How to advance regional circular bioeconomy systems? Identifying barriers, challenges, drivers, and opportunities

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Review Article

How to advance regional circular bioeconomy systems? Identifying barriers, challenges, drivers, and opportunities

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ABSTRACT

High rates of resource consumption and waste generation have put pressure on environmental systems and one of the solutions to this concerning behavior is a circular bioeconomy (CBE). However, for a CBE to succeed, new businesses and business models are needed, for which many drawbacks might be faced. Therefore, this article aimed (i) to identify the drivers, opportunities, challenges, and barriers for businesses in a CBE both from theoretical and practical perspectives, and (ii) to present the regional differences in those aspects for different continents. A mixed-method approach was adopted, comprising a systematic literature review and semi-structured interviews with 32 organizations from 18 countries in 4 continents (Africa, America, Australia, and Europe). Eight barriers and twenty challenges, as well as fifteen drivers and eight opportunities were identified. The main barrier and challenge pointed out by stakeholders were lack of financial resources/capital, and price competitiveness with traditional/linear product offers. The most prominent driver and opportunity were establishment of public policies/governmental support, and waste recovery. Regional aspects of CBEs (by continent) were also identified. Advancing CBEs requires setting strategies to overcome the lack of financial resources/capital, developing and/or making the adequate technology available locally, and enabling price competitiveness with traditional (linear and non-renewable-based) options. This study also unveils a series of managerial and business implications. There is the risk of rebound effects, such as waste becoming mainstream feedstock and bioproducts being introduced to the market on low-price strategies, thus triggering increased consumption. Premium pricing strategies need to be considered for bio-based products (compared with non-bio-based products). Moreover, technological development plays a role in driving innovation, and pioneers might lead the development of policies. For CBE systems to succeed there needs to be further technological development and greater connection among the actors in the value chain, converging in resilient circular business models for a CBE.

Contents

Abbreviations: BBI JU, Bio-based Industries Joint Undertaking; BE, Bioeconomy; CE, Circular Economy; B2B, Business-to-business; B2C, Business-to-consumer; CBE, Circular Bioeconomy; ECLAC, Economic Commission for Latin America and the Caribbean; EMF, Ellen MacArthur Foundation; GDP, Gross Domestic Product; GHG, Greenhouse Gas; MSW, Municipal Solid Waste; OEM, Original Equipment Manufacturer; R&D, Research and Development; SDG, Sustainable Development Goal; UN, United Nations.

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1. Introduction

The pressing conditions of planet Earth regarding resource consumption and waste generation have long been a subject of environmental debates and discussions (Boulding, 1966; Pearce and Turner, 1990), and therefore the transition from linear systems to more circular ones, through a circular economy (CE), has been urged (EMF, 2013a, 2013b). Nevertheless, systems that are more circular, on their own might not be entirely sustainable (Salvador et al., 2020). Moreover, it is observed that the transition to an economy based on renewable resources (Prendeville et al., 2018) might lessen environmental burdens (Hackelsberger et al., 2021), thus alleviating the pressing conditions of Earth's carrying capacity (Steffen et al., 2015), where the concept of a circular bioeconomy (CBE) emerges.

A bioeconomy (BE) is based on the use of biomass, and the production and conversion of renewable biological resources into bio-based products of high-value (e.g., food, feed, pharmaceuticals, biochemical products, and bioenergy) (European Commission, 2018). The BE has been part of many debates and included in strategic plans for a more sustainable development (Tursi, 2019). Biomass has the potential to and can play a major role in the production of food and feed (European Commission, 2012), biofuels for transportation (Souza and Pacca, 2021), electricity and heat (Lebaka, 2013), it can be used in buildings (e.g., bioconcrete) (Caldas et al., 2020), and it can be used with many other purposes (Salvador et al., 2022). Biomass alone could, for instance, surpass the global need for energy (Tursi, 2019), thus on top producing economic growth, biomass could also bring environmental benefits (Salvador et al., 2022).

BE and CE overlap (Carus and Dammer, 2018) in the integrated concept of CBE. Mitigating the risk of following a linear approach (businesses as usual) in case circular principles are not adopted (Hetemäki et al., 2017), a CBE seeks more efficient management of bio-based resources via the integration of CE principles into the BE (D'Amato et al., 2020). One of the main objectives of a CBE is to create high-added-value products from bioresources (Klitkou et al., 2019). Concisely, a CBE is an economy where bioresources are used to make products with the highest possible added value in a sustainable way, on a cascaded use of materials (and upcycling whenever possible), minimizing resource inputs from and outputs to the natural environment.

Incentives, investments, and efforts towards advancing the bioeconomy and CBE rank high in the political agenda of many countries (Temmes and Peck, 2020), which is seen across Europe (European Commission, 2012), Brazil (CNI, 2020), and Australia (Queensland Department of State Development, 2016), for instance. Nevertheless, the last few years have been especially difficult for all businesses, including BE businesses, due to the challenges posed by the COVID-19 pandemic, which has affected aspects in the three pillars of sustainability (Ranjbari et al., 2021).

In addition, BE businesses many times fail to the task of creating as much value as possible from the resources that are available (Temmes and Peck, 2020), thus struggling to realize the full potential of circularity. On that note, as the emergence of new and innovative business models (Donner et al., 2020) and new businesses altogether (Salvador et al., 2021a) are pivotal for a transition to a CBE, there is an inherent need to investigate what the drivers, opportunities, barriers, and challenges for businesses as well as their regional differences in a CBE are. Many reviews (see Table A.1 in Appendix A) have addressed different research questions and gaps. However, none of them provided a comprehensive set of barriers, challenges, drivers, and opportunities for BE businesses and the specific characteristics of those aspects in different continents.

Nonetheless, several studies have already addressed many challenges, and a few opportunities for businesses in a CBE, but limited to a context-driven approach. Bringing insights on success and risk factors for business models in a CBE in the agrifood sector, Donner and de Vries (2021a, 2021b) found that business model innovation depends on factors such as environmental and legal conditions as well as market trends, and are driven by internal objectives which are strongly linked to synergies with external actors seeking value co-creation. Donner et al. (2020) found that the most common opportunities for creating value from agrowaste are linked to business models based on the use of biogas plants, environmental biorefineries, agricultural cooperatives, agroparks, supporting structures, and entrepreneurship towards upcycling, with varying levels of interconnectedness among these options in different scenarios. Donner et al. (2021a, 2021b) identified that success and risk factors for valorizing agricultural waste and byproducts include technical, logistic, economic/financial, marketing, spatial, organizational, legal, environmental, social, and cultural aspects.

