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Published in:
Forest Policy and Economics

DOI:
[10.1016/j.forpol.2019.03.013](https://doi.org/10.1016/j.forpol.2019.03.013)

Published: 01/01/2020

Document Version
Peer reviewed version

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Please cite the original version:
Temmes, A., & Peck, P. (2020). Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives. *Forest Policy and Economics*, 110, [101896].
<https://doi.org/10.1016/j.forpol.2019.03.013>

Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives.

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1. Introduction

Enhancing the bioeconomy (BE) is high on the political agenda of many countries, including the EU as a collective whole (European Commission, 2012) and several of its individual member states (Overbeek et al., 2016) including Finland and Sweden. The circular economy (CE) is also viewed as a promising approach to help reduce global sustainability pressures (Arponen et al., 2014; Geissdorfer et al., 2017; D'Amato et al., 2017). Biorefineries are commonly seen as a supplier of the building blocks required for a BE (Bozell, 2008; Näyhä and Pesonen, 2012). This analysis is positioned in a forest industry context where we observe that these three concepts overlap.

The BE is held to enfold the idea of a socio-technical transformation that enables the replacement of non-renewable material, chemical and energy inputs to industrial systems with renewable resources (D'Amato, 2017; Bugge, 2016; Kleinschmitt et al., 2014). It is perceived to meet many sustainability requirements. In addition to reducing the use of non-renewable natural resources, it promises to contribute to reduced greenhouse emissions, provide pathways for valorization of many wastes from sectors such as agriculture, fisheries and forestry, and to stimulate rural economies (cf. European Commission, 2012). The forest sector, here referring to forestry and the forest-based industries, is expected to play a significant role in the BE (Toppinen et al., 2017). This is especially so in the Nordic countries of Finland and Sweden where the maintenance of a vibrant forestry sector is an important social and economic issue. While very large forest companies are active in both countries, significant forest holdings are also directly linked to families and rural economies as they are forest owners as well as workforce (Antikainen et al., 2017).

Biorefineries are recognised as a core component in the transition to a BE in the forest sector (cf. Toppinen et al., 2017). These are often compared to petroleum refineries in which oil feedstocks are substituted with biomass (Näyhä and Pesonen, 2012). They are expected to boost productivity and product development in both bio-based industries and the chemical sector. Biorefining innovation in the forest sector is anticipated to both increase the efficiency of raw material utilisation and to stimulate diversification for the industry whose traditional products have faced a declining market (Teräs, 2015; Näyhä and Pesonen, 2012).

Circular Economy advances are anticipated to reduce the overall demand for raw materials or prevent the loss of valuable materials (both renewable and non-renewable), or both. In the simplest terms, the CE requires that products are designed for durability, reuse, refurbishment and/or recycling rather than linear flow. Such contributions are intended to improve resource availability and to reduce impacts to ecosystem service provision (Geissdoerfer et al., 2017; Korhonen et al., 2018).

In recent times, the BE and CE concepts have been increasingly combined into a concept of circular bioeconomy (CBE) (e.g. Hetemäki et al., 2017) reflecting belief that “the bioeconomy will hugely profit from increased circularity” (Carus and Dammer, 2018, p 84.) by mitigating some sustainability related issues of the BE, particularly inefficient use of natural resources (Allen, 2016). The dual-concept is also explicitly linked to the forest sector (e.g. Hetemäki et al., 2017).

Associated with the promises listed above, CE and BE have established significant traction and are being mainstreamed (e.g. Bugge et al., 2016; Geissdoerfer et al., 2017). Yet they are not without significant critique. Within discussions of the BE for example, there are arguments that the use of biomass in a BE is not necessarily sustainable (Jørgensen and Andersen, 2012; Kleinschmit et al., 2014). Further, several different BE visions with varying degrees of compatibility introduce uncertainty regarding the value of the concept (Bugge et al., 2016). Others stress that consumption of chemicals and energy and associated environmental burdens of BE technology systems are significant (Capolupo and Faraco, 2016). Such issues apparently highlight the importance of Carus and Dammer’s (2018) indication that improvement of sustainability performance may be attained by adding CE approaches. Yet, both the concepts of BE and CE are shown to suffer from a lack of conceptual clarity in some way (D’Amato et al., 2017, Bugge et al., 2016; Geissdoerfer et al., 2017; Kirchherr et al., 2017; Korhonen et al., 2018).

Nor is the concept of biorefining fully established (Mossberg et al., 2017), understood or agreed (e.g. Bauer et al., 2017). Further, biorefining is stated to require new actors, collaboration models and innovation networks (cf. Bauer et al., 2018a, Ollikainen 2014; Wield et al. 2013; Novotny and Laestadius, 2014; Toppinen et al., 2017). Yet, indications of such new connections are difficult to find (Palm et al., 2016; Tahvanainen et al., 2016).

A clear identity and evidence of reliability and function, as well as meeting the expectations of stakeholders, are areas important for gaining legitimacy for new concepts in the society (Aldrich & Fiol, 1994). The ability to articulate a compelling vision of an innovation that can help convince one’s own sector, and then attract the participation of others is another (Howell and Higgins 1990).

As we observe a lack of academic work to delineate the CE parameters that are most important for the improvement of a BE system when pursuing a CBE approach, the themes presented above are chosen for this analysis. We also observe that empirical analysis of how real-world initiatives have sought to pursue BE, or CBE, is lacking in a forest bioeconomy context. Forest biorefinery projects present themselves as a useful area of study in this regard. As such, this work aims to delineate a set of guiding parameters and performance characteristics within the combined concepts of BE, CE and biorefining that contribute to achievement of circular bioeconomy. As the work is grounded in a Nordic forest industry biorefinery context we apply the following focus question:

How do a suite of Finnish and Swedish forest biorefinery initiatives align with general definitions and expectations related to a circular bioeconomy?

A number of working assumptions underpin this analysis. A first is that enrichment of BE concepts and practice with CE elements do offer pathways to improve the sustainability performance of BE endeavours. A second is that biorefinery initiatives are already positioned as a key element of the emergent BE and will also constitute a key element of circular forest bioeconomy efforts. A third is that conceptual inconsistency both in the discourse and in the practical application of CE, BE, and CBE concepts – may hinder the progress of initiatives that are communicated as representative of such concepts.

After this introduction we present a review of literature that enfold biorefinery initiatives within the CBE context (Section 2). This section ends with a synthesis of key parameters pertinent to the pursuit of a circular bioeconomy in the forest sector. These can alternatively be described as working principles. This constitutes the basis for the analysis of the empirical field study. After the methods section (3), the results (Section 4) documents insights from the comparison of the suite of forest biorefining initiatives in Finland and Sweden to the key parameters of the CBE discourse highlighting matches and mismatches. We use Section 5 to compare and discuss results within the analysis frame as relevant to aim and objectives of paper, and to reflect upon underlying assumptions. Section 6 concludes and outlines areas of inquiry that can further knowledge in this area.

