope of possible end products, BSG valorization pathways are still predominately "technology push". The focus thus far has been on the breweries and potential opportunities they have for developing residuals valorization pathways. For example, Martin and Parsapour (2012) and Panjičko, et al. (2015) propose biomethane and biofertilizer as potential products from BSG, Pires, et al. (2011) suggest it could be used for lignocellulosic yeast carriers (LCYC), and Meneses, et al., (2013) propose extracting bioactive phenolic compounds with antioxidant activity and incorporating it in human food.

Buffington (2014) however, propose a hub-and-spoke model where breweries feed into a central biorefinery that processes the BSG. This could be the first step in moving towards more of a demand-pull model. Nevertheless, considerably less attention is given to the nascent market for BSG end products. The BSG valorization value chain is thus characterized as low complexity, high efficiency and low supplier capability. Gereffi, et al. (2005) argued that this combination of characteristics would not result in a viable value chain, and indeed no global value chain exists for BSG. However, given its material attributes, a market value chain (see. Gereffi, et al. 2005) for BSG could evolve with more investment in supplier capability and more market-driven innovation efforts. The green brewery concept, which seeks to reduce energy consumption and resource throughput in beer brewing in general could be an important driver in this regard (Muster-Slawitsch, et al., 2011).

4.2 Dairy

Factors contributing to framing whey as a resource are environmental considerations, technical advancements in biochemistry, market expansion, and modern knowledge (Smithers, 2008). Current research has focused primarily on the qualities of the whey, processing, and end uses. The valorization of whey was driven in early stages by increasing environmental regulation for whey disposal, because disposal without treatment is a major source of environmental pollution. To prevent expensive sewage treatment, the industry has instead sought out methods to produce various products that would have market value. These include using whey for processed foods and flavorings (Ostojić, et al., 2005), nano-filtration of whey to derive products for foodstuffs (Nguyen, et al., 2003), and using whey-derived products to extend shelf life without the addition of chemical preservatives (Koutinas, et al., 2009).

The value chain for whey is currently market driven. The need for cheap and largely available substrates will likely boost industrial interest in whey (Guimarães, 2010), impelled by the functional food revolution, e.g. demand for health foods and infant nutrition. Another pull is the market for preventive medicine for muscular atrophy prevention, weight management, improved cardiovascular health, anti-cancer effects, wound treatment, infection treatment, and healthy aging (Smithers, 2008; Mirabella, et al., 2014; Kosseva 2009). There is also a growing market for biofuels (Guimarães, 2010), although this use deemed too low-value given the alternative uses mentioned.

Thus, whey and its various end products are considered as viable co-products to cheese and Greek yoghurt production. As a result, the technology for processing dairy effluent is comparatively mature (with respect to the other sectors considered in this study), even though experimental research is still being conducted on the processing of whey to produce an ever-growing variety of end products. With high complexity in the knowledge for processing whey, high efficiency, and high supplier capability, valorization of whey represents a modular value chain (see section 1.2), and this industry is characterized by delivering end products according to specific customer specifications. Future research is needed to address logistic concerns of the industrial symbiosis such as types, characteristics and amounts of residuals produced by a company, the geographical location of the dairy firm, and the geographic distribution of actors in the value chain (Mirabella, et al., 2014).

4.3 Slaughterhouse

Similar to the dairy sector, the slaughterhouses also face a stricter regulatory environment for handling of ABP, particularly when processing them for food or feed. In contrast to whey, ABP are more diverse and confronted by social and cultural barriers to using for human consumption. These factors have led to the development of an extensive non-food based market for the residuals. More advanced treatment of ABP is costly, but the added value can compensate for these increased costs (Toldrá, et al., 2016). ABP are used in many sectors such as food processing, pharmaceuticals, energy, and animal feed (Jayathilakan, et al., 2012; Toldrá, et al., 2016), fertilizer, and technological research (Jayathilakan, et al., 2012), agrotech and biotech (Toldrá, et al., 2016).

There is a dearth of quality primary studies on valorization of slaughterhouse residuals as compared to other sectors. There are many literature reviews, but comparatively fewer experimental studies. Valorization of ABP is demand driven, though this depends on geography. Where ABP are valorized, the slaughterhouse sector has a similar value chain structure to the dairy sector (modular). However, because of the diversity of ABP, their specific niche uses, and the complexity of processing them, the emerging trend has been toward more consolidation in rendering operations; there are fewer and larger rendering firms which enjoy economies of scale and scope in production and R&D. The slaughterhouses have a lower capability of processing of residuals than dairies do, and this can lead to landfilling or incineration of residuals in some parts of the world (Okoro, et al., 2017). Additionally, the regulatory and cultural conditions place limitations on the transformation of the residuals, while at the same time the economy of the meat industry depends on a market and revenue for ABP. The low flexibility in the use of ABP due to regulatory and cultural restrictions, and the consolidation of rendering firms, this leads to characteristics that approach a captive value chain (see Gereffi, et al., 2005). This can be buffered to an extent by increasing the firms' capabilities for rendering by-products on site, and/or moving towards a more symbiotic shared-site relationship between the slaughterhouses and rendering operations, which would promote a more modular value chain.