Moreover, Santagata et al. (2021) identified opportunities for a CBE in the context of food waste, which include reduced avoided loss of economic value, generation of jobs, and environmental pressure and better management of resources, while on the contrary, the authors pointed that bad management of food waste can harm human health. Angouria-Tsorochidou et al. (2021) focused on factors of success and challenges in decentralized biowaste management systems, which included regulatory, institutional, political factors, as well as accountability and liability, and financial viability. Duan et al. (2020), in turn, addressed technical, financial, and social awareness challenges and barriers in the context of organic solid waste biorefineries, which revolve around biomass supply and transportation, investment in equipment and facilities as well as managing product demand, and expertise of workforce and sustainability awareness, respectively. On a more general tone, Gottinger et al. (2020) addressed the barriers to the transition to a CBE, which can be summarized in barriers related to policies and regulations, technology and material, market and investment conditions, social acceptance, knowledge and networks, and sectoral routines and structures.

Nevertheless, in the existing literature, little to none is presented, even more so on a general approach, on what the drivers of a CBE or the opportunities for a better transition are, that is, what could benefit businesses and could be used as, perhaps, starting points for such a transition. Therefore, this paper aims to cover that gap and present an up-to-date set of challenges and barriers to be overcome in this transition. To that end, the goal of this article is twofold: (i) to identify the drivers, opportunities, challenges, and barriers for businesses in a CBE both from theoretical and practical perspectives, and (ii) to present the regional differences in those aspects for different continents. Therefore, the novelty of this paper lies in the identification of a comprehensive set of barriers, challenges, drivers, and opportunities for BE businesses and the specific characteristics of those aspects in different continents.

This first section presented the initial considerations on the theme, and the remainder of the paper is structured as follows. Section 2 depicts the methods used to conduct this piece of research. Section 3 presents the main results of this investigation, encompassing the barriers, challenges, drivers, and opportunities for businesses in a CBE on a general approach, as well as the regional differences (for barriers and challenges, drivers, and opportunities) across the continents of Africa, America, Europe, and Australia. Section 4 presents the general discussions and ways forward. Lastly, Section 5 draws on a few final remarks, limitations of this study, and suggestions for future research.

2. Methods

This research adopts a mixed-method approach comprising a systematic literature review (see Section 2.1 - Phase I), and a set of semi-structured interviews (see Section 2.2 - Phase II). Phase I comprised a systematic literature review, and phase II comprised semi-structured interviews with BE businesses. Both phases had the intent of identifying the drivers, opportunities, barriers, and challenges for businesses in a CBE.

2.1. Phase I – systematic literature review

A series of steps, presented in Fig. 1 and described hereafter, were followed to conduct the systematic literature review.

Step 1: Searches in databases. A search was conducted on September 6, 2021, on the ScienceDirect, Scopus, and Web of Science databases. The searches sought to cover all available literature up to that date, with no restrictions on type of document (thus, including journal articles – both research and review, and published and in press –, conference articles, books, and book chapters). The following query was used in the searches: *((“circular* econom*” OR “CE”) AND (“bioeconom*” OR “bio econom*” OR “bio-based econom*”)) OR (“circular*” AND (“bioeconom*” OR “bio econom*” OR “bio based-econom*”))*. The searches returned 1635 documents.

Step 2: Deleting duplicates and documents written in a language other than English. All duplicate documents were deleted, as well as the ones not written in English. Thus, only unique documents in English remained after Step 2. 919 documents remained after this Step.

Step 3: Reading title & keywords. All titles and keywords were read and the question that guided either keeping or excluding the documents was “do the title and keywords refer to a study that accounts for aspects of businesses within a CBE?”. 247 documents remained after this Step.

Step 4: Reading abstracts. All abstracts were read and the question that guided either keeping or excluding the documents was “does the abstract refer to a study that accounts for aspects of businesses within a CBE?”. 142 documents remained after this Step.

Step 5: Reading full texts. The full texts of the 142 documents were retrieved and read in full. When reading the full texts, the question that guided either keeping or excluding the documents was “does this research contribute to identifying drivers, opportunities, challenges and/or barriers for businesses in a CBE?”. 114 documents remained after this Step, thus determining the final portfolio to be used in the content analysis.

Step 6: Retrieval of records. The full texts of all 114 records were searched for and retrieved. No record had its full text not found.

Step 7: Identifying barriers, challenges, drivers, and opportunities. Step 7 comprised the content analysis and was conducted during the reading of the full texts of the documents in the final portfolio. During the reading, the authors used a reading form for registering the barriers, challenges, drivers, and opportunities for businesses in a CBE, and the

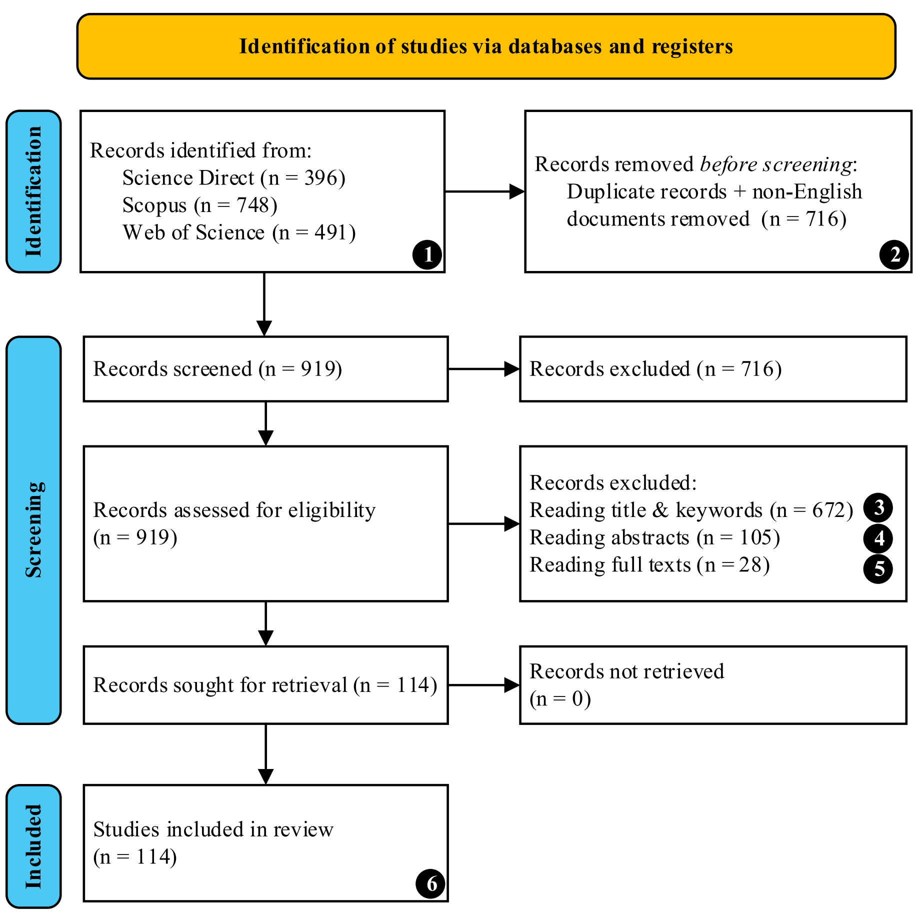

Fig. 1. Steps for systematic literature review (PRISMA method)
Source: Scheme based on Page et al. (2021).

respective literature supporting each of them. The results of this analysis are presented in Section 3.

The reading form comprised the following fields: barriers, challenges, drivers, and opportunities. During the reading, the authors annotated all information collected from each document related to each one of those aspects. After the reading, the authors went through the notes and identified the umbrella terms being dealt with, thus coding the referred aspects (barriers, challenges, drivers, and opportunities). After that, the authors conducted various rounds of pair comparisons between every two items in each aspect in order to identify duplication or overlaps. Thus, duplicated items were deleted, and overly similar ones were merged. Thereafter, those items were described, where the authors made a synthesis based on the supporting literature. These syntheses are presented in Sections 3.2, 3.3, 3.5, and 3.6.

2.2. Phase II – semi-structured interviews with bioeconomy businesses and stakeholders

To gather information on the barriers, challenges, drivers, and opportunities towards greater circularity in BE businesses from a practical perspective, a set of companies were contacted. Invitations were sent to companies and collective organizations in the continents of Africa, America (including North, Central, and South America), Asia, Europe, and Australia. From those contacted, 32 companies and collective organizations agreed to be interviewed.

The contacts were made using a range of strategies: (i) convenience sampling (contact details provided by one of the authors of this research), (ii) looking up bioeconomy-organizations in reports (such as from the Ellen MacArthur Foundation (EMF), Economic Commission for Latin America and the Caribbean (ECLAC)), (iii) accessing websites of collective organizations and groups of companies such as BioEconomy Alberta and the Bio-based Industries Joint Undertaking (BBI JU), and (iv) searching for bioeconomy-based businesses on common search engines. The 32 stakeholders were contacted and interviewed remotely from February to July 2021. The questions used in the semi-structured interviews are shown in Table 1. The demographics of the interviewees are presented in Section 3.1 and in Table B.1 (Appendix B). It should be noted that although invitations were sent to companies from Asian countries, no organization from the region responded and participated, thus no recommendations could be drawn for the continent.

For Type of organization, "Cluster" comprised groups of organizations, collective initiatives/projects, and community organizations.

For Country, the country considered for demographic purposes was the one where the CBE practices took place. A company's office might be based in one country but their practices (manufacturing, or project implementation) in another.

For Main sector/activity, interviewees were asked to which sector their company belonged. Thereafter, these descriptions were grouped by similarity into the following categories: Biochemical, Bioeconomy, Bioenergy, Chemical Products, Consulting, Digitization, Engineering, Food and Feed, Forestry, Livestock, Pharmaceutical, Recycling, Textile. The group "Bioeconomy" comprised all companies under "Cluster" as type of organization.

For Company size, the following categories were considered (according to the number of employees): micro (up to 9 employees), small (10–49), medium (50–249), large (250+). Moreover, all organizations whose type of organization was Cluster were labeled as large, since they comprised groups of organizations.

The topic-specific questions "What is your view of a Circular Economy (CE) / Circular Bioeconomy (CBE)?", "Does your organization use or enable any CE/CBE concepts? Why (main motivation for the practice(s) to be undertaken)?", and "How does CBE take place in your organization?" did not play a direct role in the analysis conducted in this research, but rather served the purpose of helping the researchers draw a picture of the activities at the organization and understand how the barriers, challenges, drivers, and opportunities would affect circular economy practices. The demographics for the practice review are presented in Section 3.1.

Phase I of this research was conducted at first in January and February 2021, and the findings from the existing literature helped build the questionnaire for the semi structured interviews. Then Phase 2 was conducted between February and July 2021. Thereafter, the literature review (conducted for Phase I) was updated in September 2021. Therefore, those two approaches complement each other, since the identification of the aspects from the existing literature aided a theory-grounded interview guide, as presented in Table 1.

The questions for the interviews were derived from the knowledge accrued from the literature review and based on the objective of the present research. Therefore, the questions were designed to (i) acquire knowledge about the activities conducted by the organizations being interviewed and how they related to a BE, (ii) identify how the barriers, challenges, drivers, and opportunities had been faced and presented in different organizations, and (iii) in case the organizations had not experienced any of those aspects, identify how they would take place in the context of the organization.

Table 1
Content of semi-structured interviews.

Identification	– Name of organization – Type of organization (Cluster, Individual Company, Research Institute) – Country – Main sector/activity (Biochemical, Bioeconomy, Bioenergy, Chemical Products, Consulting, Digitization, Engineering, Food and Feed, Forestry, Livestock, Pharmaceutical, Recycling, Textile) – Size of organization (micro, small, medium, large) – Interviewee's name and email address – Position in the company (Business Owner, Engineer, Manager, President/Director – Researcher/Analyst, Specialist/Consultant, Team Leader) – How long in the position (years)
Topic-specific questions	– What is your view of a Circular Economy (CE) / Circular Bioeconomy (CBE)? – Does your organization use or enable any CE/CBE concepts? Why (main motivation for the practice(s) to be undertaken)? – If Yes. How does CBE take place in your organization? – What are/have been (in case there are circular practices in place) barriers, challenges, drivers, and opportunities for your company to engage in more circular practices? – If No. If you were to implement CBE practices, how do you think CBE would take place in your organization? – What would be (in case there are not circular practices in place) barriers, challenges, drivers, and opportunities for your company to engage in more circular practices?

3. Results

The barriers, challenges, drivers, and opportunities presented in this section comprise, rather than a mere report of what has been found in the existing research, a synthesis of the literature consulted by the authors, coupled with a critical view of the role of each of these factors (barriers, challenges, drivers, and opportunities) for businesses to advance a CBE, and count on the practical perspectives of companies and collective organizations interviewed. Moreover, this section also presents the main results of the interviews with bioeconomy businesses, drawing on the regional differences about the motivations for adopting circular economy practices as well a more specific perspective of barriers, challenges, drivers, and opportunities, across four continents. To begin with, the next section depicts the demographics of the stakeholders that participated in the practice review.

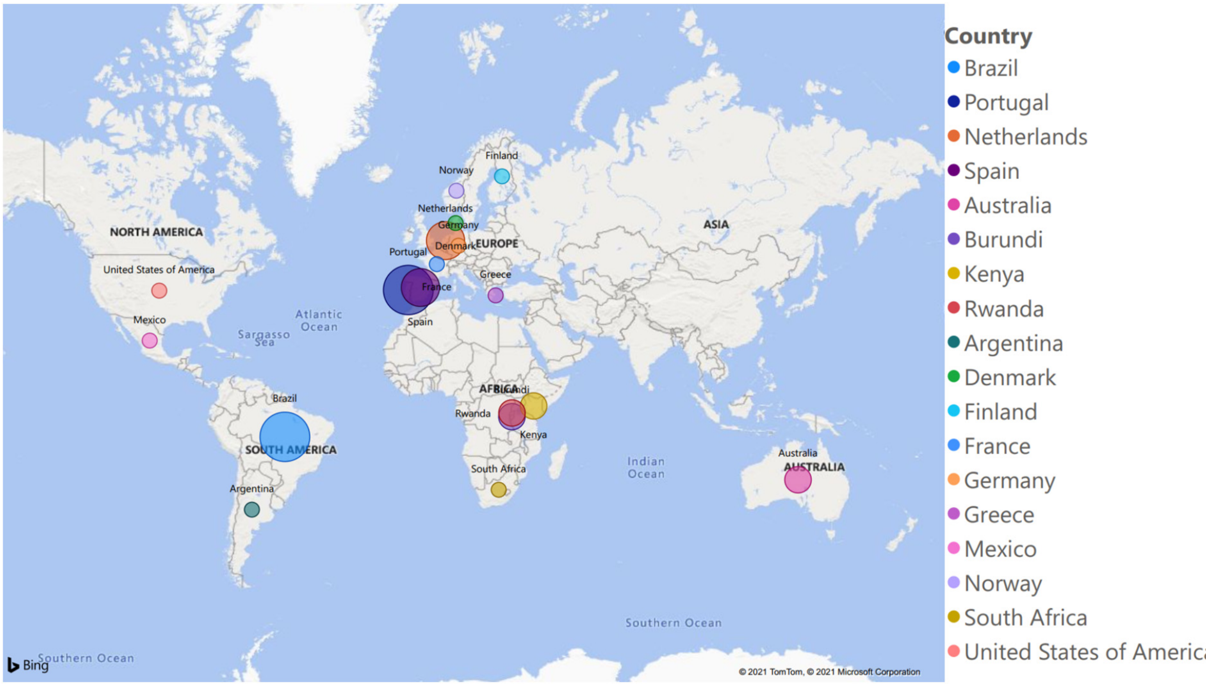

Fig. 2. Geographic location of participating organizations.

3.1. Demographics

This section depicts the demographics of the stakeholders interviewed during the practice review. Organizations from 18 countries in four continents participated in the interviews (see Fig. 2). Half of the participating organizations were from Europe (Fig. 3), with exactly 50% of the total number of countries (9 out of 18) in which the organizations' practices take place. Countries from Africa and America had the number of participating organizations (approximately 22% each) also with the same number of countries (4 each). Australia had the smallest participation (approximately 6%).

In Fig. 4 one can see the 13 sectors in which the organizations participate. Bioenergy and Food and feed are the most representative, representing 37.5% of the participating organizations. Another 34.4% comprise organizations from the sectors labeled as Biochemical, Bioeconomy, and Engineering. The remaining 28.1% of organizations are from a variety of other sectors. Fig. 4 also shows that half of the participating organizations were large (250+ employees), while 34% were small or micro, and 16% were medium.

Fig. 5, in turn, shows that the participating stakeholders within each organization occupy a variety of positions, and most participants have strategic roles within the organization. Moreover, the average years of experience in the position occupied by the participants was 5 years and 1 month (5.14 years).

Hereafter, the main results of the interviews with BE businesses are presented, drawing on the regional differences about the motivations

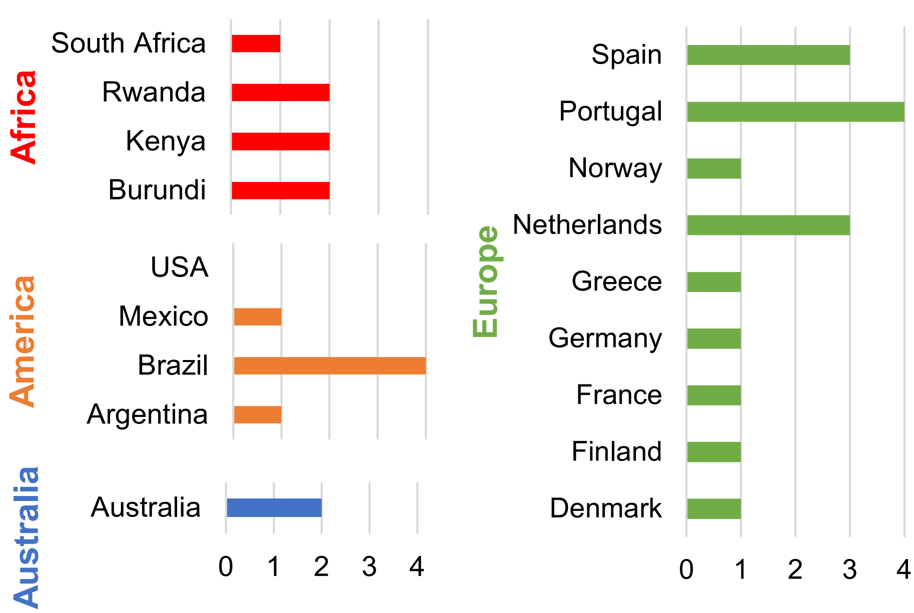

Fig. 3. Geographic distribution of participating organizations.

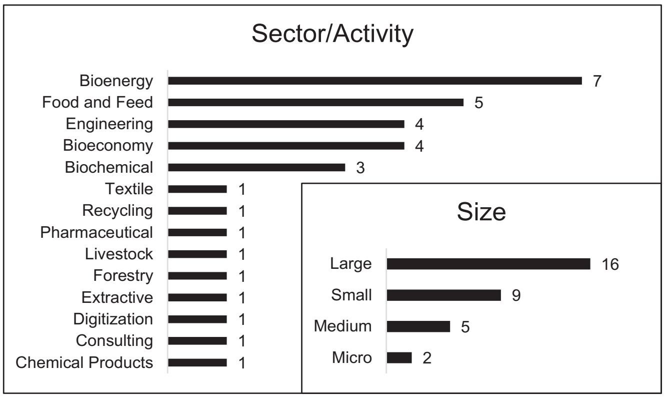

Fig. 4. Sector and size of participating organizations.

for adopting circular economy practices as well a more specific perspective of barriers, challenges, drivers, and opportunities, across four continents.

3.2. Barriers for a circular bioeconomy

For the purposes of this research, barriers are considered forces that are already in place and prevent the implementation of CBE practices (e.g., lack of technically and/or economically feasible technology to preserve a certain bioresource during long-distance travelling), making businesses having to “go around” them. The main barriers are summarized in Table 2 and detailed hereafter.

3.2.1. B-1: transportation/logistics costs and management

Transport is an issue of concern due to economic feasibility. Costs of logistics might affect the economy, and it has been widely stressed that logistical improvements by all parties, but mainly the valuation of the local economy, should be targeted.

3.2.2. B-2: limitations on infrastructure and storage capabilities

Limitations on infrastructure and storage capabilities are considered a barrier, once bioresources in general tend to perish or decompose more quickly than non-bio-based ones if not given adequate care. Improved logistics, storage, and maintenance processes would also mitigate the impacts of fluctuation in volumes of resources, and thus product outputs. Therefore, storage capabilities might need extra investments.

3.2.3. B-3: lack of knowledge on valorization pathways

Alternate handling or trading of resources and waste seems many times prevented due to lack of knowledge to develop creative and operable solutions, as well as the perception of efforts necessary for such change, including time, behavioral and cultural changes, and the costs involved.

3.2.4. B-4: lack of financial resources/capital

The lack of financial capital regards both private investors wanting to invest in such businesses, and incentives from governments. Companies that want to pursue new businesses or try to establish new valorization pathways might lack the resources needed to invest in infrastructure, new technologies (either for development or acquisition) and overheads, especially regarding implementation costs, which might be high when/if transitioning to entirely new operations.

3.2.5. B-5: overregulation or inadequate regulation

Policies to reduce waste tend to increase the costs of this raw material in the future CBE. Moreover, most countries that have policies to support bioeconomy have focused on least preferred bioenergy and biofuels, which provide the lowest value-added strategies (see Section 3.6).

3.2.6. B-6: lack of demand-pull effect

Lack of a demand-pull effect might also prevent bio-products from reaching the market.

3.2.7. B-7: cultural unfitness

A company might have a culture that will not allow, or will make it difficult, for a transition to a new or adapted business that fits the CBE.

3.2.8. B-8: seasonality of feedstock

Different types of feedstocks might be available only seasonally, which might force a company to plan having a portfolio of products that account for such fact, or (e.g.) develop and establish adequate storage facilities and processes to be able to cope with constant demand and supply.

3.2.9. B-9 (partial) lack of governmental support

There seems to be a lack of governmental support in some regions, regarding political and financial incentives or subsidies for businesses to engage in and/or maintain bioeconomy-based practices. There are regional and national differences concerning this issue, and not all valorization pathways are equally supported. In Europe, for instance, biogas production at times strongly profits from public subsidies and governmental support.

3.3. Challenges for a circular bioeconomy

For the purposes of this research, challenges are considered forces that make the implementation of CBE practices more difficult (e.g., lack of governmental support), making businesses spend more resources/effort in overcoming them. The main challenges are synthesized in Table 3 and discussed hereafter.

3.3.1. C-1: scaling-up

Many bioeconomy products still lack sufficient value generation and thus large-scale commercialization, hence being only prototypes (Reim et al., 2019).

3.3.2. C-2: maintaining a uniform product

One of the risks of valorizing bioresources lies on its supply. As it usually depends on the by-products or wastes from other processes or industries, it is difficult to ensure a continuous flow or even the same mix and quality, which calls for physical requirements and might make it difficult to maintain product uniformity.

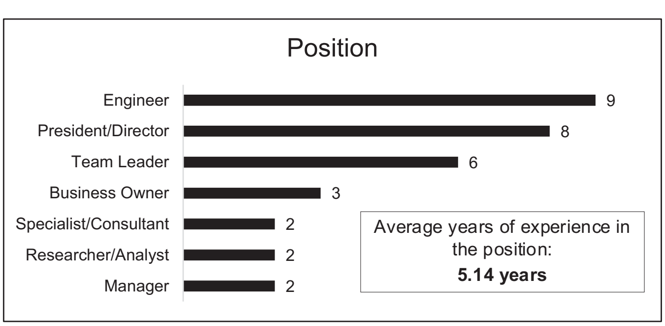

Fig. 5. Position in the organization and average years of experience.

Table 2
Barriers in a circular bioeconomy.

Type of factor	ID	Factor	Supporting literature	Number of mentions from interviews ($n = 32$)
Barrier	B-1	transportation/logistics costs and management	Awasthi et al. (2020); Banu et al. (2020a); Cheng et al. (2020); Donner et al. (2020); Donner et al. (2021a, 2021b); Duan et al. (2020); Duque-Acevedo et al. (2020b); Egelyng et al. (2018); Hagman et al. (2019); Jarre et al. (2020); Kumar and Verma (2021); Loizides et al. (2019); Pan et al. (2021); Salvador et al. (2021b); Sandvold et al. (2019); Stegmann et al. (2020); WBCSD (2019)	6
	B-2	limitations on infrastructure and storage capabilities	Banu et al. (2020a); D'Amato et al. (2020); Donner et al. (2020); Donner et al. (2021a, 2021b); Duan et al. (2020); Falcone et al. (2020); Gottinger et al. (2020); Imbert (2017); Mehta et al. (2021); Salvador et al. (2021b)	5
	B-3	lack of knowledge on valorization pathways	Banu et al. (2020b); Barcelos et al. (2021); Catone et al. (2021); Klitkou et al. (2019); D'Amato et al. (2020); Kapoor et al. (2020); Temmes and Peck (2020)	5
	B-4	lack of financial resources/capital	Angouria-Tsorochidou et al. (2021); Awasthi et al. (2019); Banu et al. (2020a, 2020b); Barcelos et al. (2021); D'Amato et al. (2020); Donner et al. (2021a, 2021b); Duan et al. (2020); Goswami et al. (2021); Gottinger et al. (2020); Gregg et al. (2020); Jesus et al. (2021); Kang et al. (2020); Kapoor et al. (2020); Kokkinos et al. (2020); Liu et al. (2021); Morone and Imbert (2020); Näyhä (2020); Puyol et al. (2017); Sarma et al. (2021); Ubando et al. (2020)	14
	B-5	overregulation or inadequate regulation	Berbel and Posadillo (2018); Donner et al. (2021a, 2021b); Duque-Acevedo et al. (2020a); Falcone et al. (2020); Gottinger et al. (2020); Imbert (2017); Kapoor et al. (2020); Kershaw et al. (2021); Ladu et al. (2020); Mak et al. (2020); Marcinek and Smol (2020); Morone and Imbert (2020); Santagata et al. (2021)	7
	B-6	lack of demand-pull effect	Imbert (2017); Stegmann et al. (2020)	5
	B-7	cultural unfitness	Klitkou et al. (2019); Mikielewicz et al. (2020); Morone and Imbert (2020); Salvador et al. (2021b)	3
	B-8	seasonality of feedstock	Donner et al. (2020); Salvador et al. (2021b)	2
	B-9	(partial) lack of governmental support	Awasthi et al. (2019); Barcelos et al. (2021); Brandão et al. (2021); Donner et al. (2021a, 2021b); Duan et al. (2020); Jarre et al. (2020); Kapoor et al. (2020); Leong et al. (2021a, 2021b); Mikielewicz et al. (2020); Mohan et al. (2018); Negi et al. (2021); WBCSD (2019)	6

3.3.3. C-3: motivating production of low-priced products

In a cascaded system, if one alternative use, even though lower in the value chain, seems attractive, it can avoid the production of an alternative product that is higher in the value chain but seems more costly. Additionally, wastes tend to be bulky, thus having a low value per ton.

3.3.4. C-4: need of investments to integrate biorefineries

Many times, considerable investments might be needed to integrate biorefineries and establish partnerships that would allow cleaner and of higher value paths.

3.3.5. C-5: finding/unveiling market demand for bio-based products

Finding or unveiling market demand for bio-based products might sometimes mean creating new market segments.

3.3.6. C-6: guaranteeing sustainability and security of biomass supply in the long term

Related to C-2, relying on by-products or wastes from other processes or industries, might pose a threat to a continuous flow and sustainable procurement of a certain resource or material. Therefore, to secure a continuous and sustainable supply of bioresources might require great involvement, engagement and proximity from biomass suppliers and/or other industries.

3.3.7. C-7: lack of public/consumer awareness

Consumer awareness (and many times behavioral change) is necessary to attract the due attention to products of a bioeconomy. It tackles the knowledge or attention customers might lack regarding products from bio-sources or recovered materials. Lack of public awareness of bio-based products and its advantages and benefits might disrupt their presence in the market.

3.3.8. C-8: economic competitiveness among recovery alternatives might affect cascading

Economic competitiveness among different alternatives for cascading might make resources soon reach an alternative from which it can no longer be recovered, thus reducing the resource life within the technical system.

3.3.9. C-9: consumer willingness to buy products of non-primary cycles

Linked to the issue of consumer awareness, consumers might avoid (for a number of reasons) products that are made from non-virgin materials.

3.3.10. C-10: company size

One the one hand, large companies are not necessarily resistant to change, but they lack the required dynamic capability; they lack knowledge, most of the time, of the end user of their products, making their strategy definition difficult. Small companies, on the other hand, consider themselves too small to uptake the complications and costs of pursuing new paths.

3.3.11. C-11: collaboration

For valorizing biomass, there is an increased need for (cross-sector, private-private and public-private) collaboration, e.g., for reaching new markets, joint investments, economies of scale, and knowledge exchange.

3.3.12. C-12: price competitiveness

Difficulty in competing in a market with cheaper products based on fossil resources - especially fuels (Solis et al., 2020).

3.3.13. C-13: quality/efficiency of final product

The quality or efficiency of products derived from bioresources might be perceived as lower than those of fossil/non-renewable resources, which can be the case of fuels. This might pose a challenge for society to switch to bio-based products altogether.

3.3.14. C-14: lack of knowledge/skills/competencies

Firms might be reluctant to go into new business areas for valorization of waste because optimized use or recovery of the resource/material is outside the company's core business. Moreover, and therefore, they might lack specific knowledge, or skills, or competency to manage related operations.

Table 3
Challenges for a circular bioeconomy.

Type of factor	ID	Factor	Supporting literature	Number of mentions from interviews ($n = 32$)
Challenge	C-1	scaling-up	Awasthi et al. (2019); Behera et al. (2021); Chandrasekhar et al. (2020); Donner et al. (2020); Donner et al. (2021a, 2021b); Gregg et al. (2020); Kumar and Verma (2021); Leong et al. (2021a, 2021b); Nagarajan et al. (2020); Santagata et al. (2021); Usmani et al. (2021)	9
	C-2	maintaining a uniform product	Awasthi et al. (2019); Donner et al. (2020); Jarre et al. (2020); Marcinek and Smol (2020); Morone and Imbert (2020)	0
	C-3	motivating production of low-priced products	Donner and de Vries (2021a, 2021b); Hagman et al. (2019)	0
	C-4	need of investments to integrate biorefineries	Barros et al. (2020); Clauser et al. (2021); Gyalai-Korpos et al. (2018); Jain et al. (2022); Marcinek and Smol (2020); Qin et al. (2021); Leong et al. (2021a, 2021b); Stegmann et al. (2020); Temmes and Peck (2020); Tsegaye et al. (2021)	2
	C-5	finding/unveiling market demand for bio-based products	D'Amato et al. (2020); Gottinger et al. (2020); Gyalai-Korpos et al. (2018); Stegmann et al. (2020)	9
	C-6	guaranteeing sustainability and security of biomass supply in the long term	Donner et al. (2021a, 2021b); Gyalai-Korpos et al. (2018); Menon and Lyng (2021); Muscat et al. (2021); Salvador et al. (2021b)	3
	C-7	lack of public/consumer awareness	Barcelos et al. (2021); Donner and de Vries (2021a, 2021b); Donner et al. (2021a, 2021b); Duan et al. (2020); Egelyng et al. (2018); Gottinger et al. (2020); Gregg et al. (2020); Jarre et al. (2020); Ladu et al. (2020); Mak et al. (2020); Marcinek and Smol (2020); Mikielewicz et al. (2020); Salvador et al. (2021b); WBCSD (2019)	11
	C-8	economic competitiveness among recovery alternatives might affect cascading	Jarre et al. (2020)	3
	C-9	consumer willingness to buy products of non-primary cycles	Donner et al. (2021a, 2021b); Jarre et al. (2020)	5
	C-10	company size	Bolwig et al. (2019); Donner et al. (2020); Näyhä (2020)	1
	C-11	collaboration	Barros et al. (2020); Brandão et al. (2021); Donner et al. (2021a, 2021b); Falcone et al. (2020); Gottinger et al. (2020); Negi et al. (2021); Sandvold et al. (2019); Temmes and Peck (2020); Santagata et al. (2021)	9
	C-12	price competitiveness	Donner et al. (2021a, 2021b); Solis et al. (2020)	14
	C-13	final product quality/efficiency	Cheng et al. (2020); Parthasarathy and Narayanan (2014)	0
	C-14	lack of knowledge/skills/competencies	Gottinger et al. (2020); Falcone et al. (2020); Hagman et al. (2019); Kapoor et al. (2020); Negi et al. (2021)	4
	C-15	product portfolio of biorefineries might vary over time	Donner et al. (2020); Hagman et al. (2019); Tsegaye et al. (2021)	1
	C-16	lack of adequate technology	Awasthi et al. (2019); Awasthi et al. (2020); Barros et al. (2020); Barcelos et al. (2021); D'Amato et al. (2020); Donner and de Vries (2021a, 2021b); Donner et al. (2021a, 2021b); Duan et al. (2020); Falcone et al. (2020); Kapoor et al. (2020); Kershaw et al. (2021); Leong et al. (2021a, 2021b); Liu et al. (2021); Marcinek and Smol (2020); Menon and Lyng (2021); Mohan et al. (2016); Mohan et al. (2018); Morone and Imbert (2020); Sandvold et al. (2019); Santagata et al. (2021); Sarma et al. (2021); WBCSD (2019)	11
	C-17	lack of standardization of inputs	Donner et al. (2021a, 2021b); Jarre et al. (2020); Maina et al. (2017); Marcinek and Smol (2020); Morone and Imbert (2020)	0
	C-18	lack of regulations and policies to promote environmentally sound product design	Gottinger et al. (2020); Jarre et al. (2020); Maina et al. (2017); Stegmann et al. (2020)	7
	C-19	lack of incentive for upcycling	Donner et al. (2020); Egelyng et al. (2018); Jarre et al. (2020); Stegmann et al. (2020); Temmes and Peck (2020)	3

3.3.15. C-15: product portfolio of biorefineries might vary over time

As it might be difficult to maintain the same mix and volume of inputs, the end products of biorefineries might vary from time to time. Therefore, for them to succeed and secure revenue, it might be necessary to maintain an array of products and perhaps large inventories of final products (when possible) to maintain steady demand and offer.

3.3.16. C-16: lack of adequate technology

This has been given a warm discussion, both regarding the existing technology that already allows taking better advantage of available bio-resources and bio-waste; however, it seems that overall technology might be immature yet, there being much more to be done in the near future and in the long term if the bioeconomy is to gain greater momentum. There is a need for adequate technologies, which are required to be economically feasible on top of being technically possible and to focus on enabling recovery rather than "separation for disposal".

3.3.17. C-17: lack of standardization of inputs

As many products in the bioeconomy originate from wastes from other processes/companies/sectors, one greater barrier for the commercialization of such products is that the inputs used might vary significantly (e.g., for every batch), making it difficult to maintain quality standards.

3.3.18. C-18: lack of regulations and policies to promote environmentally sound product design

Linked to the lack of governmental support, there appears to be little to no specific regulations or policies seeking to promote environmentally sound product design via a bioeconomy. One of the leading initiatives, though, comes from the European Commission, that has launched a joint undertaking between industry and the public sector for bio-based industries (Bio-Based Industries Consortium, 2012).

3.3.19. C-19: lack of incentive for upcycling

There is lack of specific incentives/policies promoting and sustaining the use of a resource, and economic incentives or opportunities, or support for pursuing more value-added alternatives instead of cascading down.

3.4. Barriers and challenges for regional CBE systems

As barriers and challenges sometimes overlap in a practical perspective, they are presented jointly in this section, and a discussion of the main forms in which they appear in each continent. The *italicized excerpts* are direct quotes from the interviews.

3.4.1. Barriers and challenges for regional CBE systems in Africa

One of them is the difficulty in accessing affordable technology, and the low level of readiness of technology available locally. This is also linked to the lack of governmental support or incentive through policies and the slowness in administrative procedures for the implementation of the CBE practices, which is caused by (also contributes to) the lack of a clear and coherent political framework to establish a more circular economy. High investment costs, either for initial investments or for scaling-up are often mentioned by local businesses, which is often followed by speeches that mention "*lack of sufficient funds for the implementation of our project*" and "*high investment costs*". Interviewees reported high costs of transportation, equipment, and maintaining staff, and lack of financial incentives or policies.

Pioneering can also usually a hurdle, as there might be no customers in a non-existing market. There are also difficulties for newcomers to settle in a new environment, and there is lack of awareness from the consumer/market. "*Non-existing market*" or markets with "*no customers*" have been reported to be caused by "*lack of awareness from the consumer and the market*" or even "*ignorance*", which translates into a lack of awareness or knowledge about the market and the benefits of the products commercialized in it. "*Being a pioneer* [being too early for a market that is not ready], *farmers are not ready to make a shift from* [e.g.] *soybean protein feed to black soldier flies*", has put projects on hold, even if the company in question knows that the business is viable and is succeeding elsewhere.