2. Literature review

This review first provides insights into the concepts *bioeconomy* and *circular economy* and the expectations connected to their emergence. It then examines *biorefineries* in the forest context and how CE and BE are generally related to a forest biorefinery.

2.1 Conflicting visions in the Bioeconomy concept

An early outlining of the BE concept is attributed to a Science magazine article in the 1990s (Enriquez, 1998). The BE became an important policy concept in Europe during the early 2000s (Birner, 2018, pp. 17-38) and was picked up by academia and industry after 2005. It is now a globally embraced phenomenon that has been taken up by numerous countries, both industrialized and developing (BÖR, 2015). The definition of the European Commission (2012) states: *“The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries”*.

Discussion of BE elements is found under a range of terms, *inter alia*: bioeconomy, bio-based economy, bio-based industry, bio-based society, bio-based products, and the bio-based knowledge economy (cf. Bugge et al, 2016). Further, a range of disciplines are involved in the knowledge production, and pursue different objectives. These analysts identify three different visions: *bio-technology* emphasizing its application and commercialisation across the economy; *bio-resources* focused on upgrading of biomass feedstocks and the establishment of new value chains, and *bio-ecology*, which highlights sustainability and ecological processes, management of energy and nutrients, and avoidance of monocultures, soil degradation, and biodiversity loss. D’Amato et al. (2017) indicate that a significant internal diversity of the BE narrative used in the academic literature has potential to negatively impact the value of the concept in research.

While economic growth and employment creation are central in the bio-technology and bio-resource visions, bio-ecology is more focused on protecting nature against the effects of markets (cf. Levidow et al., 2013). Indeed, the BE concept has been criticised for representing a weak form of ecological modernisation that will require increased exploitation of natural resources through (bio)-technological innovation (Kitchen and Marsden, 2011). Such views reflect fundamental critique of the focus on economic growth (Pfau et al., 2014) and commercialisation in the bio-technology and in the bio-resource visions. In a policy context, analysts (e.g. Pölzl et al., 2014, p. 391; Ramcilovic-Suominen and Pölzl, 2018) conclude that European BE policy narratives use sustainable development as a ‘selling point’, and that the policies are in fact focused on efficiency, productivity and industrial competitiveness for the production of food and biofuel. A dominant focus on pursuit of low value products is also a theme that is criticised, despite the definitions of BE advocating efforts focused on pursuit of a portfolio of high value-added products (Bauer et al., 2017).

The perception of a BE also contains different objectives in terms of a focus on reducing waste-streams of bio-resources on the one hand, and developing new products and economic value chains based on existing waste-streams from bio-resources on the other (Antikainen et al., 2017). To the degree that there emerge new economic value chains surrounding biological waste streams, reliance on waste flows can constitute a disincentive to reduce waste. These two objectives may thus constitute contrasting and internally inconsistent rationales. In summary, it appears that the BE remains a contested concept regarding the different possible futures and forms of development that are envisioned (Bauer, 2018a), and that researchers disagree on whether the BE is inherently sustainable, or may even constitute a threat to sustainability.

2.2 Blurring of the Circular Economy concept

The CE concept is built from efforts to re-imagine industrial processes based on a premise that industrial systems would be more efficient, and cause less environmental impacts, if they were modelled upon natural ecosystems where cascades of substance utilisation have evolved (Frosch & Gallopoulos, 1989). In such systems, by-products of one subsystem form the material input for another subsystem and in some cases also involve a cyclic return to the point of initiation (Frosch, 1995; Tukker, Jasser, & Klejn, 1997).

Years before the CE term entered common use, a body of work was established that identified material cycles where there are well-defined opportunities for substantial closure of certain anthropogenic material cycles (cf. Allen & Behmanesh, 1994; Sagar & Frosch, 1997; Zeltner et al., 1999). The concept of Industrial Ecology (IE) was generally applied to enhance closure of material-energy cycles in industrial operations (Ayres, 1998a,b; den Hond, 2000; Ehrenfeld, 2001; Sagar & Frosch, 1997). Industrial Symbiosis (IS) however, was more typically applied in initiatives where traditionally separate industries engage in a collective approach to physically exchange materials, energy, and/or by-products. Collaboration opportunities were often supported by geographic proximity (cf. Peck, 2003).

CE is now offered by researchers and politicians as an alternative to the linear ‘take, make and dispose’ model of the present economies. The CE is often described as having a general intent to promote closed loop systems (Murray et al., 2015) for material use via intentional changes to systems for design, manufacturing, reuse, refurbishing and recycling (e.g. EMF, 2013a; Ghisellini et al., 2016). However, three generic strategies are increasingly described (Bocken et al., 2017). These seek to narrow cycles (reduce the amount of materials needed per product or service); slow cycles (e.g. extend or intensify the use of products, and resources) or close material loops with recycling. Thus, CE advances are expected to help reduce overall demand for raw materials or prevent the loss of valuable materials (both renewable and non-renewable). According to Murray et al (2015), such approaches pursue a system achieving net reductions at the organizational supply chain and industrial levels

At present, the definition provided by the Ellen MacArthur Foundation (EMF) is that most often appearing in discourse (Kirchherr et al. 2017). EMF describes the CE as: “an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models” (EMF, 2013b, p. 7).

However, this is not universally accepted, nor considered all encompassing. In a study of 114 CE definitions Kirchherr et al. (2017) found no less than 95 different versions and little consensus between the various definitions. Other scholars also conclude that the multitude of different descriptions constitutes a barrier to its application (cf. Hirsch and Levin, 1999; Bocken et al., 2017; Blomsma and Brennan, 2017).

While the theme of sustainability is embedded in many discussions of the CE (Korhonen et al., 2018), both matches and mismatches between them remain (Geissdoerfer et al., 2017). Korhonen et al. (2018) present a position that the scientific content of the CE concept is superficial, disorganized, and appears to be a collection of vague and separate ideas, and semi-scientific concepts, drawn from several fields. It can also be observed that the ambition (or necessity) to address a wide range of implementation levels together has potential to add to confusion or uncertainty.

Circularity in connection to the use of biomass raw materials leads to the concept of circular bioeconomy (CBE) (e.g. Hetemäki et al., 2017; Carus and Dammer, 2018). Until recently, application of the concept has tended to concentrate on recycling, and in general has overlooked issues such as product design for circularity and related business models (Antikainen et al., 2017). In the context of biorefineries, CBE is mainly discussed in connection to processes that utilize waste materials such as lignocellulosics (Liguori and Faraco, 2016) or organic municipal waste (e.g. Mohan et al., 2016; Dahiya et al., 2018), or pursue cascading biomass use (Bezama, 2016; Raitanen et al., 2017; Jarre et al., 2019).

2.3 Biorefineries and the Forest Biorefinery

In forest-endowed countries such as Sweden (Bauer, 2018) and Finland (Toppinen et al., 2017) there is strong emphasis on forests as a dominant source of biomass, and the forest sector is central for a BE transition. A BE transition in the forest-based industries is typically seen to entail a shift to multiproduct biorefineries rather than pulp mills geared for paper raw material (e.g. Pätäri et al., 2011). Such views are influenced by a range of factors: environmental issues, increasing energy prices, perceptions of constraints upon the availability of forest biomass, market encroachment by ICT and competition from new forestry and pulp production areas (Karlton and Sandén, 2012; Novotny and Laestadius, 2014; Toppinen et al., 2017).

Pursuant to such, the biorefinery is often seen as a supplier of the building blocks required for a BE (Bozell, 2008) – such as chemicals, materials and fuels (Bauer et al., 2017; Toppinen et al., 2017). The pulp mill-biorefinery transition process has been envisioned as delivering full integration of biomass feedstocks plus other raw materials and energy, so as to deliver simultaneous production of fibre for paper products, plus chemicals and energy (cf. Axegård 2005; Axegård et al. 2007; Chambost & Stuart 2007). A key selling point for existing mills is apparently that it presents an opportunity to produce significant amounts of bioenergy and bioproducts so as to markedly increase revenues while still continuing to produce wood, pulp, and paper products. This is considered an attractive diversification for the industry as well as a means for supporting many social sustainability objectives (Karlton and Sandén, 2012; Hellsmark et al., 2016).

Despite an apparently clear focal point for the industry context outlined here, Bauer et al. (2017) report that biorefinery discourse in the research literature lacks consensus regarding a working definition, and that this in turn challenges discussion of the general aspects of biorefinery innovation. Among other things, they document how various actors group define the biorefinery with focus on a factory (aligned with the industry view above), while others present biorefineries as 'systems' or as a 'knowledge base' (Bauer et al., 2017, p. 538).

Bauer (2018a) further indicates that the biorefinery is neither a single technology, nor a specified set of technologies, but rather a concept for different possible configurations of processes, practices, and procedures. He also argues that a dominating narrative in biorefining is one of incremental change and reconfiguration of the current regime, and that such incrementalism may constrain renewal and deeper structural change unless challenged by policy processes and governance (p.10). Further, while manufacture of new value-added byproducts (e.g. biofuels, bulk and specialty chemicals, pharmaceuticals, etc.) are perceived as an opportunity for revenue diversification for forestry companies, Bauer (2018a) holds that contradictory biorefinery narratives regarding the envisioned roles of bioenergy contra advanced products also exist in forest biorefining circles – and that these largely follow the lines of conflict identified in earlier analyses of EU BE discourse. In a broader context, Palmeros and Parada et al. (2016) add that biorefinery design is often challenged by disciplinary boundaries that yield a narrow scope of analysis that is blind to contextual settings or stakeholder perspectives.

Despite their apparent promise, and significant support for biorefinery research and development throughout Europe (cf. Hellsmark et al., 2016; Peck et al., 2009) progress with biorefinery initiatives has been slow. Indeed, Mossberg et al. (2017) claim that biorefinery technologies have fallen into the ‘valley of death’ between the pilot/demonstration stages and commercialisation/diffusion. Similar difficulties are observed in North America (Bauer et al., 2017).

2.4. A framing of BE, CE and biorefinery concepts

Within this analysis, the ‘biorefinery’ as a concept differs from that of BE and CE in the forest industries context as it is viewed as an industrial unit rather than as a broader economic system. Despite this difference, biorefineries are considered to be essential building blocks of a BE and will overlap with broader systems. They have both significant scale, and a theoretical capacity to deliver a broad palette of outputs to the economic system in a manner analogous to incumbent fossil petroleum-refineries. Biorefinery initiatives can therefore be analysed both against the discourse on biorefineries themselves and as components serving the concept of BE and CBE.

D’Amato et al. (2017) found that CE generally deals more with industrial processes and resource efficiency in the whole chain, while the starting point of BE and biorefineries is the use of biological resources as raw materials. The ‘system’ for a CBE can thus be seen as a CE where non-renewable material, chemical and energy inputs to industrial systems are replaced by renewable biological resources.

The main benefits of the BE and biorefineries are often perceived to be *economic* – increased value-added and diversification towards novel products and value chains; and *social* – delivering benefits to rural livelihoods. The CE is more explicitly connected to *environmental sustainability* through its interest in reduction of waste and potential to reduce demands for natural resources.

As a summary of insights from literature, and as a framework to support analysis for the empirical study (Section 4) the various aspects of the three concepts are summarised in Table 1.

Table 1. Summary of various characteristics of bioeconomy, circular economy and biorefinery concepts used in the literature reviewed in this paper.

	Biorefinery	Bioeconomy	Circular Economy
Guiding precepts	Industrial unit. Efficient use of all biomaterial components. Product and revenue diversification. Focus on new value-added products. Shift to increased share of high value lower volume outputs.	Economic, techno- and ecological systems. Increasing bio-material use in existing & novel value chains. Establishment of new biomass value chains. Resource focused. Commercialisation of bio-technology.	Economic & technological systems. Replacement of the 'end-of-life' concept. Resource focused (eco-efficiency with increasing decarbonisation) Hierarchy: reduce, reuse, recycle and recover.
Scope and span	Production Conversion of biomass to a spectrum of marketable products and energy. Industries: agriculture, paper pulp, energy, chemicals, pharmaceuticals.	Production Conversion of renewable materials into food, feed, bio-based products and bioenergy. Industries: agriculture, forestry, fisheries, food and pulp and paper production, plus portions of chemical, biotechnological and energy industries.	Production, distribution and consumption. Micro level (products, companies, consumers) to macro level (city, region, nation and beyond). Enfolds industrial symbiosis and industrial ecology.
Mode of operation & transition	Displace fossil-based refineries and refining systems.	Displace fossil-derived inputs to the economy with biomass-derived inputs.	Pursue resource efficiency (narrow), elongate product life (slow), and circularize (close) material cycles.
Sustainability	Assessment of sustainability is case and context specific.	Key focus on economic aspects of sustainability – economic growth and employment creation. Ecological limits to biomass supply.	Conserve natural resources at all stages of production and use. Elimination of waste and toxics.
Internal tensions or inconsistencies	Competition for biomass supply. Geographical limitations on biomass availability. Additional demands on supply, logistics & infrastructure systems. Dominant focus on high volume, low value-added outputs.	No explicit focus on reduction of material flows. Conflicting elements in bio-resource, biotechnology and bio-ecology visions. Circularity arguments commonly rest upon CO ₂ cycle (mineralisation cycle).	Few definitions and applications adhere to guiding hierarchy. Key focus in practice is recycling. Thermodynamic considerations limit practicality of cycle closure.

3. Methodology

This paper utilises the results of a project study that assessed 'in the field' biorefinery activities in Finland and Sweden between 2015 and 2017 (cf. Antikainen et al., 2017). The biorefinery component of that work was initiated as an extensive desktop research seeking to identify all

bioeconomy innovations and projects documented in publicly available material in both Finland and Sweden. This was based on various database searches of government materials (e.g. innovation agencies, energy agencies, research foundations, and so forth) and reports (academic, industry based and governmental) followed by the pursuit of leads from discussions with potential informants. Swedish casework was reinforced by the outputs of a parallel study reported independently (Peck et al., 2016). This reviewed advanced biofuel initiatives in the Swedish forest sector post year-2000.

Additional literature for this analysis was identified utilising searches combining terms ‘circular economy’ or ‘bioeconomy’ with ‘definition’; and b) searches combining terms ‘circular economy’ with either bioeconomy, and bio-based*, and c) the terms bioeconomy and circular economy combined with ‘biorefine*’. The intent being to identify a base suite of recent peer-reviewed analyses that address the general coherence of the CE and BE concepts in use; their utilisation together, and their utilisation or applicability in the biorefining context – with particular focus on forest sector activities.

To further support the desktop study 12 interviews were carried out. Interviewees were selected applying a purposive sampling approach (Palys, 2008; Trochim, 2002) targeted to find informants with direct experience of biorefinery initiatives and research, as well as knowledge of as broad a selection of aspects relevant to biorefineries as possible (Table 2). The companies interviewed included both incumbents and new entrants to the forest industry and they all were involved in concrete commercially oriented projects rather than preliminary plans. The researchers interviewed were experienced professionals in the fields of wood chemistry, biorefining, advanced biofuels and biomaterial research.

To support interpretation and analysis, two stakeholder discussion/review sessions were organized within the project to review and discuss preliminary findings and prime areas of query. Session participants were selected reflecting parameters of experience and relevance such as: authorship of relevant report(s) or scientific article(s); involvement in drafting, negotiating, or communicating governmental or industry positions on biorefinery initiatives; or substantial involvement in governmental or industry-led efforts in the field.

The cases described in the project study (Antikainen et al., 2017) were subject to analysis in this work with the support of the framework built on the literature review of this study (Section 2).

Table 2. Sources of data

	Interviewed organizations	Other sources
Sweden	Forest companies (Domsjö, Södra) Research institutes (Rise, SP, LTH) Industry organizations	Desktop study, multiple telephone interviews/discussions, conference and biorefinery event observation and interactions.
Finland	Forest companies 4 interviews (MetsäFibre, Paptic, StoraEnso, Repolar) Universities and research institutes 3 interviews (Aalto University, VTT, Åbo Akademi)	Desktop study, conference observation, participation in steering group work of a research project.

4. Results

This section presents results in two forms. First, a summary of biorefining initiatives in Finland and Sweden; analyzed using the framework presented in Section 2. Second, a selection of biorefinery cases are presented in more detail to provide deeper insights into the specific approaches pursued.

4.1. Finnish and Swedish forest biorefinery initiatives

The desktop study focused upon Finnish and Swedish biorefinery projects that pursue industrial scale. While a number of these are already in operation, several remain in different phases of planning. A summary of the cases is shown in Tables 3a and 3b, where background information, and the main BE and CE aspects relevant to each project are provided.

At the time of analysis, the facilities that can be classified as wood biorefineries in Finland and Sweden were mostly owned by forest sector incumbents. However, bioenergy production initiatives have also developed separately from the existing forest industry, a number by companies in the energy sector, and a number of projects put forward by new consortiums are also observed.

While planning proceeds for the majority of Finnish cases that are not yet operational, in Sweden many of the projects were placed on hold in the mid-planning stage.

In both countries, most plants target biofuel production – with a basic BE objective to displace fossil inputs for transportation. While no far-reaching efforts to increase the value added of products were found, there were some projects which pursue this approach. The most notable examples are moves towards production of dissolving pulp for textiles, and efforts to use all wood components more effectively, or radically improve the internal circulation of production processes.

In relation to the CE we only assessed the CE aspects that can be implemented in the biorefineries themselves and did not speculate on the downstream value chains. Across the suite of studies we found no significant CE achievements.

Table 3a. A sample of Finnish Biorefinery initiatives (modified from Antikainen et al., 2017).

Activity	Owner	Products	Biorefinery characteristics	Bioeconomy characteristics	Circular Economy characteristics
Äänekoski bioproduct mill, on stream	Incumbent pulp	Softwood and hardwood pulp, energy (kraft)	Efficient use of biomaterial components.	Displacement of fossil-derived inputs.	Resource efficiency at production stage (internal recycling and improved value-added products). Industrial symbiosis (shared infrastructure).
Sunila pulp mill LignoBoost, on stream	Incumbent pulp	Lignin in dried form (in addition to the earlier products kraft pulp and energy)	Efficient use of biomaterial components.	Displacement of fossil-derived inputs.	Resource efficiency at production stage (internal recycling and improved value-added products).
Enocell, dissolving pulp, on stream	Incumbent pulp	Dissolving pulp on one of the two kraft pulp lines	Product and revenue diversification.	Displacement of fossil-derived inputs (textile market).	Resource efficiency at production stage (improved value-added products).
Kemijärvi pulp, planned	Domestic investors, public actors	Dissolving kraft pulp	Product and revenue diversification	Displacement of fossil-derived inputs (textile market).	Resource efficiency at production stage (improved value-added products).
Kuopio pulp, planned	Domestic investors	Kraft pulp	No discernible biorefinery characteristics reported.	Displacement of fossil-derived inputs (fuel market).	Industrial symbiosis (existing infrastructure).
Lappeenranta biodiesel plant, on stream	Incumbent pulp	HVO biodiesel for transport use	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Kajaani Cellunolix, planned	Incumbent fuels	Ethanol from sawdust for transport fuel	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Fortum Otso, Joensuu, on stream	Incumbent energy (incumbent pulping)	Pyrolysis oil from wood chips	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Kaidi biofuel Kemi, planned	Foreign industry	biodiesel from wood	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Scandinavian Biopower, Ristiina, under construction	Foreign investor	Biocoal pellets	Displace fossil-based refining.	Displacement of fossil-derived inputs (in e.g. industrial and thermal coal fired power)	No discernible CE activities.

Green Fuel Nordic, Iisalmi and Lieksa, planned, under construction	New entrant fuel	Pyrolysis oil from wood	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market)	No discernible CE activities.
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Table 3b. A sample of Swedish Biorefinery initiatives (modified from Antikainen et al., 2017).

Activity	Owner	Products	Biorefinery characteristics	Bioeconomy characteristics	Circular Economy characteristics
Domsjö Fabriker, Örnköldsvik, on stream	Foreign industry	Dissolving pulp (sulphite), lignin, ethanol	Efficient use of biomaterial components.	Displacement of fossil-derived inputs.	Effective use of more wood components.
Södra, Mörrum, on stream	Incumbent pulp	Dissolving pulp (kraft), heat and power. Lignin in dried form.	Product and revenue diversification. Efficient use of biomaterial components.	Displacement of fossil-derived inputs (textile and fuel markets).	Increased value-added. Effective use of wood components. Improved internal recovery and recycling. Ideas for value added products.
StoraEnso Innovation Centre for Biomaterials, Stockholm, R&D	Incumbent pulp	Research centre, identification of business opportunities	Product and revenue diversification.	Innovation to replace fossil derived materials.	Effective use of wood components. Ideas for value added products.
Chemrec (and Domsjö Fabriker), Örnköldsvik, planned, on hold	New entrant, technology	Output: DME and methanol	Displace fossil-based refining. Efficient use of biomaterial components.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Bioraff (biorefinery) Norrtorp, planned, on hold	Consortium: waste mgt., municipality, energy sector.	Methanol and/or methane, heat	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
GoBiGas, Göteborg, Stage 1 under construction	Incumbent municipal utility	Methane, heat	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Värmlands Methanol, planned, on hold	New entrant, fuel	Methanol, 10 GWh/yr surplus heat in district heating	Displace fossil-based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.

Bio2G E.ON Sverige AB, planned, on hold	Incumbent, energy sector	Methane, heat 10MW internal power potential for N ₂ liquid and for biorefinery setup for CO & H ₂	Displace fossil- based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Renfuel, Bäckhammar	New entrant fuel	Lignin oil for fuel and chemical synthesis	Displace fossil- based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
Preem, Gothenburg (both operational and in planning)	Incumbent, oil sector	Renewable diesel and gasoline, Bio- oils	Displace fossil- based refining.	Displacement of fossil-derived inputs (fuel market).	No discernible CE activities.
SunPine, Piteå (operational)	Consortium: fossil oil, forestry	Raw tall diesel separated from raw tall oil	Displace fossil- based refining.	Displacement of fossil-derived inputs (fuel & chemical markets).	No discernible CE activities.

4.3. Selected forest biorefinery cases

The following selected cases provide details of projects that are operational at commercial scale. These are intended to deliver further insights into different aspects of biorefineries – and thus to support interpretation of results recorded in Tables 3a and 3b. First, a biofuel case represents the larger proportion of examples found in the study, then three cases provide details of endeavours that include different approaches.

4.3.1. Biofuels from wood in Finland

The Biofuels Directive (Directive 2003/30/EC) created a market for biofuels, mandating fuel distributors to incorporate biofuels in diesel and in gasoline (Peixoto et al., 2013). With growing criticism of the use of agricultural outputs for fuel, the use of wood as raw material has gradually gained higher priority. Not least as it is seldom associated with competition for land suited to food-production.

The three large Finnish forest industry companies, Stora Enso, UPM and Metsä Group, were developing biodiesel raw material production from wood in the early 2010s. There were high expectations of the potential for forest biorefineries to produce fuels and the companies actively sought public investment support for these facilities from both national and EU sources. However, challenges for both the technologies and profitability of these processes were experienced – and the development of wood-based biodiesel was discontinued by all three companies. Later, the Chinese company Kaidi announced its intention to build such a factory in Northern Finland. While the final investment decision had not been made in 2018, Finnish pulping companies had expressed concerns that this will increase competition for raw material in Northern Finland.

Shifting to an alternative strategy, UPM built a biorefinery producing biodiesel from tall oil (a pulp process by-product) in Lappeenranta, Finland. Testing of the product took place in 2013 and commercial production commenced in 2015. As this venture is reliant upon a process by-product that constitutes only a few percent of wood by volume it is also subject to critique from a raw

material availability point of view because of competing industrial uses for tall oil. Chemicals producers that utilise it in their value chains argue that tall oil is a valuable raw material, that should be used as input for materials, rather than for energy. UPM however, argues strongly that tall oil should continue to be defined as a residual material. A strong financial driver for this is a policy regime that allows for so called double counting in connection to the EU biofuel legislation (Directive 2009/28/EC).

4.3.2 Multi-product strategy by Domsjö Fabriker, Örnsköldsvik, Sweden

Domsjö sulphite pulp mill in Örnsköldsvik, Sweden was founded in 1903 for production of paper pulp and later dissolving pulp for textile fibres, mainly viscose. For a number of environmental and technical reasons sulphite paper pulp gradually lost competitiveness against kraft pulp and it was sold to a private consortium in 2000 and further to its present owner in 2011. Post 2000, the company shifted strategy and moved to new markets (Novotny and Laestadius, 2014) and the three main products of Domsjö Fabriker are now dissolving pulp for viscose, purified lignosulphonates for concrete, and ethanol for fuel. The production capacity of lignin is approximately half of that of pulp. The main components of wood are effectively used to create marketable products: cellulose for dissolving pulp, lignin for lignosulphonates and the dissolved sugar components for ethanol production. In addition there is an increase in the value added from the original products in the case of dissolving pulp and lignosulphonates. In recognition of its process and product portfolio, Domsjö Fabriker has gained a reputation of being the foremost biorefinery in Sweden (Hetemäki et al., 2011).

Similar strategies to Domsjö Fabriker have been developed by other companies running sulphite pulp mills as a way of confronting competitiveness challenges. Informants indicate that Borregaard in Norway is a prime example of an innovator that has developed a portfolio of lignin-based products. The Lenzing Group in Austria is another, having developed their own textile value chain based on cellulose and chemicals production based on the hemicellulose components of wood.

4.3.3 Dissolving pulp for textile use by StoraEnso, Enocell and Södra Cell, Mörrum

In response to a decreasing market demand for paper pulp, producers have also sought new applications for pulp. One attractive example is dissolving pulp for textile fibres. Dissolving pulp is by no means a novel product, but it is only recently that processes have been developed for kraft pulp mills (Novotny and Laestadius, 2014). Dissolving pulp has a somewhat higher price than paper pulp and even taking into account the lower yield, the value added of the product is higher.

Even if dissolving pulp production as such cannot be considered as a transformation of a pulp mill into a biorefinery, it has changed the materials balance of a plant such as Södra Cell's Mörrum mill. This in turn opens opportunities for diversification. A changed materials balance has allowed this operation to start refining increasing shares of their black liquor into lignin by the Lignoboost technology. Dried lignin can be used as fuel pellets at the mill to replace fossil fuels, and the dried product can also be sold to various purposes depending on the purity of the material. A development towards increasing the value-added of lignin is thus underway.

4.3.4 Bioproduct mill of MetsäFibre, Äänekoski, Finland

Metsä Fibre has recently started a large pulp mill, which the company calls a bioproduct mill. The organisation deliberately avoids referring to it as a biorefinery. Despite this, there are reasons to portray it as an example of development in line with some CBE precepts. Firstly the mill contains significant innovations in cleaner production technologies that step beyond business as usual in the pursuit of resource efficiency. Biogas production from waste streams has allowed the mill to avoid fossil support fuels, and there are novel steps in process chemical recovery that significantly reduce

overall demand for input chemicals. In addition, the efficiency of the energy production from the lignin fraction is much higher than the present state-of-the-art technologies. This change enables a 10% increase in the total amount of bioenergy in Finland. Further, the company is in the process of building partnerships with various companies with an aim to achieve new industrial symbiosis systems that utilize a range of by-product side streams from the facility.

While the presence of items aligned with a CBE are noted, the company representatives themselves state that it still is predominantly a paper pulp mill, in spite of their choice to label it as a 'bioproduct mill'. Also the development of alliances with smaller companies mainly concern products with relatively high volumes, such as composites, textiles and lignin products, and therefore do not require major changes in the business logic. Further, efforts pursuing the use of the valuable wood molecules in small volume products were not discerned in this study, and little information is available regarding planned alliances.

5. Discussion

This section contains a brief review and summary of the biorefinery projects and then the various components of BE, CE and biorefinery concepts provided in Table 1 (Section 2.4) are used to scrutinise the degree of alignment of field activities with the BE, CE and Biorefinery concepts.

5.1 Biorefinery approaches pursued

There are a number of significant differences between Finnish and Swedish cases. In general it is observed that Finnish projects are more tied to large incumbent forest actors, while the Swedish actor groups are more diverse. Finnish projects primarily focus in three areas: displacement of fossil inputs at the producing plant itself; production of pulp that has increased value-added for new markets (i.e. dissolving pulp for textiles); and production of renewable transportation biofuels. These projects are either running, in planning, or are being realised. In contrast, roughly half of the Swedish projects were led by non-forest sector actor constellations in pursuit of transportation biofuels. Most of them were 'on-hold' at the time of the case study analysis. Several transport fuel initiatives also pursued fuels outside mainstream fuel systems, including synthetic biogas, DME and methanol. Several of these projects also include(d) local government actors and explicitly pursued regional development aims. Swedish projects that are tied to incumbent forest-sector actors are connected to renewable fuels, dissolving pulp for textiles or pursue multi-product strategies.

The majority of projects across both countries represent incremental steps taken within existing technology paradigms and include only small changes in the business logic, which supports views regarding the typical behaviour of incumbents in major technological shifts (cf. Apajalahti et al., 2017). Novel types of inter-industry connections considered important for new growth businesses (Tahvanainen et al., 2016) – for example links to the incumbent fossil chemical sector (Bauer, 2018b) – are still largely missing from forest biorefinery endeavours.

5.2 BE characteristics

Most initiatives analysed in this study fulfil many aspects expected in a BE: they are fed by biomass; contribute to the displacement of fossil inputs in processes; contribute to broader economic growth, and to rural economies; and are incrementally stepping up efforts to increase the use of bio-materials in various value chains. Moreover, some cases document efforts to create additional value from by-products or waste streams (cf. Bosman & Rotmans, 2014).

However, we find that the initiatives studied here appear most aligned with the *bio-resources* vision or to a lesser extent to the *bio-technology* vision, but not to the *bio-ecology* vision, reinforcing findings by other analysts (Bugge et al., 2016; Kitchen and Marsden, 2011; Levidow et al, 2013). This study also demonstrates a dominance of low-value products, such as fuels in biorefinery initiatives (cf. Bauer et al., 2017). Case informants also highlight the presence of both debate and concern among actors regarding the sufficiency of wood raw material reflecting international discussions (cf. Sluka and Peck, 2015). It is also clear that current process pathways experience or expect shortages of some specific wood components – for example tall oil is already subject to direct competition.

The emphasis on low-value products such as fuels – that have a short lifecycle and are immediately degraded to CO₂ in a single use phase guarantee the loss of any valuable molecules of the wood structure, such as lignin, hemicelluloses and some extractives. Business models that pursue ‘short’ lifecycles, not only contribute to product value destruction (Bocken et al, 2014), but also fail to pursue the overall dematerialisation effects of product lifetime extension, a weakness noted by D’Amato et al (2018). These developments also reinforce views by authors such as Leopold & Petit-Boix, (2018), who note a general over-representation of CBE business models that pursue fossil fuel displacement over approaches that may lead to dematerialization. Innovation pathways such as pursuit of biomaterials, or replacement of bulk and especially fine chemicals, are not realised, and may even be undermined by current initiatives.

With the exception of Domsjö, this study shows limited evidence of the pursuit of ‘chemical building blocks in a bioeconomy’ such as alcohols, sugar alcohols, bio-hydrocarbons, furans, and organic acids produced. As such, this study does not suggest that the pursuit of BE in the forest sector is transforming it, but rather it documents evidence of an industry searching for incremental improvement of its efficiency, productivity and economies of scale.

5.3 CE and CBE characteristics

The contribution of forest biorefineries to the CE concept observed in our cases is generally limited to measures that improve the overall material efficiency (e.g. Sokka et al., 2010) and efficient use of all wood components (Arponen et al., 2014; D’Amato et al., 2019). While it can be argued that increasing the value added of the products also enhances material efficiency (contributing to the “reduce” aspect of CE), it can also be argued that pursuit of resource efficiency via such pathways is simply ‘business as usual’. Textile applications may also return a longer life cycle in use than paper fibres and as such contribute to a slowing of material cycles, but this was not the scope of this study. While CE activities are also clearly present in the well-established practices of paper recovery and recycling – an issue highlighted as a CE achievement in a number of studies (Arponen et al., 2014) – this study notes that substantial pursuit of strategies to add value, extend product lifetime or close material cycles beyond existing fibre cycling is lacking. This stated, this study addressed only the ‘biorefinery’ (industrial entity) level. These findings do not preclude that future biorefineries can support recycling by designing more products in a way that supports recovery, and recycling.

Even considering the whole value chain, circularity appears precluded in the case of renewable fuel initiatives based on virgin forest biomass, and in many cases fuel production even competes for the raw material of higher value products such as specialty chemicals or material applications. Further, arguments that are posed indicating that the return of carbon to the natural cycle constitute circularity patently ignore core principles embodied in the CE concept. Finally, the broad consortia and, which are considered important for effective models of the CE (Antikainen et al., 2017) were not identified.

5.4 Enhancing the sustainability of biorefinery applications

General discussions of forest biorefineries are laden with expectations regarding their potential to contribute to both the BE and to sustainability efforts in general. The cases reviewed in this analysis however, demonstrate that most actors emphasize efficient use of the wood raw material and minimization of process waste as the main sustainability contribution for forest biorefineries. While this does improve resource efficiency, it also provides evidence that implementation of such strategies is far from complete if viewed from the CBE perspective.

Switching to the biorefinery concept itself, it is noted that the items focused on in this study were all in general terms 'industrial units' rather than 'multi-entity systems'. As stated, a central ethos for many operations has been simply to seek more efficient utilisation of biomaterial feedstocks. Also, a number of the existing pulp mills have established industrially symbiotic relationships with their host systems – for example by providing low carbon heat and electricity. While these advances and inter-relations can be seen to constitute good models for future deliberate strategies, it is clear that the majority have grown organically over the years rather than as deliberate biorefinery strategies.

The case studies also show that there have been innovations to valorise by-product streams such as lignin for chemical products rather than energy. However, efforts to pursue radical innovation for product and revenue diversification are limited. While efforts to shift to dissolving pulp are noted as a product portfolio shift of notable scale, there can be divergent views upon whether this is truly novel. It can be argued that dissolving pulp for viscose-related products is simply returning at scale to the Nordic forest sphere after a long period of limited interest. While this has required innovation and development of new processes, it is interpreted here as a shift to an alternative bulk commodity flow rather than a shift towards a marked increase in the value added of the products. This is still considered embryonic. While we have seen research in areas such as nano-fibres (e.g. Dufresne, 2013) and specialty chemicals (e.g. Holmbom et al., 2003) and some SMEs have started marketing pharmaceuticals (Antikainen et al., 2017), this work did not find examples of clear diversification to a broader spectrum of marketable products as part of biorefinery initiatives.