4.4. Forestry

Research in valorization of forestry byproducts is highly dependent on case study analyses and industry surveys, and has focused largely on the resource procurement, valorization, and business strategies. The value chain for residuals from the pulp and paper industry is characterized by a potential transition from low supplier capability to high supplier capability. Forestry resources has many potential uses, yet national forest polices have tended to be dependent on parties' views regarding utilization of the forest, thus generally short-term and unpredictable (Näyhä and Personen, 2012). Generally, the market drives the output of end products, based on the prices (Näyhä and Personen, 2014). However, large capital and research investment required for the forestry industry to develop innovations for new end uses has been a barrier, resulting in low efficiency in terms of responding to changes in the market. This sector is characterized by relatively few large firms, a high fragmentation of forest ownership among many small forest owners, a strong historical legacy, large capital expenses required for developing new end use products, and a risk adverse management focused primarily on resource procurement and management. This makes planning and logistics costly, and thus investments in new biorefineries have higher economic risk. Coupled with poor returns, shareholders have reduced willingness to invest in innovation for the long-term (Björkdahl and Börjesson, 2011). The forest industry has not been proactive enough and has instead concentrated more on optimization of existing business operations rather than investing in new biorefineries and increasing its scope of products (Hämäläinen, et al., 2012).

Thus, the value chain for this industry has historically been hierarchal, with a large degree of vertical integration and managerial control (see Gereffi, et al., 2005). However, with the large number of competing firms for biomass, polymers and niche chemicals, the forestry industry has been developing toward a more integrated industrial symbiosis with eco-industrial parks. This subsequently represents a shift toward a relational value chain with complex mutual dependence between different firms (see Gereffi, et al., 2005). This suggests research a need for more experimental research and innovation in producing a large scope of end products. The relational value chain, characterized by industrial symbiosis, would be beneficial for the forestry industry.

Innovations are expected particularly in new extraction methods of hemicellulose or lignin, and in the development of new enzymes (Hämäläinen, et al., 2011). There are two main trajectories for the sector: (1) gasification of biomass and biofuel production, and (2) separation of niche products with high added value. There is not yet a sufficient pull from the market for these end products, though this may change in the near future as the demand for sustainable, renewable, and bio-based products increases. The image of producing environmentally sustainable products is potentially a competitive advantage for forestry firms (Näyhä and Horn, 2012).

5. Conclusions

Applying the analytical typology for value chain formation (Gereffi, et al., 2005) to the brewery, dairy, slaughterhouse, and forestry sectors allows for an assessment of the sector-specific factors that influence their formation. In this light, we find that the value chains are influenced and constrained by the materiality of the residuals, regulation (particularly for disposal), the technology involved in transformation, the firms' capabilities, the relevant actors, and the market formation. While we find parallels between sectors, both historically and today (e.g., the regulatory pressure and revenue needs for dairies and slaughterhouses, limited firm capabilities in both breweries and slaughterhouses, etc.), each sector has unique challenges and opportunities.

In terms of waste handling, the dairy sector historically resembled the brewery sector of today. While the dairy sector has advanced biorefinery capabilities and responded effectively to (or even created) the rising demand for products based on residuals, the situation in the brewery sector regarding BSG is pretty much unchanged. Breweries could invest more in transformation capabilities (e.g. the green brewing concept), and eventually more research would be needed in market formation for BSG to establish more market pull. Slaughterhouse residuals face stricter restrictions than that of dairy and brewing, thus research should focus on non-food based sectors, such as pharmaceuticals or niche chemicals, in order to further develop the value chain. Finally, forest residuals have much greater potential, should firms choose to invest in capacity building (i.e., biorefineries) and more research is focused on market development.

Waste minimization through the valorization of bio-residuals is a key component to the circular bioeconomy. While research and innovation into transformation and processing of residuals is needed, more attention should also be given to other aspects of the value chain. This would better promote valorization pathways and new markets, creating a market pull rather than just a technology push for residuals from the food and forestry sectors.

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Highlights

- Utilization of bio-residuals promotes the circular bioeconomy
- Value chain theory is applied to understand the valorization pathways for bio-residuals
- The dairy sector is the most well-developed whilst the slaughterhouse sector faces challenges in regulation and resource complexity.
- The brewery sector has capability challenges and low demand for spent grains, whilst the forestry industry faces challenges from institutional legacies.
- In the promotion of valorization of residuals, more research is needed in all aspects of the value chain to support the circular bioeconomy.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: