



The circular bioeconomy: Its elements and role in European bioeconomy clusters

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ABSTRACT

Biomass is projected to play a key role in meeting global climate targets. To achieve a resource-efficient biomass use, European bioeconomy strategies increasingly consider the concept of a circular bioeconomy (CBE). We define the term CBE via a literature review and analyze the concept's role in north-west European bioeconomy clusters through interviews. We identify strategies regarding the clusters' feedstock and product focus, and investigate what role biorefineries, circular solutions, recycling and cascading play. Finally, we discuss gaps in CBE literature and the potential contributions of the CBE to sustainability. The analyzed bioeconomy clusters move towards a CBE by increasingly considering residues and wastes as a resource, developing integrated biorefineries and focusing more on material and high value applications of biomass. However, there is so far only little focus on the end-of-life of bio-based products, i.e. on circular product design, recycling and cascading. Key challenges for implementing circular strategies are policies and regulations, costs and the current small size of bio-based markets. Amongst the product sectors the interviewees identified as promising for the bioeconomy, plastics and construction & building materials have most recycling and cascading potential. While the CBE could contribute to improving the sustainability of the bioeconomy, the concept is not inherently sustainable and its potential trade-offs need to be addressed. Especially social aspects, cascading, circular product design, and aspects related to product use seem to be underrepresented in CBE literature, while the topics biorefinery, wastes and residues as well as waste management are significantly covered.

1. Introduction

Biomass is projected to play an important role in meeting the global climate targets set in the Paris agreement (Creutzig et al., 2015; Daiglou et al., 2019; Rogelj et al., 2018; Rose et al., 2014). For the chemical industry, heavy road transport and marine and aviation sectors, biomass is one of the few options to replace their fossil feedstock with a renewable resource, thereby reducing the sectors' Greenhouse-gas (GHG) emissions (Bazzanella and Ausfelder, 2017; Carus and Raschka, 2018; International Energy Agency (IEA), 2018; S. de Jong et al., 2018; Mawhood et al., 2016). Hence, the concept of a bioeconomy (BE) has been put forward by the European Union (European Commission, 2012) and by almost 50 countries around the globe (Fund et al., 2018). A bioeconomy can be defined as the "production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy" (European Commission, 2012).

A strong optimism has been observed regarding the benefits of the bioeconomy (McCormick and Kautto, 2013); some bioeconomy strategies and scientific publications consider the bioeconomy to be inherently sustainable (Hetemäki et al., 2017; Pfau et al., 2014). However, there are also various publications highlighting potential trade-offs and negative impacts (McCormick and Kautto, 2013; Pfau et al., 2014): They expect an increased pressure on water bodies and natural ecosystems and question the emission reduction potential. Some key issues in this debate evolve around the competition for land, i.e. direct and indirect land-use change, agricultural intensification, eutrophication and risks posed by invasive species (Pfau et al., 2014). While some authors consider the bioeconomy to be "circular by nature" (Carrez and Van Leeuwen, 2015; Sheridan, 2016), Hetemäki et al. (2017) see the risk of following a linear business-as-usual approach if the principles of a circular economy (CE) are not considered. The CE is defined by the European Commission (2015) as minimizing the generation of waste and maintaining the value of products, materials and resources for as

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long as possible.

As a response to these critical discussions, the updated bioeconomy strategy of the [European Commission \(2018a\)](#) announces that the “European Bioeconomy needs to have sustainability and circularity at its heart” ([European Commission, 2018a](#)). Since the publication of the EU action plan for the CE ([European Commission, 2015](#)), “practically all of the European bioeconomy(-related) strategies” have increasingly been linked to the CE ([Fund et al., 2018](#)).

Merging these two concepts has led to the term ‘circular bioeconomy’ (CBE), which appeared around 2015 and is increasingly used in scientific publications since 2016 (see section 2.1). However, there have been only few attempts to define the term and to describe what the CBE concept actually entails (see sections 2 and 3.1). Furthermore, a bottom-up perspective on the role of the CBE in regional bioeconomy clusters is missing. This perspective is particularly relevant since many key strategies towards a more resource-efficient and circular bioeconomy, e.g. integrated biorefineries and cascading use of biomass which are both defined in chapter 3.1, depend on a close cooperation of local actors from agriculture, industry, research and regional public institutions, e.g. within bioeconomy clusters¹. The important role of regional clusters in driving the European bioeconomy is increasingly recognized ([Haarich, 2017](#); [Kircher, 2012](#)).

With this paper we aim to contribute to a better understanding of the CBE concept and furthermore investigate to what extent it already plays a role in the strategies of selected regional bioeconomy clusters.

To this end, the paper addresses the following research questions (RQ):

- 1 What are the defining elements of a CBE?
- 2 What are the strategies and foci in selected bioeconomy clusters regarding (i) feedstocks; (ii) products; (iii) biorefineries; (iv) circular thinking, cascading and recycling?
- 3 Do the clusters implement the CBE elements defined in RQ1 in their strategies?

Moreover, we (4) discuss the potential contributions of the CBE to sustainability and (5) identify gaps in literature and cluster strategies that deserve more focus when moving towards a CBE.

The focus of this study is North-West Europe, namely the Netherlands, Belgium, the United Kingdom, Germany and France. These countries represented 51 % of the turnover of the EU bioeconomy in 2015 ([European Commission, 2018c](#)). Furthermore, north-west Europe is traditionally a major hub for the European petrochemical industry, a sector that heavily relies on biomass for decarbonization; these five countries alone are still responsible for almost 66 % of the EU chemical sales in 2018 ([CEFIC, 2018](#)). This makes this region a relevant case study to explore RQ 2 and 3.

After describing this paper’s materials and methods, we define the CBE concept and its elements, based on a literature review (RQ1). The second part of the results presents strategies in the selected bioeconomy clusters (RQ2) based on interviews with their representatives. Finally, we discuss (a) if the clusters implement the CBE elements defined in RQ1 and (b) the potential contributions of the CBE to sustainability.

2. Materials & methods

This research consists of two work-streams (see [Fig. 1](#)): Work-stream A is a literature review of publications on the CBE concept to answer RQ1, and work-stream B covers interviews with bioeconomy cluster-

¹ While clusters greatly vary in their size and degree of organization, they can be generally defined as a “geographically proximate group of interconnected companies and associated institutions in a particular field, including product manufacturers, service providers, suppliers, universities, and trade associations” ([Su and Hung, 2009](#)).

representatives and their subsequent analysis to answer RQ2. In the discussion (C) both work streams are linked to answer RQ3.

2.1. CBE literature review

We searched for the term CBE and its synonyms (Boolean string: “circular bioeconomy” OR “circular bio-based economy” OR “circular bio-economy”) within titles, abstracts and keywords on Elsevier’s scientific search engine Scopus and found 84 peer-reviewed publications in English dating from 2016 to 2019.

2.1.1. Qualitative analysis

The titles, abstracts and - where necessary - the full texts of these 84 documents were screened to identify those publications that do not only mention the term CBE but also define or explain the concept. This limited the results to five publications. Analyzing the bibliography of these five publications, e.g. identifying frequently mentioned authors, led to the inclusion of four additional documents, of which three are not peer-reviewed. We analyzed these nine documents (Appendix A) in detail to identify key elements of the CBE.

2.1.2. Analysis of keywords

In a second step we used the software VOSviewer to compare the author and index keywords of the initial 84 CBE documents to 1275 bioeconomy (BE) publications found on Scopus for the same period 2016–2019; Boolean string: (“bioeconomy” OR “bio-based economy” OR “bio-economy”) AND NOT (“circular bioeconomy” OR “circular bio-based economy” OR “circular bio-economy”). The goal was to observe differences in the occurrences of keywords, in particular on topics identified as important CBE elements in the qualitative analysis of the nine documents (see Appendix A). We clustered similar keywords and treated them as synonyms (see Appendix B). To compare the relative importance of a keyword in CBE and BE documents, the number of keyword occurrences in CBE and BE documents was divided by the total number of CBE and BE publications respectively.

Eventually, we used the CBE elements identified in this literature review to derive a CBE definition (RQ1).

2.1.3. Limitations

Comparing the share of keywords of the only 84 available CBE documents to keywords of the 1275 BE documents might lead to an exaggeration of some findings; the results may show high differences in relative terms, while being derived from a small number of publications. Moreover, when clustering similar keywords, a few subjective choices have been made. By attaching the list of the clustered keywords in Appendix B, these choices are made transparent.

For the detailed qualitative analysis, only nine documents were identified and selected. This sample is not very diverse as four publications are closely linked to the forest-based bioeconomy ([Dalia D’Amato et al., 2018](#); [Falcone et al., 2020](#); [Hetemäki et al., 2017](#); [Temmes and Peck, 2019](#)).

2.2. Interviews with representatives of bioeconomy clusters

We conducted seven semi-structured interviews with representatives of seven north-west European bioeconomy clusters (see [Fig. 2](#)). The interviews were complemented by an analysis of overview documents and web pages of the clusters, which provided additional insights into the strategies and focus areas of the clusters (see Appendix C).

2.2.1. Selection of clusters and interviewees

The clusters were selected in consultation with the project stakeholders (see acknowledgments). Following the relatively open definition of clusters by [Su and Hung \(2009\)](#) (see footnote 1), clusters of different size and degree of organization were considered. According to

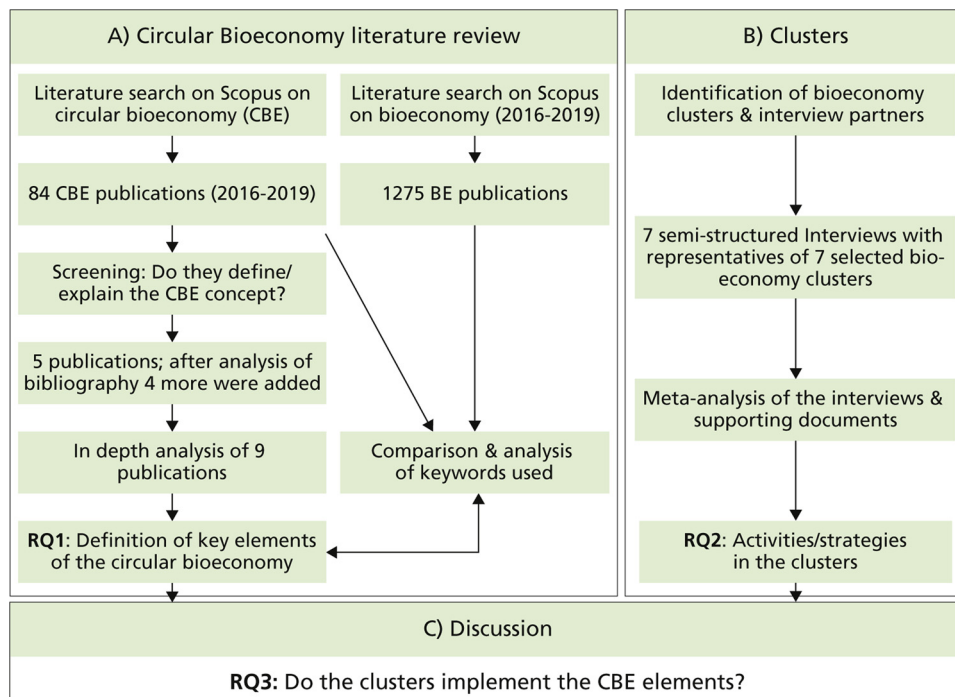


Fig. 1. Research approach and structure.

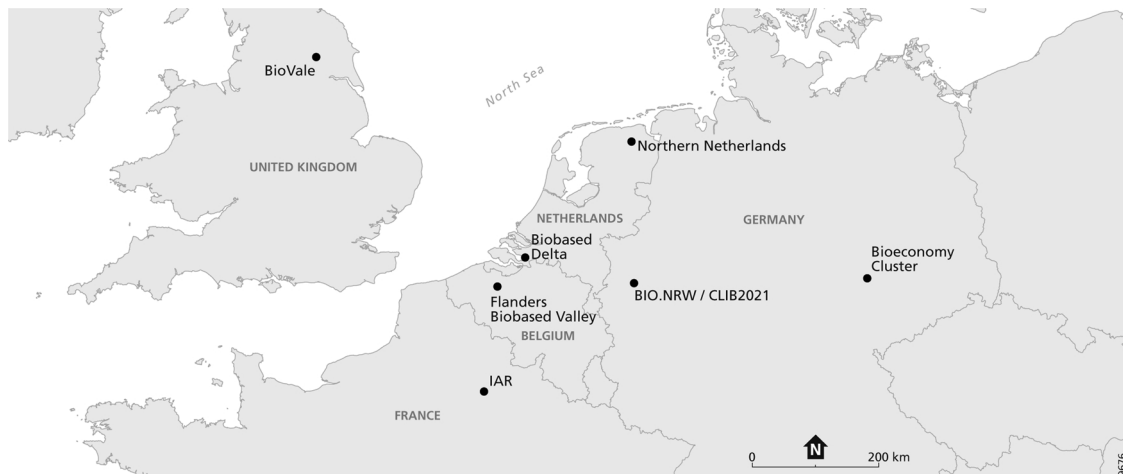


Fig. 2. Selected bioeconomy clusters.

the project focus (see introduction), only clusters from north-west Europe covering a wider range of bioeconomy sectors and involving both public and private actors were selected. Another important factor for consideration was international visibility and impact, signaled by their involvement in international cooperation and projects: Four of the seven selected clusters closely collaborate within the 3BI intercluster² and three within the BIG-C, the Bio Innovation Growth mega Cluster³, highlighting their role as key actors of the bioeconomy in north-west Europe. The bioeconomy region Northern Netherlands was added following recommendations of the project stakeholders.

² Within the 3BI intercluster (Brokering Bio-Based Innovation) the four clusters BioVale, Bio-based delta, Bioeconomy cluster and IAR cooperate in research, development and deployment of biomass conversion technologies. (van der Hoeven, 2015)

³ Within the Big-C the members Bio-based Delta, BioNRW / CLIB2021 and Flanders Biobased Valley work together on a leading cross-border bioeconomy region (BIG-C, 2019).

For each of the clusters we interviewed a key knowledge holder with a good overview of the activities in the respective cluster and region: Managing directors (4) and in three cases other cluster representatives that were recommended by project partners or interviewees. The interviews were conducted between February and April 2018 (2 in person, 2 via Skype, 3 via phone).

2.2.2. Interview approach

The interview approach applied in this paper can be classified as a semi-structured interview according to Bryman (2012), allowing a change of sequence in asking the prepared questions and allowing for more general, open questions as well as for further questions not defined in the interview schedule. This relatively flexible approach can help identifying new priorities and foci of the interviewees that were not yet considered by the interviewer (Bryman, 2012) and was therefore considered suitable for the explorative nature of this study. However, there were also pre-coded questions, meaning that a range of answers was provided. But also in this case, the schedule allowed for

adding additional options not foreseen by the interviewer.

The interviews focused on strategies and activities in the clusters regarding the following topics:

1 Feedstocks

Based on the interviews and supporting documents the different types of primary biomass feedstocks used in the clusters (structured in lignocellulosic crops, starch crops, sugar crops, oil crops and algae) were classified in a qualitative manner according to their importance within the cluster as main, complementary and prospective feedstock. The same method was applied for assessing the role of agricultural and forestry residues, wastes (from industry and from consumers) and CO₂ as a resource. The results were then sent to the interview partners for correction and confirmation. Only the feedstocks that were at least named twice were considered in the results.

2 Product sectors

The interviewees were asked about the focus of their cluster's research and innovation programs regarding the uses of biomass, namely energetic (e.g. for biogas and biofuels) and material uses. Material biomass use is referring to all non-energetic uses of biomass, ranging from applications in the chemical industry to food & feed as well as for construction materials. Furthermore, the interviewees were asked to name bioeconomy product sectors with a high or low growth potential in the future (up to 2030).

3 Biorefineries

The questions aimed at identifying the type of biorefineries (according to Cherubini et al., 2009) the clusters are working on and at what stage these projects are (research, pilot and demonstration, commercial).

4 Cascading, recycling and other circular strategies

After asking the interviewees for their understanding of cascading, the further questions aimed at identifying cluster activities regarding the end of life of bio-based products, e.g. strategies or projects on cascading, recycling and circular product design.

The interviews were transcribed and the relevant answers coded according to the interview foci (as described in e.g. Gorden, 1992). Together with the complementing documents providing an overview of the cluster's strategies, the coded answers were analyzed and compared to identify common trends, key differences and the underlying reasons for the cluster's choices.

2.2.3. Limitations

The small sample size of bioeconomy clusters does not allow for

general conclusions on the status of the CBE in north-west Europe. Furthermore, the clusters are not comparable in size, degree of organization, feedstock or product focus. Nonetheless, the selected seven clusters provide interesting case studies that give valuable insights into the strategies and challenges of some of Europe's leading bioeconomy clusters. Due to the diversity of the sample, the analysis covers a wide range of bioeconomy developments in north-west Europe, by representing different local circumstances and focus areas. However, it still excludes certain bioeconomy regions, in particular the forest-rich Scandinavian countries. Moreover, the clusters are from countries that have comparably strong CE-policies and well-established waste management sectors in place. Therefore, conclusions from this study are region-specific and might not apply to regions with a different feedstock and industry focus or a less developed CE. Finally, basing the cluster assessment solely on interviews and strategy/overview documents just allows for indicative conclusions on the foci and trends in clusters, as not the whole range of projects and reports of each cluster was analyzed.

2.3. Analyzing the cluster activities and strategies in the context of the CBE

The CBE elements identified in the literature review (RQ1, Appendix A) then served as a framework for analyzing the strategies of the bioeconomy clusters (RQ2) to answer RQ3: Do the clusters implement the CBE elements in their strategies. Combining both research streams in the discussion helps us to see in how far the still largely academic concept of a CBE is already a reality in practice and allows us to identify potential shortcomings in literature and industry that deserve more focus when moving towards a CBE.

3. Results

3.1. Defining the CBE and its elements

In this section we identify and define key elements of the CBE based on a literature review (Appendix A) and an analysis of keywords used in scientific publications (Appendix D). From this analysis we eventually derive a definition of the term CBE and discuss its implication on biomass use.

3.1.1. CBE elements in literature

We identified three overarching perspectives on the CBE in relation to the bioeconomy and CE (see Fig. 3): Before the term CBE appeared, the Ellen MacArthur Foundation (2013) implied that the bioeconomy is an integral part of the CE by including the biological cycle into their CE illustration. Similarly, Temmes and Peck (2019) see the CBE as a CE where "non-renewable [...] inputs to industrial systems are replaced by renewable biological resources". The European Commission (2017a) defined the CBE as the application of the CE concept to biological resources, products and materials. We analyzed nine publications

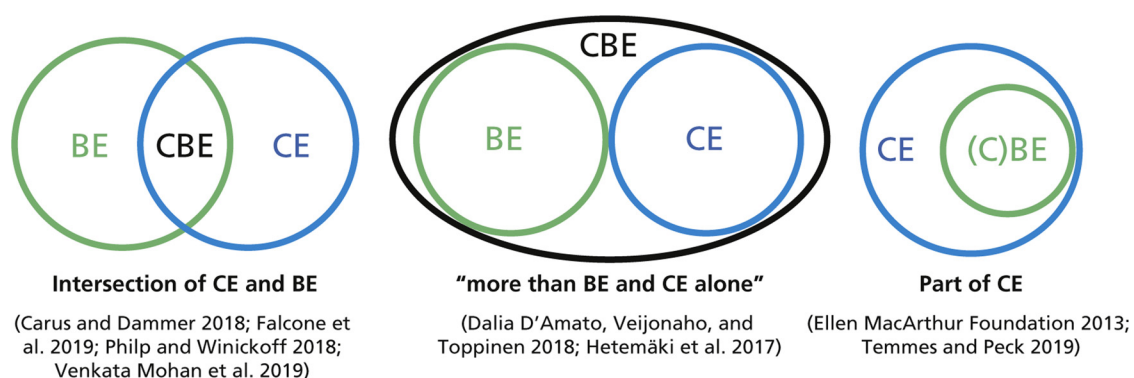


Fig. 3. Perspectives on the circular bioeconomy (CBE) in relation bioeconomy (BE) and circular economy (CE).

explaining the CBE concept. Four of them define the CBE as the intersection of BE and CE (Carus and Dammer, 2018; Falcone et al., 2020; Philp and Winickoff, 2018; Venkata Mohan et al., 2019) while Hetemäki et al. (2017) and Dalia D'Amato et al. (2018) argue for a more comprehensive vision and see the CBE as “more than bioeconomy or circular economy alone”.

While the perspectives on the term differ, the analysis of the CBE publications showed that they often refer to similar CBE elements: All of the nine analyzed publications highlight the *use of wastes and residues as a resource*. Furthermore, keywords relating to wastes & residues are used 3.5 times more in CBE compared to BE documents (see Appendix D).

The efficient use of biomass is considered part of the CBE by all nine authors, even though their definitions of efficiency vary or are not given. As Ekins et al. (2017), we argue for a definition of *resource-efficiency* that considers technical efficiency (material output/material input), resource productivity (economic output/material input) and emission intensity (emission output/material input). Considering these three interpretations of resource-efficiency allows for a more balanced approach; maximizing for only one might negatively influence the others, e.g. maximizing the technical efficiency might be very energy intensive and thus increase emissions and costs. Resource-efficiency as a keyword does only play an insignificant role (see Appendix D); although keywords referring to efficiency strategies are frequent (see the following paragraphs).

(Integrated) biorefineries are considered an important part of the CBE by seven of nine CBE publications and are seen as a measure to improve the resource-efficiency and total value of the biomass (Hetemäki et al., 2017; Temmes and Peck, 2019; Zabaniotou, 2018). Moreover, keywords relating to biorefinery are used almost three times more in CBE documents compared to BE ones. E. De Jong et al. (2012) define a biorefinery as “the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)” (E. De Jong et al., 2012). Integrated biorefineries are a combination of several biomass conversion technologies that allow for more flexibility and cost reduction (McCormick and Kautto, 2013). They do thus ease the use of side-streams and wastes and facilitate the combined production of high value products (e.g. fine chemicals) with lower value products (e.g. bioenergy).

Maintaining the value of products, materials and resources for as long as possible and the *waste hierarchy*⁴ are two of the key principles of the CE concept of the European Commission (2015) and therefore also apply to biological resources in a CBE (European Commission, 2017). Five of the nine analyzed CBE publications also referred to those principles. However, these principles do not necessarily result in the most economical or environmentally friendly solution (see discussion section). We therefore rather suggest the *optimization* of the value of biomass *over time* as a key characteristic of the CBE. Such an optimization can focus on economic (e.g. for profit), environmental (e.g. for GHG emissions) or also social aspects (e.g. for job creation) and ideally considers all three pillars of sustainability.

The *cascading use of biomass* could facilitate such an optimization over time. Six of nine publications considered cascading as an element of the CBE, while its use in keywords is insignificant. Cascading has various definitions in literature but usually the common theme is the “sequential use of resources for different purposes” (Olsson et al., 2018). Within the bioeconomy literature cascading use of biomass is mostly defined similarly; e.g. Fehrenbach et al. (2017) define it as the processing of biomass into a bio-based final product which is used at least once more either for material or energy purposes. We also adopt this

definition, as it is in line with the European Commission (2017b) and further literature (Kosmol et al. 2012; Meyer 2017; Odegard et al., 2012). However, Olsson et al. (2018) pointed out that cascading is also sometimes interpreted as an order of priority, aiming for the highest added value (Odegard et al., 2012; Zabaniotou, 2018). Fig. 4 contrasts these two interpretations of cascading. Furthermore, cascading in the context of biorefineries is often used to describe co-production⁵ and factory-internal recycling and recovery loops (Odegard et al., 2012; Zabaniotou, 2018). In recent years economic aspects have been highlighted when talking about value optimization (Olsson et al., 2018), even though there are various ways of defining the resource quality or the value of cascading choices; some of them are intrinsic (e.g. chemical structure, embodied energy) and others are based on human value judgements (e.g. economic, environmental, cultural) (Sirkin and Houten, 1994).

Waste management is an important topic in CBE publications; keywords related to this theme are used 4.2 times more in CBE publications compared to BE documents. *Recycling* and other circular waste management strategies are considered part of the CBE by all nine analyzed publications.

Circular product design was mentioned in five publications, while it only has a marginal share in keywords for both CBE and BE publications.

Four publications also advocate for an increased product utilization in the CBE by *sharing* and see *prolonged use or durability* of bio-based products as an element of the CBE. However, the concept of the sharing economy (see Curtis and Lehner, 2019) as well as prolonged use/durability are ignored by the remaining publications and are not existent within the keywords.

Looking at the keywords, *sustainability, climate change and other environmental impacts* seem to play a slightly more salient role in CBE publications compared to BE ones (see Appendix D). All nine analyzed publications highlight sustainability issues when discussing the CBE. However, the *social aspects* seem to fall short in the CBE discourse, both in keywords as well as in the conceptual discussions as only three of nine highlight them.

3.1.2. CBE definition

Fig. 5 illustrates the CBE and its elements and Appendix A shows their coverage in literature.

Considering these elements, we suggest the following CBE definition:

The circular bioeconomy focuses on the sustainable, resource-efficient valorization of biomass in integrated, multi-output production chains (e.g. biorefineries) while also making use of residues and wastes and optimizing the value of biomass over time via cascading. Such an optimization can focus on economic, environmental or social aspects and ideally considers all three pillars of sustainability. The cascading steps aim at retaining the resource quality by adhering to the bio-based value pyramid⁶ and the waste hierarchy where possible and adequate.

3.1.3. CBE impact on biomass use

The analysis of keywords used in CBE documents showed an almost 50 % stronger focus on material biomass uses (bio-based chemicals and materials, food & feed) compared to energy and fuels, while this ratio is balanced in BE documents (see Appendix D). Using biomass directly for energy or fuels makes it impossible to maintain its value via reuse or

⁴ The Waste hierarchy introduced by the EU Directive 2008/98/EC on waste (Waste Framework Directive) provides a priority order for waste management with waste prevention as the first priority, followed by re-use, recycling, recovery and disposal.

⁵ Co-production can be defined as the “production of different functional streams (e.g. protein, oil and an energy carrier) from one biomass stream” (Odegard et al., 2012)

⁶ The bio-based value pyramid is a commonly used way to classify biomass uses according to their value and volume, see Fig. 6.

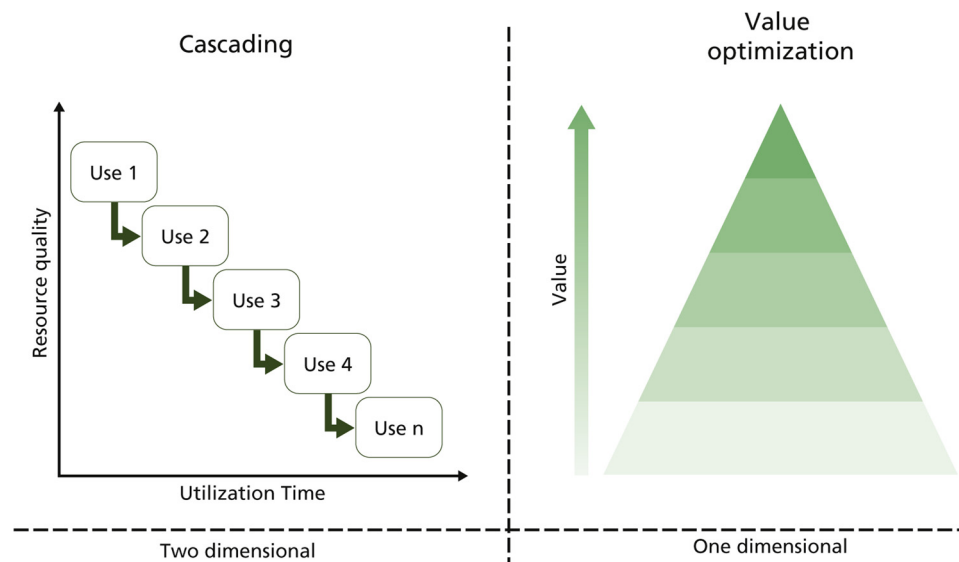


Fig. 4. Two common interpretations of cascading (own illustration based on Sirkin and Houten (1994)).

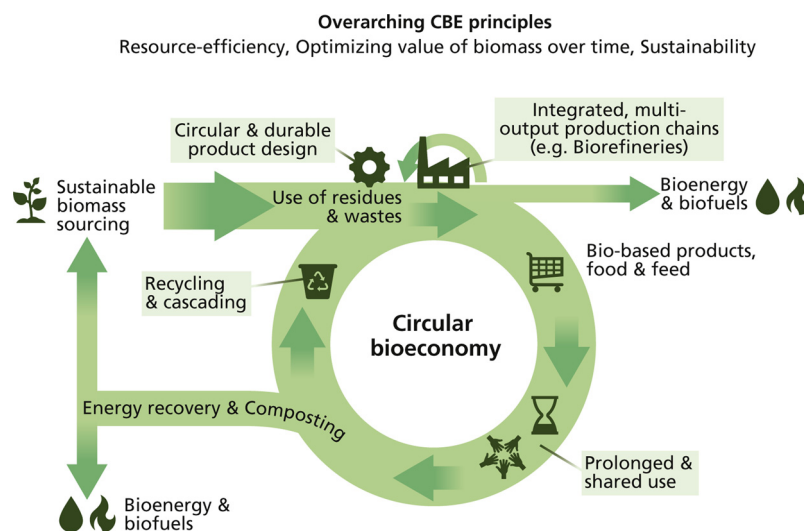


Fig. 5. The circular bioeconomy and its elements.

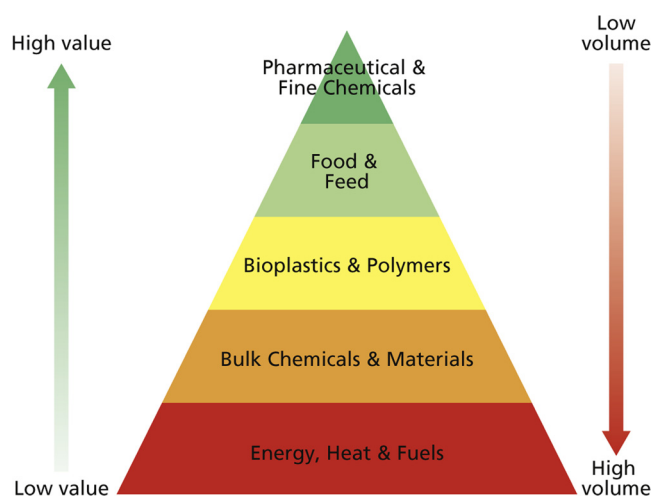


Fig. 6. Bio-based value pyramid (Own illustration adapted from various sources: Davis et al., 2017; Lange, 2014; Márquez Luzardo and Venselaar, 2012).

recycling (Carus and Dammer, 2018). Hence, the CBE could induce a reduction of direct energetic use of biomass or a reallocation of biomass resources with biomass suitable for high-value applications going to materials while lower quality biomass is used for energetic purposes. In a CBE, more biomass would ideally first be delegated to a material use before – after one or potentially multiple cascading steps – it would be delegated to a final energetic use or composting. In theory, this cascading would follow a movement down the bio-based value pyramid (Fig. 6) and the waste hierarchy, moving from high value to lower value biomass applications. Moving from the upper part of the bio-based value pyramid and the waste hierarchy to the lower part theoretically goes along with decreasing options for further uses and cascading opportunities, due to the lowering of the resource quality. Staying on the upper part of both hierarchies would therefore theoretically be desirable in a CBE. However, in practice, applications on the lower part might still be preferable from an environmental and economic perspective (see discussion section).

Those publications advocating for a comprehensive vision of the CBE (Dalia D'Amato et al., 2018; Hetemäki et al., 2017) highlight sustainable sourcing of biomass. However, the majority of the CBE documents seems to focus on how the feedstock is used and on the role

of residues and waste. Consequentially, the literature review did not reveal a clear preference regarding the types of primary feedstocks or the origin of feedstocks (import or local). However, supporters of a European circular (bio) economy often highlight the argument of reducing the dependency on imports by keeping resources in the loop. Thus, one might expect a slight preference in a CBE for locally sourced feedstocks (see e.g. [Bio-based Industries Consortium, 2017b](#)).

3.2. Strategies in European bioeconomy clusters

The interviews with representatives from seven north-west European bioeconomy clusters aimed at identifying current strategies in their respective clusters and regions. The analysis of the interviews is structured in the clusters' strategies regarding a) feedstocks, b) products, c) the role of biorefineries, and d) the role of circular thinking, cascading and recycling.

3.2.1. Feedstock strategies

We examined the following three aspects of the cluster's feedstock strategies: the type of primary biomass used, the use of residues and wastes as a resource, and the origin of the biomass feedstocks (import or local).

[Table 1](#) shows the type of primary biomass feedstocks used in the clusters and their importance. We see that lignocellulosic feedstocks (mainly wood chips but also grasses) play an important role in almost all clusters, either as main (4) or complementary feedstocks (2), while it is seen as a prospective feedstock in only one case. Starch and sugar crops are also relevant feedstocks for the majority of the clusters; for three clusters they are a main feedstock. Oil crops on the other hand play a major role in only two of the clusters. Algae were mentioned as a prospective feedstock by two interviewees but do not (yet) play a relevant role.

Even though primary feedstocks are dominant in most clusters, [Table 2](#) shows that residues and wastes are already playing a relevant role as well. Especially agricultural and/or forestry residues are considered a feedstock by all clusters. Six interviewees classify them as either main (2) or complementary feedstock (4), and one considers them as a prospective feedstock. Industry and household wastes do not play such an important role. Only three clusters consider them as main or complementary feedstock and one as a prospective feedstock. Lastly, three interviewees see CO₂ as a prospective feedstock for their cluster.

[Fig. 7](#) compares the importance of residues and wastes between the clusters (Y-Axis) and provides some insights into different strategies regarding the origins of the feedstocks used in the clusters (X-Axis). Based on the discussions with the interviewees, the clusters were positioned according to their focus on imports or local feedstocks.

Only BioVale (United Kingdom) and BIO.NRW / CLIB2021 (Germany) consider residues or wastes as a key resource, while these are just complementary or prospective feedstocks for the remaining five clusters (see Y-axis of [Fig. 7](#)). However, the clusters still seem to struggle with the practical implementation of using wastes and residues on an industrial scale. Most projects are still on the level of feasibility studies and research and development.

The results show that three of the seven clusters have a strong strategic focus on locally produced feedstocks (BIO.NRW/CLIB2021, IAR and Bioeconomy cluster) and use only very small amounts of imported biomass. For BioVale, local feedstocks play an important role

Table 1
Primary biomass feedstock types and their role in the clusters (n = 7 clusters).

Feedstock role in cluster	Lignocellulosic	Starch	Sugar	Oil	Algae
Main	4	3	3	2	–
Complementary	2	2	1	–	–
Prospective	1	–	–	–	2

Table 2

Role of residues and wastes in the clusters (n = 7 clusters).x`.

Feedstock role in cluster	Agricultural / forestry residues	Wastes (Industry & households)	CO ₂
Main	2	2	–
Complementary	4	1	–
Prospective	1	1	3

(focus on local wastes and residues) but the cluster also makes use of the biomass supply (mainly wood chips) coming in from the regional Humber seaports. Biobased Delta and Northern Netherlands are much more inclined to import biomass, but they also have an interest in using locally available resources, e.g. from local sugar beet farmers (Biobased Delta). Flanders Biobased Valley has the strongest focus on imports.

Reasons for the diverging feedstock strategies between the clusters are manifold. The cluster location plays a key role. The four clusters with a stronger focus on imports are all situated close to major European harbors (see [Fig. 7](#)). However, also the importance of certain actors within the clusters is a relevant factor. Having a strong role of farmers associations within the cluster will most likely result in a much stronger role of local feedstocks as it is e.g. the case with IAR. If the cluster evolves more around industry stakeholders, it is more likely that using local resources is less of a priority if their price and stability of supply is outperformed by imports. Harbor vicinity in combination with strong agricultural stakeholders within the cluster will likely result in dual strategies: the Biobased Delta focuses on the one hand on wood chips and pellets import (Redefinery program) and on the other hand on using locally available sugar beets (Sugar delta programme) ([Biobased Delta Foundation, 2017b](#)).

The figure also shows that no cluster has a strong focus on imports and at the same time considers residues and wastes as a main or complementary feedstock, while all clusters with a strong focus on local feedstocks (the French and German clusters) consider residues and waste at least as complementary feedstock. The clusters seem to not consider importing wastes and residues via their harbors but only refer to locally available wastes and residues. However, the presence of a harbor does not exclude a key role of wastes and residues, as the example of BioVale shows. The available local farmland also plays an important role in the feedstock strategy. A limited amount of agricultural areas in the region can either result in a feedstock strategy that heavily relies on imports (e.g. Flanders Biobased Valley) or in a stronger focus on making use of residues and wastes (e.g. BIO.NRW / CLIB2021).

The interviews provided insights into the diverse feedstock strategies of the clusters, which are the result of their different local circumstances. This diversity in strategies and regions is also reflected in publications providing an overview of Europe's bioeconomy regions ([Bio-based Industries Consortium, 2017a](#); [Haarich, 2017](#)) and makes it difficult to design a "one fits all" policy on EU level.

3.2.2. Product strategies: Energetic vs material biomass use and promising bioeconomy sectors

All interviewees described a clear shift in their research and innovation programs from energetic to material biomass use. A reason for this development could be concerns that the support for e.g. biofuels and bioenergy might be reduced. We can indeed notice some negative signals for certain energetic biomass sectors, e.g. that the revised Renewable Energy Directive (RED II) caps the contribution of biofuels produced from food and feed crops to the Renewable Energy goals ([European Commission, 2018d](#)). However, the RED II also contains a target for advanced biofuels and an overall renewables target of 32 % for 2030, to which bioenergy could significantly contribute if it meets the sustainability criteria. However, NGOs increasingly pressure the sector to reduce direct biomass use for energy and to focus more on cascading and material applications of biomass (see e.g. [Greenpeace](#)

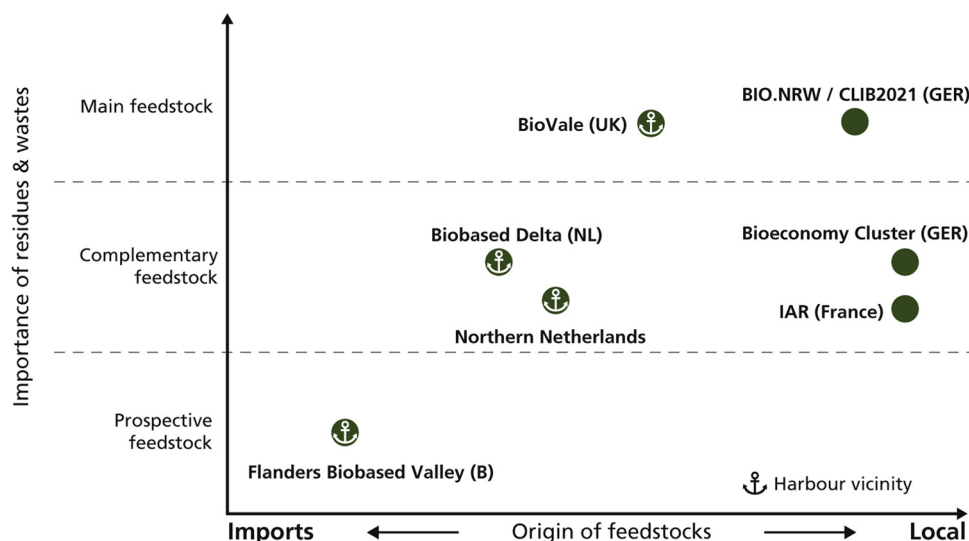


Fig. 7. Origin of biomass in the clusters (local vs imports) and importance of wastes & residues.

et al., 2012; Natuur and Milieu, 2018; WWF, 2017). Also on national level we can observe some tendencies towards the cascading principle and material and high value-applications, such as in the discussions on the climate agreement of the Netherlands (van Veldhoven-van der Meer, 2019).

Two cluster representatives mentioned that they prefer a business model that works without subsidies and thus see a more stable business environment and better chances to compete on the market for high quality products, especially if the bio-based products offer additional features that fossil competitors do not offer, such as biodegradability. Another interviewee explained the trend to material biomass uses in research & innovation with the higher research needs in these sectors, while there are already more mature technologies for biofuels and bioenergy. Furthermore, bioenergy usually requires larger feedstock volumes to be profitable, while e.g. fine chemicals require lower biomass inputs. Densely populated bioeconomy regions without harbor access and small agricultural areas as North-Rhine Westphalia thus showed a strong focus on pharmaceuticals, fine and specialty chemicals.

The cluster's focus on materials refers to research and innovation projects and does therefore not mean that the energetic use of biomass only plays a minor role. The clusters could still have large installed capacities of e.g. biogas or biofuel plants⁷, while their research and innovation increasingly evolves around material biomass use. Furthermore, some local policies support energetic biomass uses, such as in the Haut de France region (IAR cluster) for biogas.

Looking at the turnover of bioeconomy sectors in the countries the clusters are located in (Belgium, France, Germany, Netherlands, United Kingdom), we observe a rising turnover of bio-based chemicals, pharmaceuticals, plastics and rubber (NACE classification) by 6.4 % between 2011 and 2015, while the turnover of biofuels decreased by 44 % in the same period (European Commission, 2018c). However, bio-based electricity demonstrated the by far highest percentage growth with almost 123 % (European Commission, 2018c). The International Energy Agency (IEA) projects a decline for conventional biofuels until 2023 but an increase for novel advanced biofuels from non-food crops (Bahar et al., 2018). Furthermore, bioenergy capacities are expected to increase in Europe from 41.7 GW in 2017 up to 49.9 GW in 2023, while co-firing biomass is increasingly questioned (Bahar et al., 2018), e.g. the Netherlands is planning not to issue any new grants for co-firing

⁷ For example, the Rodenhuisdok biorefinery cluster for biofuels and bioenergy in Flanders (Biobased valley) or the Drax power station in Yorkshire, one of the largest European bioenergy plants (BioVale).

biomass (Government of The Netherlands, 2017).

Hence, looking at commercial developments we see a mixed picture and cannot identify a clear trend towards material biomass uses. Nevertheless, the shift in the cluster's research and innovation towards material biomass use could be a relevant indicator for the future focus of the bioeconomy clusters.

We asked the cluster experts which product sectors they see as promising (or not) for the future bioeconomy. Not all felt comfortable in providing an encompassing answer as such an assessment is rather speculative and potentially sensitive concerning their own strategy.

Fig. 8 shows that the experts mostly mentioned rather higher value applications of biomass as promising sectors. Especially bioplastics, pharmaceuticals and food and feed additives are considered to have a significant potential for the bioeconomy. Bio-composites and (innovative) construction and building materials were also named, which could be classified as lower to medium value on the bio-based value pyramid (see Fig. 6). High volume but low value applications like bioenergy, biofuels and bulk chemicals were even assessed negatively by the cluster experts.

In general, most of the experts see potential mainly in highly functionalized biomass applications with high economic value such as fine and specialty chemicals. They do not see great opportunities in competing with fossil alternatives in lower value applications like bulk chemicals under current circumstances, due to their low price and lacking policy support. This suggests a change in the bioeconomy, as in particular bulk chemicals received attention in the past as a promising sector (Dornburg et al., 2008; Patel et al., 2006).

To conclude, the interviews revealed a product strategy of the clusters that demonstrates a shift in the clusters' research and innovation programmes from energetic to material use of biomass and an upward movement on the bio-based value pyramid towards low volume but high value biomass applications. The implications of these results for the CBE are discussed in section 4.1.

3.2.3. The role of biorefineries in the clusters

IEA's biorefinery definition (see chapter 3.1) includes more “traditional” biorefineries combining e.g. biofuel with food and feed production as well as more recent biorefinery concepts, e.g. lignocellulosic biorefineries producing a range of chemicals together with bioenergy and/or biofuels. While current biorefineries are mainly based on a single conversion technology, the goal is to move towards integrated biorefineries, i.e. a combination of several conversion technologies that allow for more flexibility and cost reduction (McCormick and Kautto, 2013). Cherubini et al. (2009) and Gnsansounou and Pandey (2017)

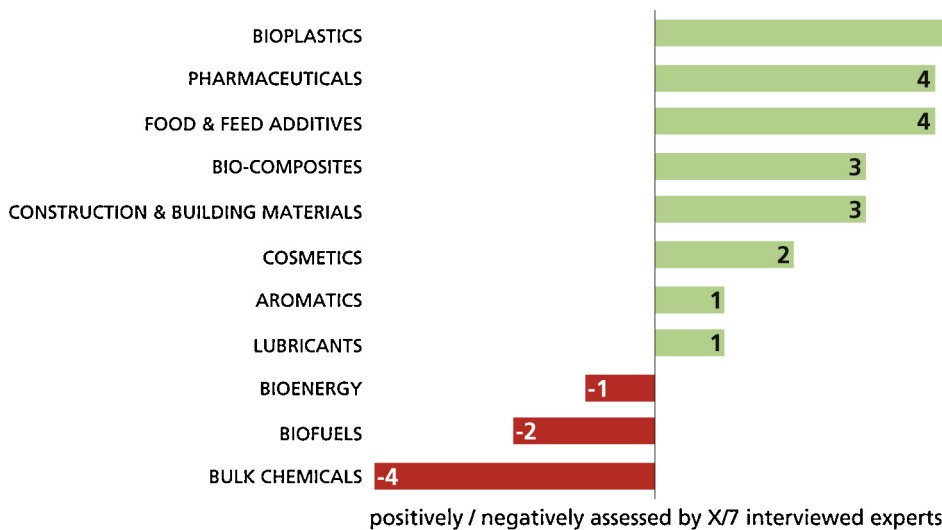


Fig. 8. Potential of sectors for the bioeconomy according to the 7 cluster experts. A minus symbolizes a negative assessment (little prospects) of the sector. 2) The aggregation level of product sectors is not coherent, due to the open answers the interviewees could provide. For example aromatics are intermediate chemicals that could end up in a variety of products like cosmetics or pharmaceuticals.

provide an overview of the wide range of biorefinery types, which can be classified according to their feedstocks (e.g. lignocellulosic, oil or starch crops), their platforms (intermediates like syngas or sugars) and their products (e.g. fuels, chemicals).

All seven clusters are working on biorefinery concepts for their region and five of them have at least one biorefinery (pilot) plant in place or under construction. Biorefineries on commercial scale only exist in three clusters and they are producing a combination of biofuels and animal feed⁸. All clusters are working towards lignocellulosic biorefineries and three of them have already pilot plants in place or under construction. Examples are listed in Appendix E.

Without going into detail on the projects, we can conclude that there are significant efforts towards biorefineries and the integrated production of bio-based energy, fuel, chemicals and materials throughout all of the considered clusters. The more advanced biorefinery projects with a high technology readiness level still evolve around bioenergy and biofuels production. However, the trend in research and development seems to go towards a more integrated co-production of a range of bio-based products with an increased importance of chemical applications such as in the pilot plants of the clusters IAR, Bioeconomy cluster and Northern Netherlands (Avantium, 2018; Ernhofer, 2012; Procethol 2G, 2010).

3.2.4. The role of circular solutions, cascading and recycling

When asked to define the term cascading, the interviewees revealed differences in their understanding of the concept. Six interviewees referred to the term as (1) favoring the highest value-added use of biomass and three also see (2) making use of the entire feedstocks including all by-products (i.e. via co-production) as part of cascading. Three of the interview partners defined cascading as (3) the sequential use of biomass. All three definitions are common interpretations of the term and all three approaches also have its role to play in the CBE. As discussed in chapter 3.1, we define cascading as the sequential use of bio-based products and refer to the other two interpretations as value optimization (1) and co-production in integrated biorefineries (2). Implementing the CBE requires a proper communication of the concept and a clarification of the term cascading across the bioeconomy sector. The same is true for other important CBE concepts as Näyhä (2019) indicated.

The interviews and the analysis of publicly available cluster strategies and business plans showed that there is so far no coherent concept or strategic focus within the clusters on cascading use, recycling

and generally on how to deal with bio-based products at the end of their life. Only Bio-based Delta articulated the goal of updating its strategy to incorporate the national policy goals regarding the CE (Biobased Delta Foundation, 2017b). Three representatives stated that they have at least one project dedicated to end-of-life options within their clusters but said that the topic is not in the focus of most projects. Two interviewees referred to rather small-scale activities of individual companies in their region in establishing closed-loop recycling schemes for their products, e.g. for bio-based carpets.

Two experts see one of the reasons for this comparably small role of the topic in their cluster in the fact that the bioeconomy is still quite nascent and that the focus is thus more on the preceding steps, i.e. developing and improving the technologies and products before thinking about potential end-of-life scenarios. Fig. 9 shows challenges and drivers seen by the interviewed experts for implementing circular solutions. Impeding policies and regulations were mentioned most, e.g. the classification of a material as waste often limits its further use. According to the interviews, two challenges for implementing recycling schemes on a bigger scale are the comparably still small share of bio-based products on the market and the difficulty of tracing bio-based materials flows throughout value chains. Furthermore, three interviewees see higher costs of circular business models, e.g. because the low oil price facilitates the use of virgin feedstocks compared to recyclables. The interviewees also refer to technological challenges and difficulties in recycling composite materials. Moreover, inconsistent waste management practices across Europe were mentioned as a hurdle as well as the lack of waste management companies accepting and adapting to bio-based products. One interviewee also feared an unstable supply of wastes and residues as a resource and a dependency on production changes of companies supplying these wastes and residues. Lastly, also a lack of funding for circular business cases was seen as a challenge by one expert.

As a driver for circular business cases three interviewees named that investors increasingly ask for end-of-life solutions. Two experts also simply see a business case for using wastes and residues as complementary feedstock to reduce costs. Three interviewees see policies and regulations as a way to foster circular business models, e.g. by taxing GHG-emissions, fostering demand via public procurement and by introducing regulations that prevent the contamination of products hampering recycling. Fostering circular product design is seen as key, e.g. by educating product designers accordingly. Furthermore, efforts towards enhancing the cooperation along the supply chain and amongst regions have been mentioned as well as better showcasing the benefits of cascading biomass use.

⁸ One of these plants closed down shortly after the interviews took place (Tighe, 2018)

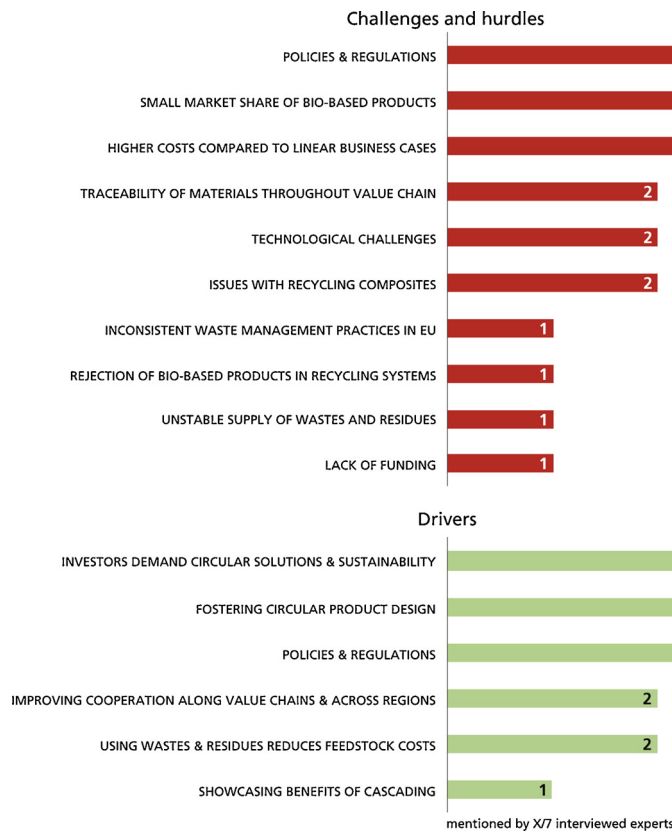


Fig. 9. Challenges, hurdles and drivers for implementing circular solutions according to the 7 interviewed experts.

4. Discussion

4.1. Implementation of CBE elements in the clusters

The interviews showed that the clusters are mostly addressing elements of the CBE related to the production phase (top of Fig. 5): They increasingly consider residues and wastes as a feedstock and work on resource-efficient biomass use in integrated biorefineries. Using residues and wastes has the potential to achieve higher GHG-emission reductions compared to primary biomass use (Creutzig et al., 2015) and could reduce feedstock costs (see Fig. 9). Residues and wastes could potentially meet a significant part of global biomass demand by 2050 but sustainability constraints should be acknowledged (see e.g. Hanssen et al., 2019 on biomass residues).

The clusters seem to address CBE elements aiming at the use and end-of-life of bio-based products (i.e. product design, recycling and cascading) only to a limited extent. Nonetheless, the interviews confirmed a stronger focus on material biomass uses within the clusters' research & innovation programs, which we described as a likely development in a CBE (chapter 3.1.3). Furthermore, the interviewees see more opportunities in products with a high economic value (Fig. 8) and thus indicate a movement up the bio-based value pyramid (Fig. 6). This movement theoretically allows for more recycling and cascading options as a higher resource quality of biomass is maintained. However, in practice, this cascading potential is difficult to realize.

According to Braungart et al. (2007), product groups can be structured in biological nutrients (i.e. biodegradable materials) or technical nutrients, i.e. materials with the potential to stay in the technical cycle via reuse and recycling. The latter requires collection, separation and recycling schemes for bio-based products that are often not in place yet, and which are probably only profitable when implemented on a large scale; but most bio-based products still have a comparably small market share (Aeschelmann and Carus, 2015; Panchaksharam et al., 2019).

Moreover, many products are difficult to collect, separate and recycle (Carus and Dammer, 2018), amongst them several named as promising in Fig. 8: i.e. cosmetics, pharmaceuticals, lubricants, additives, bio-composites. For these materials aiming for their integration into the biological cycle, i.e. by making them biodegradable, seem like more promising approaches. From the sectors in Fig. 8, only bioplastics and construction & building materials have a higher recycling and cascading potential because they are produced on larger scale and are easier recoverable compared to the other product groups. However, also for these sectors, this potential strongly depends on (1) the availability of suitable collection, separation and recycling systems and (2) on the design of the products, which should avoid the use of composites or incompatible and hazardous materials (see de Aguiar et al., 2017) and meet other waste management requirements. Despite being highlighted as a driver in the interviews, the analysis of CBE publications and cluster interviews/strategies showed that circular product design does not seem to play a significant role so far. Moreover, design for durability and a prolonged and shared product use did not appear to be a major topic in the analyzed CBE publications.

4.2. Towards a sustainable, circular bioeconomy?

Implementing the overarching CBE principles, i.e. sustainability and optimizing the value of biomass over time, in practice is a challenge, as it requires perfect foresight and cooperation across value chains. Furthermore, various potential trade-offs need to be considered, e.g. between sustainability dimensions or optimizing product design for either prolonged use or easy repair or recycling. The benefits of CBE strategies like using wastes and residues, recycling and cascading still have to be proven in practice and are probably case specific. A paper by Daioglou et al. (2014) indicated that recycling and recovery options "do not necessarily reduce energy demand or carbon emissions". Case studies on cascading pathways of bioplastics, textiles, paper and wood conducted

by Fehrenbach et al. (2017) showed environmental benefits for intelligently designed cascading pathways, even though not overwhelmingly large for some cases. Bais-Moleman et al. (2018) showed significant GHG emissions reductions for cascading wood; however, they also acknowledge short-term trade-offs with the energy sector.

By focusing on material biomass uses and aiming for high-value biomass applications, the interviewees indicated a movement up the bio-based value pyramid. While this theoretically increases the recycling and cascading potential, it might lead to a trade-off with energetic biomass use: Using biomass to displace fossil-based electricity, heat and transport fuels at a large scale might offer a higher absolute GHG mitigation potential than using biomass for material applications. For example, Daioglou et al. (2015) showed that biomass use in the electricity sector promises the highest GHG-mitigation potential when replacing coal. However, as other renewables such as solar and wind are reaching higher shares in the future energy mix (Rogelj et al., 2018), this mitigation potential will likely diminish over time. While the electricity sector could use other renewables for decarbonization, biomass is one of the few short term decarbonization options for the chemical industry, heavy road transport and marine and aviation sectors (Bazzanella and Ausfelder, 2017; Carus and Raschka, 2018; International Energy Agency (IEA), 2018; S. de Jong et al., 2018; Mawhood et al., 2016). The CBE could reduce the competition between biomass uses by using biomass resource-efficiently and cascade it over potentially multiple material applications before delegating it to an energetic use.

The EU bioeconomy strategy sees a sustainable and circular bioeconomy as a key contributor to a GHG-neutral Europe (European Commission, 2018b). The importance of GHG-emissions in the CBE discourse is also reflected in the frequent use of keywords related to climate change in the analyzed CBE publications. However, there are also various other sustainability aspects to be considered, which are not highlighted as much in the analyzed CBE literature (see 3.1.1). Amongst them are social aspects, and impacts related to feedstock production like land-use change and eutrophication. By keeping biomass in the loop, the CBE has the potential to reduce primary feedstock demand and its related emissions. However, this only holds true if the CBE does not follow the paradigm of continuous economic growth (Giampietro, 2019), offsetting its potential benefits with excessive biomass use and rebound effects (Dalia D'Amato et al., 2018). After all, both CE and bioeconomy are resource-focused concepts that do not address degrowth topics (D. D'Amato et al., 2017). Criticism of the CE and bioeconomy also largely applies to the CBE, even though the ambition is to be better, to be *"more than bioeconomy or circular economy alone"* (Dalia D'Amato et al., 2018; Hetemäki et al., 2017).

To achieve this goal, the CBE will need to address its critics claiming a lack of evidence regarding its environmental and social value (Dalia D'Amato et al., 2018; Temmes and Peck, 2019) by following a comprehensive sustainability vision and showing its benefits case by case. However, it is a complex question which biomass uses, cascading chains and end-of-life strategies are most beneficial in terms of reducing emissions. To what extent the current cluster strategies support a sustainable, circular bioeconomy can thus not be finally answered.

5. Conclusions and recommendations

The concept of a CBE has increasingly found its way into European bioeconomy strategies and reports. A CBE as defined in this paper focuses on (a) the sustainable, resource-efficient valorization of biomass in integrated production chains (e.g. biorefineries) while making use of residues and wastes and (b) on optimizing the value of biomass over time via cascading steps. This will likely reduce the direct energetic use of biomass in favor of material applications to enable a prolonged and more resource-efficient biomass use (e.g. via reuse, recycling and cascading).

The analyzed bioeconomy clusters seem to move towards a more

circular bioeconomy, by increasingly considering wastes and residues as a resource, investigating options for integrated biorefineries and putting more focus on material and high value applications of biomass. However, there is only little focus on solutions concerning product design and the end of life of bio-based products. The interviewees highlighted as key challenges for implementing circular strategies impeding policies and regulations, costs and the small size of bio-based markets.

While the CBE has the potential to improve the sustainability of the current bioeconomy, the discussion showed that the concept is not inherently sustainable and needs to address its potential drawbacks and trade-offs. Especially social aspects, cascading, product design, and aspects related to product use (durability, sharing) seem to be under-represented in CBE literature, while the topics biorefinery, wastes and residues as well as waste management are significantly covered.

Practitioners in bioeconomy clusters can support the development towards a CBE by (1) facilitating cooperation between stakeholders along and across supply chains; (2) fostering bio-based product design that facilitates durability, reuse, repair, recycling or biodegradability; (3) fostering the use of residues and wastes as resource; (4) intensifying the cooperation with the waste management sector to ensure that the bio-based products can be integrated in collection, separation, recycling and composting schemes.

However, to move towards a sustainable CBE clear guidance for practitioners in bioeconomy clusters is needed. This and other papers (see e.g. Näyhä, 2019) revealed different understandings of key CBE concepts amongst practitioners. This calls for an alignment of CBE terminology. Secondly, all the benefits and trade-offs of the CBE have to be laid out: An integrated assessment of the CBE in the context of the wider economy is needed to analyze the aggregated impacts of different biomass uses and the potential benefits of different end-of-life strategies. Such an analysis could contribute to defining pathways and overall policy goals, but it needs to be complemented by case studies developing specific recommendations for implementing these goals. For instance, research needs to show under which circumstances multiple cascading steps are actually beneficial from an environmental, social and economic point of view but also how these cascading chains can be implemented in practice. For a successful transition to a sustainable CBE many more actors need to be involved; e.g. consumers, investors, as well as architects and engineers need guidance towards the implementation of CBE principles. Moreover, current efforts in establishing a monitoring system for the bioeconomy also need to include indicators measuring circularity.

The diversity observed in the clusters' circumstances highlights the importance of designing specific regional CBE-strategies, taking the local strengths and weaknesses into account while avoiding "one fits all" solutions. Furthermore, policies and research programs should focus more on product design and end-of-life strategies for bio-based products as there are only few initiatives addressing it within the clusters. Focusing on the recycling and cascading potential of bio-based plastics and construction & building materials is recommended, as they are produced on larger scale and are easier recoverable compared to the other named sectors. For the other sectors the interviewees considered promising, i.e. cosmetics, detergents and lubricants, efforts improving their biodegradability seem more promising. Moreover, policies increasing the CO₂ price would foster the CBE by increasing the economic competitiveness of resource-efficiency measures and using wastes & residues over primary resources. For optimizing the emission mitigation potential of the CBE, clear policy incentives are needed that do not just foster the bioeconomy as a whole but focus on those biomass uses and cascading pathways that promise the highest emission mitigation potential.

Declaration of Competing Interest

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.

Acknowledgement

We would like to thank all the interview partners for their time and valuable insights. Without them this paper would not have been possible.

Appendix A. Publications on the CBE concept

This table shows the nine documents chosen for the literature review and their coverage of the CBE elements presented in chapter 3.1.1:

1 = Use of wastes and residues as resource; 2 = Resource-efficiency; 3 = biorefinery; 4 = Maintaining the value of products, materials and resources for as long as possible and/or the waste hierarchy; 5 = Cascading use of biomass; 6 = Waste management (e.g. reuse, recycling); 7 = Circular product design; 8 = Prolonged use / durability; 9 = Sharing economy; 10 = Sustainability; 11 = Social aspects.

Title	Author & year	CBE elements covered
Results of initial Scopus search (peer-reviewed)		
The Circular Bioeconomy - Concepts, Opportunities, and Limitations	(Carus and Dammer, 2018)	1, 2, 3, 4, 5, 6, 8, 9, 10
Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs	(Dalia D'Amato et al., 2018)	1, 2, 3, 4, 5, 6, 7, 9, 10, 11
Redesigning a bioenergy sector in EU in the transition to circular waste-based Bioeconomy - A multidisciplinary review	(Zabaniotou, 2018)	1, 2, 3, 4, 6, 10
Towards a sustainable forest-based bioeconomy in Italy: Findings from a SWOT analysis	(Falcone et al., 2020)	1, 2, 3, 6, 7, 8, 10
Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives	(Temmes and Peck, 2019)	1, 2, 3, 5, 6, 8, 10
Added after bibliography analysis (peer-reviewed)		
Can circular bioeconomy be fueled by waste biorefineries — A closer look	(Venkata Mohan et al., 2019)	1, 2, 3, 5, 6, 7, 8, 9, 10
Added after bibliography analysis (not peer-reviewed)		
The circular bioeconomy in Scandinavia	(Reime et al., 2016)	1, 2, 3, 6, 10
Leading the way to a European circular bioeconomy strategy	(Hetemäki et al., 2017)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Realising the circular bioeconomy	(Philp and Winickoff (2018)	1, 2, 3, 4, 5, 6, 7, 10, 11

Appendix B. Keyword allocation to topics

Similar keywords used in the CBE and BE publications were clustered and treated as synonyms. The below table is the thesaurus file used for the keyword analysis in VOSviewer.

Keyword	replace by
Resource efficiencies	resource efficiency
resource use efficiency	resource efficiency
resource-efficient	resource efficiency
Biorefineries	Biorefinery
Biorefinery Concept	Biorefinery
Biorefinery Process	Biorefinery
Biorefining	Biorefinery
integrated biorefinery	Biorefinery
lignocellulosic biorefinery	Biorefinery
Refining	Biorefinery
waste biorefinery	Biorefinery
eco design	product design
ecodesign	product design
eco-design	product design
productdesign	product design
Cascade	Cascading
Cascading use	Cascading
Anaerobic digestion	Waste Management
Compost	Waste Management
Composting	Waste Management
landfill	Waste Management
Recovery	Waste Management
Recycling	Waste Management
resource recovery	Waste Management
solid waste management	Waste Management
waste disposal	Waste Management
waste incineration	Waste Management
waste minimization	Waste Management
waste recycling	Waste Management
waste reduction	Waste Management
waste technology	Waste Management
Waste Treatment	Waste Management
Waste Water Management	Waste Management
Wastewater treatment	Waste Management
Agricultural Residues	Wastes & Residues
Agricultural waste	Wastes & Residues

Agricultural wastes	Wastes & Residues
bio waste	Wastes & Residues
biowaste	Wastes & Residues
crop residue	Wastes & Residues
Food Waste	Wastes & Residues
forest residues	Wastes & Residues
forestry residues	Wastes & Residues
industrial waste	Wastes & Residues
lignocellulosic residues	Wastes & Residues
municipal solid waste	Wastes & Residues
organic residues	Wastes & Residues
organic waste	Wastes & Residues
organic wastes	Wastes & Residues
residue	Wastes & Residues
residue valorization	Wastes & Residues
residue valorizations	Wastes & Residues
residues	Wastes & Residues
solid waste	Wastes & Residues
solid wastes	Wastes & Residues
Waste	Wastes & Residues
waste products	Wastes & Residues
waste valorization	Wastes & Residues
waste valorizations	Wastes & Residues
Waste Water	Wastes & Residues
Wastes	Wastes & Residues
alternative energy	Bioenergy & Biofuels
Biodiesel	Bioenergy & Biofuels
Biodiesel	Bioenergy & Biofuels
bioelectric energy sources	Bioenergy & Biofuels
Bioenergy	Bioenergy & Biofuels
Bio-energy	Bioenergy & Biofuels
bioenergy productions	Bioenergy & Biofuels
bioenergy technology	Bioenergy & Biofuels
Bioethanol	Bioenergy & Biofuels
bio-ethanol production	Bioenergy & Biofuels
Biofuel	Bioenergy & Biofuels
Biofuel Production	Bioenergy & Biofuels
Biofuels	Bioenergy & Biofuels
Biogas	Bioenergy & Biofuels
biogas production	Bioenergy & Biofuels
Biomass power	Bioenergy & Biofuels
electricity	Bioenergy & Biofuels
energy	Bioenergy & Biofuels
energy conversion	Bioenergy & Biofuels
energy market	Bioenergy & Biofuels
energy resource	Bioenergy & Biofuels
energy resources	Bioenergy & Biofuels
energy systems	Bioenergy & Biofuels
energy yield	Bioenergy & Biofuels
Ethanol	Bioenergy & Biofuels
fuel	Bioenergy & Biofuels
fuel economy	Bioenergy & Biofuels
Fuels	Bioenergy & Biofuels
lignocellulosic ethanol	Bioenergy & Biofuels
Renewable Energies	Bioenergy & Biofuels
Renewable Energy	Bioenergy & Biofuels
renewable energy source	Bioenergy & Biofuels
biobased chemicals	Bio-based Products
bio-based chemicals	Bio-based Products
biobased materials	Bio-based Products
bio-based materials	Bio-based Products
Biobased Products	Bio-based Products
biochemicals	Bio-based Products
biocomposites	Bio-based Products
bio-composites	Bio-based Products
biodegradable polymers	Bio-based Products
biological materials	Bio-based Products
biological product	Bio-based Products
biological products	Bio-based Products
biomaterial	Bio-based Products
biomaterials	Bio-based Products
Bioplastic	Bio-based Products
bioplastics	Bio-based Products
bio-plastics	Bio-based Products
Biopolymer	Bio-based Products
Biopolymer	Bio-based Products
Biopolymers	Bio-based Products
bioproduct	Bio-based Products
bioproducts	Bio-based Products
building materials	Bio-based Products

Chemicals	Bio-based Products
construction industry	Bio-based Products
construction materials	Bio-based Products
fibers	Bio-based Products
industrial chemicals	Bio-based Products
Lactic Acid	Bio-based Products
Lactid Acid	Bio-based Products
organic chemicals	Bio-based Products
plastic	Bio-based Products
plastics	Bio-based Products
Platform Chemicals	Bio-based Products
Polymer	Bio-based Products
polymers	Bio-based Products
reinforced plastics	Bio-based Products
solvents	Bio-based Products
succinic acid	Bio-based Products
succinic acids	Bio-based Products
value added products	Bio-based Products
value-added chemicals	Bio-based Products
wood chemicals	Bio-based Products
paper and pulp industry	Pulp & Paper
pulp and paper	Pulp & Paper
pulp and paper industry	Pulp & Paper
furniture industry	wood products
furniture production	wood products
wood-based products	wood products
wooden construction	wood products
Animal food	Food & Feed
Food	Food & Feed
Food & Processing	Food & Feed
Food industry	Food & Feed
food processing	Food & Feed
food production	Food & Feed
food products	Food & Feed
food safety	Food & Feed
Food Supply	Food & Feed
fruit	Food & Feed
fruits	Food & Feed
Vegetable	Food & Feed
Vegetables	Food & Feed
program sustainability	Sustainability
sustainability assessment	Sustainability
sustainability criteria	Sustainability
sustainability indicators	Sustainability
sustainability issues	Sustainability
sustainability transition	Sustainability
sustainability transition	Sustainability
sustainability transitiond	Sustainability
sustainability transitions	Sustainability
sustainable agriculture	Sustainability
sustainable business	Sustainability
sustainable chemistry	Sustainability
Sustainable Development	Sustainability
sustainable development goals	Sustainability
sustainable forest management	Sustainability
sustainable management	Sustainability
sustainable production	Sustainability
Carbon	Climate Change
Carbon Dioxide	Climate Change
Carbon Footprint	Climate Change
climate	Climate Change
Climate Change Mitigation	Climate Change
Climate models	Climate Change
Gas Emissions	Climate Change
Global Warming	Climate Change
Greenhouse effect	Climate Change
Greenhouse gas	Climate Change
Greenhouse gases	Climate Change
low carbon economy	Climate Change
Methane	Climate Change
biodegradation, environmental	Environmental Aspects
biodiversity	Environmental Aspects
biodiversity conservation	Environmental Aspects
Chemical Contamination	Environmental Aspects
Comparative Life cycle assessment	Environmental Aspects
conservation of natural resources	Environmental Aspects
contaminated land	Environmental Aspects
contamination	Environmental Aspects
ecological footprint	Environmental Aspects
Ecosystem	Environmental Aspects

ecosystem service	Environmental Aspects
ecosystem services	Environmental Aspects
Ecosystems	Environmental Aspects
emission control	Environmental Aspects
Environment	Environmental Aspects
Environmental Aspect	Environmental Aspects
environmental assessment	Environmental Aspects
environmental benefits	Environmental Aspects
environmental concerns	Environmental Aspects
environmental footprints	Environmental Aspects
environmental health	Environmental Aspects
Environmental Impact	Environmental Aspects
Environmental Impact Assessment	Environmental Aspects
environmental impacts	Environmental Aspects
environmental indicator	Environmental Aspects
environmental indicators	Environmental Aspects
environmental issues	Environmental Aspects
Environmental Management	Environmental Aspects
environmental monitoring	Environmental Aspects
environmental parameters	Environmental Aspects
environmental performance	Environmental Aspects
Environmental Protection	Environmental Aspects
Environmental Sustainability	Environmental Aspects
environmental-friendly	Environmental Aspects
Eutrophication	Environmental Aspects
forest ecosystem	Environmental Aspects
hazardous waste	Environmental Aspects
land use	Environmental Aspects
land use change	Environmental Aspects
LCA	Environmental Aspects
Life Cycle	Environmental Aspects
Life Cycle Analysis	Environmental Aspects
Life Cycle Assessment	Environmental Aspects
Life Cycle Assessment (LCA)	Environmental Aspects
pollution	Environmental Aspects
soil pollution	Environmental Aspects
water pollution	Environmental Aspects
Agricultural worker	Social aspects
consumption	Social aspects
consumption behaviour	Social aspects
economic and social effects	Social aspects
employment	Social aspects
environmental awareness	Social aspects
Food security	Social aspects
Housing	Social aspects
rural development	Social aspects
slca	Social aspects
Social acceptance	Social aspects
Social capital	Social aspects
social life	Social aspects
social life cycle assessment	Social aspects
social responsibilities	Social aspects
social responsibility	Social aspects
social-economic	Social aspects
society	Social aspects
socio-economic	Social aspects
socioeconomic condition	Social aspects
socioeconomic conditions	Social aspects
socio-economic impacts	Social aspects

Appendix C. Considered documents and homepages of the bioeconomy clusters

Name	Year	Source
Bio-based Delta, Netherlands		
Business plan Biobased Delta Foundation 2018-2020	2017	(Biobased Delta Foundation, 2017b)
Homepage of Biobased Delta	2018	(Biobased Delta Foundation, 2017a)
BioEconomy cluster, Germany		
Endbericht Spitzencluster BioEconomy - Zusammenfassung	2018	(BioEconomy Cluster Management GmbH, 2018b)
Homepage of BioEconomy Cluster	2018	(BioEconomy Cluster Management GmbH, 2018a)
BIO.NRW / CLIB2021, Germany		
BIO.NRW Cluster der Biotechnologie Nordrhein-Westfalen	2018	(BIO.NRW, 2018)
CLIB2021 Technologie Cluster	2018	(Cluster industrielle Biotechnologie, 2021 e.V., 2018aCluster industrielle Biotechnologie e.V, 2018aCluster industrielle Biotechnologie, 2021 e.V., 2018a)
RIN Stoffströme - Regionales Innovationsnetzwerk	2018	(Cluster industrielle Biotechnologie, 2021 e.V., 2018bCluster industrielle Biotechnologie e.V, 2018bCluster industrielle Biotechnologie, 2021 e.V., 2018b)

Bioeconomy Science Center BioVale, United Kingdom	2018	(Bioeconomy Science Center, 2018)
BioVale Strategy 2018-2022	2018	(BioVale, 2018b)
BioVale	2018	(BioVale, 2018a)
Flanders Biobased Valley, Belgium		
Good Practice: Ghent Bioeconomy Valley	2015	(VITO NV, 2015)
Flanders Biobased Valley	2018	(Flanders Biobased Valley, 2018)
IAR, France		
The Futurol project	2010	(Procethol 2G, 2010)
Recoltes des projets labellises et finances	2015	(Pôle Industries and Agro-Ressources (IAR), 2015)
An Original Business Model: The Integrated Biorefinery	2015	(Schieb et al., 2015)
Homepage of IAR	2018	(Pôle Industries and Agro-Ressources (IAR), 2018)

Appendix D. Comparison of keyword use in CBE and BE publications

Production & End-of-life	CBE		Residues & wastes	BE		Sustainability	CBE		Product focus	BE	
	efficiency	0,01		0,01	0,07		0,32	0,2		0,48	0,24
Resource- efficiency	0,01	0,01	Residues & wastes	0,25	0,07	Sustainability	0,32	0,2	Bio-based products incl. food & feed	0,48	0,24
Biorefinery	0,3	0,1	Waste management	0,3	0,07	Climate change & other environmental impacts	0,54	0,35	Bioenergy & biofuels	0,32	0,24
Product design	0,05	0,01	Cascading	0,01	0,004	Social aspects	0,05	0,08			

Indicator: Number of keyword occurrences divided by total number of CBE publications (84) and BE publications (1275) respectively.

Appendix E. Examples of biorefinery plants and concepts in the clusters

Project name	Cluster	Stage	Feedstocks*	Platform*	Products*
Organosolv	Bioeconomy cluster (Leuna)	Pilot	Lignocellulosic	Sugars, Lignin	Chemicals & building blocks, polymers & resins (plastics, binder), biomaterials
Zambezi	Northern Netherlands	Pilot	Lignocellulosic	Sugars, Lignin	Chemicals & building blocks, polymers & resins, bioethanol, electricity & heat
Bazancourt-Pomacle Biorefinery	IAR	Commercial	Sugar crops, starch crops	Sugars	Bioethanol, Chemicals & building blocks, animal feed, polymers & resins
Futurol	IAR	Demonstration	Lignocellulosic	Sugars, Lignin	Bioethanol, polymers and resins, electricity and heat
Ghent biorefinery cluster	Flanders Biobased Valley	Commercial	Oil crops, starch crops	Oils	Bioethanol, biodiesel, animal feed
Redefinery	Biobased Delta	Business plan	Lignocellulosic	Sugars, Lignin	Chemicals & building blocks, bioethanol, biomaterials, electricity and heat

*According to biorefinery classification scheme of Cherubini et al. (2009).

References

- Aeschelmann, Florence, Carus, Michael, 2015. Biobased building blocks and polymers in the world: capacities, production, and applications—status quo and trends towards 2020. *Ind. Biotechnol.* 11 (3), 154–159. <https://doi.org/10.1089/ind.2015.28999.fae>.
- de Aguiar, J.éssica, et al., 2017. A design tool to diagnose product recyclability during product design phase. *J. Clean. Prod.* 141, 219–229.
- Avantium, 2018. Avantium to Open Pilot Biorefinery; Sights Already Set on Commercial Scale-Up. Press Release.
- Bahar, Heymi, et al., 2018. Renewables 2018 - Analysis and Forecasts to 2023.
- Bais-Moleman, Anna Liza, et al., 2018. Assessing wood use efficiency and greenhouse gas emissions of wood product cascading in the European Union. *J. Clean. Prod.* 172, 3942–3954. <https://doi.org/10.1016/j.jclepro.2017.04.153>.
- Bazzanella, Alexis Michael, Ausfelder, Florian, 2017. Low Carbon Energy and Feedstock for the European Chemical Industry. Frankfurt am Main. http://dechema.de/dechema_media/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf.
- BIG-C, 2019. BIG-C - BioInnovation Growth Mega-cluster. Web Page. <https://www.bigc-initiative.eu/> (Accessed July 12, 2019).
- Bio-based Industries Consortium, 2017a. Bioeconomy Regions in Europe.
- Bio-based Industries Consortium, 2017b. Strategic Innovation and Research Agenda (SIRA).
- BIO.NRW, 2018. BIO.NRW Cluster Der Biotechnologie Nordrhein-Westfalen. Web Page. <https://www.bio.nrw.de> (Accessed February 20, 2018).
- Biobased Delta Foundation, 2017a. Biobased Delta. Web Page. <https://biobaseddelta.nl/> (Accessed February 4, 2018).
- Biobased Delta Foundation, 2017b. Business Plan Biobased Delta foundation 2018-2020. Bergen Op Zoom. https://biobaseddelta.nl/wp-content/uploads/2018/08/business_plan_biobased_delta_public_en_0.pdf.
- BioEconomy Cluster Management GmbH, 2018a. BioEconomy Cluster. Web Page. <http://en.bioeconomy.de/> (Accessed March 8, 2018).
- BioEconomy Cluster Management GmbH, 2018b. *Endbericht Spitzencluster BioEconomy - Zusammenfassung*. Leuna.
- Bioeconomy Science Center, 2018. Bioeconomy Science Center. Web Page. <https://www.biosc.de> (Accessed February 20, 2018).
- BioVale, 2018a. BioVale. Web Page. <https://www.biovale.org/> (Accessed February 13, 2018).
- BioVale, 2018b. *BioVale Strategy 2018-2022*. York.
- Braungart, Michael, McDonough, William, Bollinger, Andrew, 2007. Cradle-to-Cradle design: creating healthy emissions - a strategy for eco-effective product and system design. *J. Clean. Prod.* 15 (13–14) 1337–48.
- Bryman, Alan., 2012. *Social Research Methods*, 4th ed. Oxford University Press, Oxford.
- Carrez, Dirk, Van Leeuwen, Patrick, 2015. Bioeconomy: circular by nature. *The European Files* (38), 34–35. <http://europeanfiles.eu/wp-content/uploads/issues/2015-september-38.pdf>.
- Carus, Michael, Dammer, Lara, 2018. The Circular Bioeconomy - Concepts, Opportunities, and Limitations. *Ind. Biotechnol.* 14 (2), 83–91.
- Carus, Michael, Raschka, Achim, 2018. Renewable Carbon Is Key to a Sustainable and Future-Oriented Chemical Industry. Hürth.
- CEPIC (European Chemical Industry Council), 2018. Facts & Figures of the European Chemical Industry. Brussels.
- Cherubini, Francesco, et al., 2009. Toward a common classification approach for biorefinery systems. *Biofuels Bioprod. Biorefining* 3 (5), 534–546. <https://doi.org/10.1002/bbb.172>.
- Cluster industrielle Biotechnologie 2021 e.V., 2018a. CLIB2021 Technologie Cluster. Web Page. <https://www.clib2021.de> (Accessed February 20, 2018).
- Cluster industrielle Biotechnologie 2021 e.V., 2018b. RIN Stoffströme - Regionales Innovationsnetzwerk. Web Page. <https://www.stoffstroeme.de/> (Accessed February 24, 2018).
- Creutzig, Felix, et al., 2015. Bioenergy and climate change mitigation: an assessment. *Gcb Bioenergy* 7 (5), 916–944. <https://doi.org/10.1111/gcbb.12205>.
- Curtis, Steven Kane, Lehner, Matthias, 2019. Defining the sharing economy for

- sustainability. Sustainability (Switzerland) 11 (3).
- D'Amato, D., et al., 2017. Green, circular, bio economy: a comparative analysis of sustainability avenues. *J. Clean. Prod.* 168, 716–734.
- D'Amato, Dalia, Veijonaho, Simo, Toppinen, Anne, 2018. Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs. *For. Policy Econ.* (October). <https://doi.org/10.1016/j.forpol.2018.12.004>. 101848.
- Daigoulou, Vassilis, et al., 2014. Energy demand and emissions of the non-energy sector. *Energy Environ. Sci.* 7 (2), 482–498. <http://xlink.rsc.org/?DOI=C3EE42667J>.
- Daigoulou, Vassilis, et al., 2019. Integrated assessment of biomass supply and demand in climate change mitigation scenarios. *Global Environmental Change Journal* 54. <https://doi.org/10.1016/j.gloenvcha.2018.11.012>.
- Daigoulou, Vassilis, Wicke, Birka, Faaij, Andre P.C., van Vuuren, Detlef P., 2015. Competing uses of biomass for energy and chemicals: implications for long-term global CO₂ mitigation potential. *Gcb Bioenergy* 7 (6), 1321–1334. <https://doi.org/10.1111/gcbb.12228>.
- Davis, Chris B., Aid, Graham, Ben, Zhu., 2017. Secondary Resources in the Bio-Based Economy: A Computer Assisted Survey of Value Pathways in Academic Literature. *Waste and Biomass Valorization*.
- Dornburg, Veronika, Hermann, Barbara G., Patel, Martin K., 2008. Scenario projections for future market potentials of biobased bulk chemicals. *Environ. Sci. Technol.* 42 (7), 2261–2267. <https://doi.org/10.1021/es0709167>.
- Ekins, Paul, et al., 2017. *Resource Efficiency: Potential and Economic Implications*. Ed. International Resource Panel. UNEP.
- Ellen MacArthur Foundation, 2013. Towards the Circular Economy.
- Ernhofer, Wolfgang., 2012. Holz-Bioraffinerie-Pilotanlage Eröffnet. *PROCESS*.
- European Commission, 2012. Innovating for Sustainable Growth: A Bioeconomy for Europe. Brussels.
- European Commission, 2015. Closing the Loop - an EU Action Plan for the Circular Economy. European Commission, Brussels.
- European Commission, 2017. Horizon 2020 Work Programme 2018 – 2020: 9. Food Security, Sustainable Agriculture and Forestry, Marine and Maritime and Inland Water Research and the Bioeconomy, Brussels.
- European Commission, 2018a. A Sustainable Bioeconomy for Europe: Strengthening the Connection Between Economy, Society and the Environment. Updated Bioeconomy Strategy, Brussels.
- European Commission, 2018b. Bioeconomy: the European Way to Use Our Natural Resources Bioeconomy - Action Plan. Brussels.
- European Commission, 2018c. Knowledge Centre for Bioeconomy. Database. https://ec.europa.eu/knowledge4policy/bioeconomy_en (Accessed September 23, 2019).
- European Commission, 2018d. Renewable Energy – Recast to 2030 (RED II). (Accessed February 6, 2019). <https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii>.
- Falcone, Pasquale Marcello, Tani, Almona, Tartiu, Valentina Elena, Imbriani, Cesare, 2020. Towards a sustainable forest-based bioeconomy in Italy: findings from a SWOT analysis. *For. Policy Econ.* 110, 101910.
- Fehrenbach, Horst, et al., 2017. *Biomass Cascades - Increasing Resource Efficiency by Cascading Use of Biomass — From Theory to Practice*. Dessau-Roßlau. <http://www.umweltbundesamt.de/publikationen/biomassekaskaden-mehr-ressourceneffizienz-durch>.
- Flanders Biobased Valley, 2018. Flanders Biobased Valley. *Web Page*. <http://www.fbbv.be/en> (Accessed March 13, 2018).
- Fund, Christin, El-Chichakli, Beate, Patemann, Christian, 2018. Bioeconomy Policy (Part III): Update Report of National Strategies Around the World. Berlin.
- Giampietro, Mario, 2019. On the circular bioeconomy and decoupling: implications for sustainable growth. *Ecol. Econ.* 162, 143–156. <https://www2.scopus.com/inward/record.uri?eid=2-s2.0-85065086740&doi=10.1016%2Fj.ecolecon.2019.05.001&partnerID=40&md5=c93a61432766b15c023133a6a44d0308>.
- Gnansounou, Edgard, Pandey, Ashok, 2017. Life-Cycle Assessment of Biorefineries Classification of Biorefineries Taking Into Account Sustainability Potentials and Flexibility. Elsevier B.V.
- Gorden, Raymond., 1992. Coding interview responses. Basic Interviewing Skills. F.E. Peacock, Itasca. http://www.indiana.edu/~educy520/sec5982/week_5/qual_data_analy_ex2.pdf.
- Government of The Netherlands, 2017. Confidence in the Future - 2017–2021 Coalition Agreement. <https://www.government.nl/documents/publications/2017/10/10/coalition-agreement-confidence-in-the-future>.
- Greenpeace, et al., 2012. NGO Briefing: Sustainability Issues for Solid Biomass in Electricity, Heating and Cooling. <http://www.birdlife.org/sites/default/files/attachments/EU-Joint-NGO-briefing-biomass-sustainability-energy-March2012.pdf>.
- Haarich, Silke., 2017. *Bioeconomy Development in EU Regions*. Luxembourg.
- Hansen, Steef V., et al., 2019. Biomass Residues As Twenty-first Century Bioenergy Feedstock—A Comparison of Eight Integrated Assessment Models. *Climatic Change*.
- Hetemäki, Lauri, et al., 2017. Leading the way to a European circular bioeconomy strategy" ed. Pekka Leskinen. From Science to Policy 5. http://www.efi.int/files/attachments/publications/efi_fstp_5_2017.pdf.
- van der Hoeven, Diederik., 2015. 3BI – Brokering Bio-Based Innovation. Bio-based News (Accessed July 12, 2019). <http://news.bio-based.eu/3bi-brokering-bio-based-innovation/>.
- International Energy Agency (IEA), 2018. The Future of Petrochemicals - Towards More Sustainable Plastics and Fertilisers. <http://doi.apa.org/getdoi.cfm?doi=10.1037/0003-066X.55.1.44>.
- De Jong, E., Higson, A., Walsh, P., Wellisch, M., 2012. Bio-Based Chemicals. Value Added Products from Biorefineries.
- de Jong, Sierk, et al., 2018. Renewable jet fuel supply scenarios in the European Union in 2021–2030 in the context of proposed biofuel policy and competing biomass demand. *Gcb Bioenergy* 10 (9), 661–682. <https://doi.org/10.1111/gcbb.12525>.
- Kircher, Manfred., 2012. The Transition to a Bio-Economy: National Perspectives. *Biofuels Bioprod. Biorefining* 6 (3), 246–256.
- Lange, Lene., 2014. The Importance of Fungi and Mycology for Addressing Major Global Challenges. *IMA Fungus*.
- Márquez Luzardo, N.M., Venselaar, J., 2012. bio-based targeted chemical engineering education; Role and impact of bio-based energy and Resource development projects. *Procedia Engineering*.
- Mawhood, Rebecca, et al., 2016. Production pathways for renewable jet fuel: a review of commercialization status and future prospects. *Biofuels Bioprod. Biorefining* 10 (4), 462–484. <https://doi.org/10.1002/bbb.1644>.
- McCormick, Kes, Kautto, Niina, 2013. The bioeconomy in Europe: an overview. *Sustainability (Switzerland)* 5 (6), 2589–2608.
- Natuur & Milieu, 2018. Biomassavisie 2018 - De Rol van Biomassa in Een Duurzame Economie. Utrecht. <https://www.natuurenmilieu.nl/themas/kenniscentrum/biomassavisie-natuur-milieu/>.
- Näyhä, Annukka, 2019. Transition in the Finnish forest-based sector: company perspectives on the bioeconomy, circular economy and sustainability. *J. Clean. Prod.* 209, 1294–1306. <https://www2.scopus.com/inward/record.uri?eid=2-s2.0-85057147703&doi=10.1016%2Fj.jclepro.2018.10.260&partnerID=40&md5=dc0fd7c74de1395252a3cf28746b78bd>.
- Odegard, Ingrid, Croeze, Harry, Bergsma, Geert, 2012. *Cascading of Biomass: 13 Solutions for a Sustainable Bio-Based Economy*. Delft.
- Olsson, Olle, et al., 2018. Time to Tear down the Pyramids? A Critique of Cascading Hierarchies as a Policy Tool. *Wiley Interdiscip. Rev. Energy Environ.* 7 (2), e279. <https://doi.org/10.1002/wene.279>.
- Panchaksharam, Yamini, et al., 2019. Roadmap for the Chemical Industry in Europe Towards a Bioeconomy.
- Patel, M., et al., 2006. 5 Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals From Renewable Resources - the Potential of White Biotechnology the BREW Project. Utrecht.
- Pfau, Swinda F., Hagens, Janneke E., Dankbaar, Ben, Smits, Antoine J.M., 2014. Visions of sustainability in bioeconomy research. *Sustainability (Switzerland)* 6 (3), 1222–1249.
- Philp, J., Winickoff, D., 2018. OECD Science, Technology and Industry Policy Papers. Realising the Circular Bioeconomy, Paris. <https://doi.org/10.1787/31bb2345-en>.
- Pôle Industries, Agro-Ressources (IAR), 2015. Recoltes Des Projets Labellises et Finances. Laon.
- Pôle Industries, Agro-Ressources (IAR), 2018. Pôle Industries & Agro-Ressources (IAR). *Web Page*. <https://www.iar-pole.com/> (Accessed March 14, 2018).
- Proctel 2G, 2010. The Futuro Project.
- Reime, Marianne, Røste, Rannveig, Almasi, Alexandra, Coenen, Lars, 2016. The Circular Bioeconomy in Scandinavia. Oslo.
- Rogelj, J., et al., 2018. Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.L., Lonnoy, E., Maycock, T., Tignor, M. (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*, Ed. T. Waterfield. IPCC.
- Rose, Steven K., et al., 2014. Bioenergy in energy transformation and climate management. *Clim. Change* 123 (3–4), 477–493. <http://link.springer.com/10.1007/s10584-013-0965-3>.
- Schieb, Pierre-Alain, Lescieux-Katir, Honorine, Thénot, Maryline, Clément-Larosière, Barbara, 2015. An original business model: the integrated biorefinery. *Biorefinery 2030: Future Prospects for the Bioeconomy*. Springer, Berlin, pp. 1–123.
- Sheridan, Kathryn., 2016. Making the bioeconomy circular: the biobased industries' next goal? *Ind. Biotechnol.* 12 (6), 339–340. <https://doi.org/10.1089/ind.2016.29057.ksh>.
- Sirkin, Ted, Houten, Maarten, 1994. The cascade chain. *Resour. Conserv. Recycl.* 10 (3), 213–276. <https://linkinghub.elsevier.com/retrieve/pii/0921344994900167>.
- Su, Yu Shan, Hung, Ling Chun, 2009. Spontaneous vs. policy-driven: the origin and evolution of the biotechnology cluster. *Technol. Forecast. Soc. Change* 76 (5), 608–619. <https://doi.org/10.1016/j.techfore.2008.08.008>.
- Temmes, Armi, Peck, Philip, 2019. Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives. *For. Policy Econ.* <https://www2.scopus.com/inward/record.uri?eid=2-s2.0-85064269403&doi=10.1016%2Fj.forpol.2019.03.013&partnerID=40&md5=e03ef191194fc6f60d965f2623f48e4e>.
- Tighe, Chris., 2018. Bioethanol Plant to Close Citing 'Lack of Pace' for Change. *Financial Times*. <https://www.ft.com/content/14dfd5e-b1f0-11e8-99ca-68cf89602132>.
- van Veldhoven-van der Meer, Stientje., 2019. Uitwerking Afspraken Klimaatakkoord over Duurzame Biomassa. <https://www.rijksverheid.nl/binaries/rijksverheid/documenten/kamerstukken/2019/07/04/uitwerking-afspraken-klimaatakkoord-over-duurzame-biomassa/uitwerking-afspraken-klimaatakkoord-over-duurzame-biomassa.pdf> (Accessed 20.1.2020).
- Venkata Mohan, S., et al., 2019. Can circular bioeconomy Be fueled by waste biorefineries — a closer look. *Bioresour. Technol. Rep.* 7 (July). <https://doi.org/10.1016/j.biteb.2019.100277>. 100277.
- VITO NV, 2015. Good Practice: Ghent Bioeconomy Valley. <https://berst.vito.be/node/832>.
- WWF, 2017. EU Bioenergy Policy - Ensuring That the Provisions on Bioenergy in the Recast EU Renewable Energy Directive Deliver Genuine Climate Benefits. http://www.wwf.eu/media_centre/publications/?uNewsID=302612.
- Zabanitotou, A., 2018. Redesigning a bioenergy sector in EU in the transition to circular waste-based Bioeconomy-A multidisciplinary review. *J. Clean. Prod.* 177, 197–206.