5.5 Conceptual incoherence as a constraint

This study examined the alignment of activities-in-the-field with the CE, BE and Biorefinery concepts. It has been guided by the view that real world endeavours should live up to social and political expectations created by their conceptual framing, communication or even 'hype' if they are to avoid disappointment and disillusionment (e.g. Konrad et al., 2012). It has also built upon views that a 'better' reputation, and clear sustainability benefits can positively influence access to resources such as financial and human resources, raw materials, and political support.

This study found evidence that communications surrounding biorefineries commonly refer to the BE, and now increasingly to the CE. Thus in 'talk' at least, it appears that the CBE concept is becoming established. Common practice in the field appears to frame almost all larger scale activities that process biomass as biorefinery endeavours – even though they may not match performance parameters or strategies found among guiding principles for a biorefinery (e.g. shift from low value commodity flows as one example). When circularity is added to the mix, drawbacks associated with dominating high volume, low value strategies become even more apparent as it is then easier to discern where material cycling is precluded, and value destruction takes place.

As generally positive views pertaining to biorefinery activities were observed in this study, this common framing of so many 'biomass processing' initiatives as 'biorefining' may reflect a form of branding – that seeks to take advantage of a popular concept. On the other hand, this, along with varying degrees of vagueness surrounding the application of BE and CE concepts, may also reflect

strategies that seek to frame concepts broadly so as to appeal to more stakeholders. Aldrich and Fiol (1994) for example, present ideas that there are situations where proponents of new endeavours make use of encompassing symbolic communication in efforts to garner cognitive legitimacy more quickly. Thus, the utilization of multi-concept framing' including no less than three catchwords of the day, each with apparently high levels of social and political traction, may be tempting. This stated, in general it was observed that proponents of 'biorefinery' initiatives limit communications to their place in the bioeconomy, rather than a circular bioeconomy. The use of the latter term being more prevalent in scholarly circles.

Another area introduced in this paper, was the potential importance of a clear identity, and evidence that encourages stakeholders to believe an endeavour will be functional and reliable (cf. Aldrich & Fiol, 1994). Also, that a compelling vision for the offering can help convince sectoral actors, and then attract the participation of outsiders (cf. Howell and Higgins 1990), and that uncertainty amongst potential sponsors or collaborators, often associated with varying degrees of confusion about the function or prospects for approaches or technologies, may amplify challenges to new areas endeavour (Singh & Tucker, 1986). A premise underpinning this work as that multiple concepts may similarly bring with them issues of unclear identity and an unclear picture of function – thus potentially undermining resource access.

Such a lack of clarity, and limited evidence of delivery of sustainability benefits called for by the working principles is a phenomena that has clearly been observed in this study. This in turn reflects indications by D'Amato et al. (2018) that (a lack of) evidence of environmental and social value yielded by forest based circular bioeconomy is a concern, and calls by Manninen et al. (2018) for reference systems to measure such.

On the surface, this appears to be a concern of stature, however we deem that data yielded in the study provides only circumstantial evidence that it may be associated with constraints to project resources. While it is observed that projects proposed by forest non-incumbents had a high propensity for failure, and that most projects that have continued to implementation have large forest sector actors behind them, a causal link to these issues was not discernible.

One area related to physical resources was however encountered. This work confirmed earlier observations (e.g. Peck et al., 2016) that there are growing tensions between industry actors mostly related to competition to biomass resources. Especially in Finland the high support for bioenergy and biofuels is questioned by many, and pressures to move towards high value-added products are growing. While not immediately reflecting incoherence of concepts, this can be related. It is conceivable that as awareness of the limitations of the 'bioeconomy' approaches (e.g. being pursued in areas such as biofuels) do not live up to expectations of a 'circular bioeconomy', and even prevent biorefinery visions being achieved, then critics will gain additional leverage.

5.6 Contribution

It is considered that the analysis has contributed to the emerging scholarly literature of circular bioeconomy in two areas. While, the analysis has in essence confirmed the general expectations outlined by key claims at the start of the paper, we hold that the body of work has added novel details and insights in the context of the forest biorefinery – and thus also in context of the forest bioeconomy.

A first is the delineation of precepts – or 'working principles' that can support the application of CBE thinking in practice (e.g. support value, longevity and relevance in study and practice). In essence, specific areas where BE approaches may be made more sustainable via inclusion of CE thinking have

been identified. This contributes directly to calls for scholarly examination of the relationship between the CE and BE, including friction points (e.g. Leipold & Petit-Boix, 2018). It can also help underpin the development of indicators for a sustainable circular bioeconomy (e.g. Pauliuk, 2018; Manninen et al., 2018). While focused on the biorefinery context of this paper, such insights should be generalisable in broader application, not least as biorefinery applications are accorded significant importance for the transition towards a bioeconomy.

A second contribution is made in the area where challenges related to (a lack of) conceptual coherence, clear identity, and evidence of reliability is projected by scholarly literature (e.g. D'Amato et al., 2018; Manninen et al., 2018). In broad terms, these indicate that confusion and uncertainty may affect the value and validity of concepts in study, and even constrain successful emergence of the concepts in practice, for example because of ambiguous expectations of their commercial value (DeBoer et al., 2019). Here, this analysis has documented areas where such inconsistent application is found in literature, and gathered empirical evidence from the field.

We hold that the latter item in particular adds to the scholarly literature. Case examples demonstrate how the activities and strategies pursued by a suite of forest biorefining initiatives generally fail to match the working principles (precepts) present in the general discourse enfolding the concepts.

5.7 Reflection on assumptions and limitations

We firstly briefly reflect on the validity of the suite of assumptions that underpin this analysis. A first was that adding CE elements to BE concepts would provide mechanisms to improve the sustainability performance of BE endeavours. We argue that there is evidence that this is valid. Case examples in particular, show how circularity framing can highlight areas where value can be preserved, and sustainability functions improved. A second premise was that a study focused on forest biorefinery initiatives would add value to a CBE discussion. Again, we deem that this is valid and that the content of the paper provides ample evidence that biorefineries – despite their limitations – will be a key element of forest bioeconomy efforts. And also that circularity insights are valid for a biorefinery. The third assumption was that conceptual blurring and inconsistency in the discourse – and general inconsistencies in the application of CE, BE, and CBE concepts – may hinder the progress of initiatives. Here we would argue that while we have confidence that this remains a valid assumption, there was limited evidence of causality found in the study.

Regarding limitations within the work, two are selected here for consideration. The first regards the validity of the Swedish/Finnish geographical setting for the study. Among other things, these two countries host forest sectors that contribute extremely high proportions of national export revenues in comparison to other countries (cf. Antikainen et al., 2017). This in essence defines them as 'outliers'. However, we argue that these examples are useful and generalizable to larger geographical area, and to broader CE and BE settings. Firstly, the forest biorefinery context has been established as central for a BE transition, and thus can be expected to be emulated in many jurisdictions where technologies and infrastructure are comparable. Secondly, as the paper has also been built from the broader CE, BE literature, insights from that part of the work are immediately relevant to the body of scholarly work.

A second limitation to be addressed is that this work presents a study based predominantly on desktop work supported by a limited number of interviews. However, as this work draws upon a sizeable body of work documented in two earlier studies, this is considered of lesser concern. The primary source for this work, a significant international research project that underpins this paper documented in Antikainen et al. (2017), provides an in-depth picture of the majority of BE/CBE

initiatives underway in the focus countries. Swedish cases were also supported by earlier work spanning a subset of initiatives in Sweden, documented in Peck et al. (2016). This covered essentially all major advance biofuel initiatives in Sweden.

6. Conclusions

The aim of this paper has been to examine *how do a suite of Finnish and Swedish forest biorefinery initiatives align with general definitions and expectations related to a circular bioeconomy?* A key task for this analysis was to relate the matches and mismatches between concepts and ‘in-the-field activities’. One reason for examining such issues was the premise that a lack of coherence between the ‘talk’ and the ‘walk’ may in turn negatively affect access to key resources and support, and thus constrain efforts to establish biorefineries. This presumption is also examined.

6.1. High expectations but limited delivery of sustainability improvements

We conclude that a clear identity for a CBE has not been established. Rather, two unclear concepts – CE and BE – are being morphed together. However, it was possible to compile a relevant set of characteristics of CE, BE and biorefineries to support the assessment of the performance of industrial initiatives.

The industrial entities examined, are undoubtedly parts of the BE. However, the expectations of the creation of as much value added in relation to the amount of raw material as possible was generally not met. We document that a significant proportion of Finnish and Swedish projects are designed for biofuels production. Particularly in Finland this is driven by policy support, whereas in Sweden, policy frameworks for biofuels have been much more uncertain (cf. Peck et al, 2016) and a number of projects were cancelled, or mothballed after piloting. As such, this work affirms the relevance of concerns raised by Leopold Petit-Boix (2018) that policy frameworks can drive developments away from resource-to-material applications towards fuel applications. As such, we conclude that the developments are not yet moving Europe towards a BE as defined in the Finnish and Swedish strategies (cf. Antikainen et al., 2017).

We mostly did not find widespread and innovative portfolio diversification for the effective use of all wood components. Further, the use of the term ‘biorefinery’ associated with facilities focused predominantly on the production of fuels appears inappropriate.

Regarding circularity, an even more critical stance can be taken. With the absence of substantial circular flows from society that are directed back to forest sector production entities that are framed as biorefineries, current forest biorefinery initiatives enfold only early steps in wood value chains. Thus, CE aspects related to preservation of embedded material value, or cycle closure, do not even appear relevant. Indeed, strategies focused on fuel production rapidly close the biomass loop back to CO₂ directly ignoring a central CE strategy to slow material cycles. Such observations echo concerns (e.g. D’Amato et al., 2018) regarding the absence of business strategies pursuing longer-life products in forest based circular bioeconomy business models.

As such we conclude that at present in the biorefinery developments the additional of ‘circular’ appears inappropriate. Claiming circularity in biorefineries would thus appear to add limited value at best, and may be seen as a source of confusion or reputational risk at worst.

Despite reservations about the levels of progress made to date, we nevertheless conclude that the pursuit of CE concepts in forest biorefining is worthwhile. Indeed various industrial symbiosis

elements are developing at an entity level and have potential to extend further out into society. Further, material science developments focusing on conversion of higher proportions of biomass to longer-life products where there is potential to both recover, and recycle materials and organic molecules indicate will likely provide pathways for linking to societies greater circular flows.

6.2 Ways forward

As a first general approach to further develop CBE, there is significant unused potential through the development of small volume, high value-added products, developments that can take place in collaboration with separate often smaller companies. Smaller in this instance seen as advantageous, as these can often be more flexible, dynamic and innovative (cf. D'Amato et al., 2018). Further, authors such as Burgelman (1984) have detailed how innovation proponents within larger, well established organisations can often experience difficulties in bringing forward new technologies that do not meet the needs of their main customers, or may appeal only to small or emerging markets. Such approaches are developing in cases such as that of Metsä Fibre in connection to its new Äänekoski mill.

A second area of importance to a CBE is more effective use of all wood components to reduce wastage of valuable molecules. As noted, when viewed from a CE perspective, some BE pathways such as renewable fuels can actually be perceived as wastage – or indeed a form of material value-destruction when material cycles are short and essentially linear. Informants to this study indicated that work with hemicelluloses has significant potential in this regard.

For both of these areas of work, innovative or higher value products, particularly those with material (or molecular) properties suitable for longer life applications, material recovery and recycling may also open opportunities for increased circularity in arenas of time and space well beyond plant or production cluster boundaries, an approach also recognized as missing in wood cascading literature by Jarre et al. (2019).

Thirdly, interfirm resource sharing, which has been practiced for a long time in some shared geographical locations (cf. Chertow, 2007; Jacobsen, 2006; Sokka et al., 2010) can be further developed. Also broader collaboration patterns are suggested to support development both in BE (cf. Bauer 2018b) and in the CE, but a number of questions remain. As examples: What is the role of networks in achieving the CBE objectives in the forest sector? How much of this is to be intra-sectoral or cross sectoral? Which 'building blocks of the bioeconomy' can enter high value material cycles where circularity can be a central functionality?

While this study has shown considerable circumstantial evidence that conceptual blurring, and the loose framing of forest biorefinery initiatives may be counterproductive, this has not been addressed in detail, and nor has it been widely studied elsewhere. The impact of communications and the roles of various stakeholders in building the identity and legitimacy for biorefineries is one area worthy of systematic study in order to understand the mechanisms for improving, or protecting, access to resources for novel concepts like biorefineries. Also delineation of the ways how inconsistency in communications may be a barrier to access to resources would be useful for practitioners. It also remains unclear whether large actors such as pulp incumbents would be affected by such issues in ways that new innovators or smaller firms are (if at all).

Finally, the functions of policy mechanisms as they drive forest biorefining both towards and away from BE and CE concept fulfilment are clearly significant. Policy is thus also linked to the general legitimacy of new concepts such as biorefineries, and as such the role of policy as a barrier as well as a driver is worthy of study in this context.

Acknowledgements

Much of this material is drawn from the project *Renewal of manufacturing towards a sustainable circular bioeconomy and implications for innovation policy* (RECIBI) supported by the Finnish Agency for Innovation (Tekes) and Sweden's innovation agency Vinnova. Material is also drawn from a study for the project: P38116-1 "Systemic Constraints and Drivers for Production of Forest-derived Transport Biofuels in Sweden", the support of the f3 – Energimyndigheten (Swedish Energy Agency) collaborative research program "Förnybara drivmedel och system" (Renewable transportation fuels and systems) is also acknowledged. This paper has been developed as a dual effort between the authors and they share authorship.

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