Collaboration (of the lack of it) can also be a backdrop. Building a sustainable (and constant) supply chain; relying on big partners and their infrastructure increases vulnerability by diminishing independence of business decisions, and skepticism or reluctance to engage in collaboration to share a technology, thus preventing to raise awareness. Cultural habits can also withhold the possibility of innovating. People might see non-traditional products and practices as unconventional, because they might lack awareness, and it makes people skeptical of the benefits of new practices. It can lead to a lack of demand-pull effect when, for instance, "*people see including insects in their diets as tabu*".

Workforce challenges are also mentioned, such as the lack of workforce willing to do manual jobs such as sorting waste. Besides that, COVID-19-related challenges and barriers have also taken place. Effects of the COVID-19 pandemic have forced companies to put operations on hold. "*COVID-19 has forced to stop production for an undetermined period of time, due to the possibility of handling contaminated waste*", when companies remained idle with no expectation of when to return to normal activities.

3.4.2. Barriers and challenges for regional CBE systems in America

Lack of awareness was constantly referred to by interviewees. It was noted a need for "*increased awareness and education on what a bioeconomy and a circular bioeconomy are, and their benefits*". There are also cultural challenges (*status quo*) which need to be overcome for shifting to new products, services, or businesses altogether. On the one hand, consumers are not completely aware of the sustainability benefits of recovering value from byproducts and might be skeptical of the use of side streams as feedstocks (they might not want to buy or have low expectations - which can lower willingness to try - over something they know was made from a byproduct). However, on the other hand, there is also stakeholder risk adversity, where "*shareholders do not want to be the first to try a new technology or are skeptical about the new practices being profitable*". This also links to collaboration (or lack thereof) issues, where it has been reported there to be a "*need to overcome the fear of collaboration and sharing information and responsibilities*".

Costs are also high up in the list of challenges and barriers in America, where "*high initial costs for implementing new technologies* [or practices]" many times prevent business innovation towards a more sustainable production and consumption. This is many times related to new regulations and the lack of capabilities and/or infrastructure. Regulations might require "*investments in new technologies and other capital investments*", which only add to the lack of general infrastructure and the existing need for capacity building (e.g., training personnel on technical skills).

Moreover, building on the challenges related to infrastructure and governmental support, it is often difficult for consumers to shift to new products or services because of the general lack of infrastructure in the region, for instance, for "*replacing diesel engines with biomethane engines*", there is a difficulty in "*finding a repair shop or fuel stations*". Still regarding governmental support and inadequate internal structure, it has been reported excessive and lagging bureaucracy, which can prevent companies from going forward with projects or delaying the development of new products.

There is also "*lack of regulation* [and policy support] *favoring products resulting from more circular and environmentally-friendly products*" or cleaner supply chains. This often prevents the establishment of new markets, signaling a need for developing such new markets and raising awareness through research, development, and innovation, and making it public. One last aspect is logistics. Logistic challenges have been repeatedly emphasized in the commercialization of bio-based products. Food products, for instance, have limited time availability for handling and consuming before expiration.

3.4.3. Barriers and challenges for regional CBE systems in Australia

The difficulties for CBE businesses in the case of Australia include the differences in regulation across the country, as in Australia "*each state has a different regulation on environmental protection*", which makes it difficult for businesses to work in different states. This also leads to a lack of policy stability, when businesses need to have "clear, well-flagged policy". On top of that, there might be "*overregulation for products and streams that do not carry a high risk*", which might take place because of the different requirements across the country.

Access to capital incentives is also a key concern. CBE businesses can be capital-intensive, and even though there have been incentives (e.g., Biofutures Program) they might not be of easy access. On top of that, it has been noted stakeholder risk adversity, where "*stakeholders do not want to be the first to try a new technology*", and businesses lose in collaboration opportunities. This is also linked to "technology and cost challenges", basically technology-cost competitiveness, as technologies that promote a more circular bioeconomy might not be commercially competitive with other practices yet, and they are usually capital-intensive (e.g., "*AD has not been commercially competitive with other disposal practices yet*").

3.4.4. Barriers and challenges for regional CBE systems in Europe

Although European countries are considered highly industrialized and developed, low level of technology-readiness is still an issue in some sectors, i.e., uncertainty of functional performance and reliability on technology ("*how long it will last*"). The high costs of developing new and making use of recently developed technology is also highlighted, especially when "*being newcomers, competing with well-established businesses*". Moreover, CBE practices are often prevented from taking place because of "*higher costs* [including infrastructure and operations] *when* *compared to* [traditional, linear] *synthetic alternatives*", and low-price competitiveness with fossil-based alternatives. Besides that, some industries are still very traditional, with a linear mindset, and there is a "*need to change the mentality of the industry*".

Lack of knowledge and awareness is reported both internally and externally. Internally, companies might lack business acumen (especially for newcomers, competing with well-established businesses), and lack of technical knowledge on ever developing technology for "*finding useful end-uses for sidestreams*", when often sidestreams are seen as not as valuable as virgin resources. Externally, lack of awareness takes place both from the consumer and the producer side (market/supply chain). From the market side, buyers (B2B and B2C) might not be willing to try out new products. From the supply chain side, there might be lack of collaboration for solving a problem (company individualism), and difficulty in finding the correct partners, getting them onboard and working together.

Finding feedstock that do not compete with food production, at a feasible price, and with the right level of availability/scale, also weighs in when strategizing CBE practices. This also leads to challenges in scaling-up, in light of the need for supplier development, where a network of "*suppliers will not exist* [at least in large scale] *until the technology* [and the product] *is well-established*". Lack of regulatory stability has been highlighted as a concerning challenge at certain times, and a barrier at other times. "*Changes in government and therefore regulatory requirements*", and regulatory impediments (e.g., when it is necessary to have a license to trade side streams, even for companies that might be part of the same group) have prevented or slowed down businesses in their pursuit of CBE-related practices. Moreover, COVID-19-related challenges also have been reported, including the need for restructuring supply chains (e.g., extraction/collection and transportation of resources) due to economic fallout.

3.5. Drivers for a circular bioeconomy

For the purposes of this research, drivers are considered forces that are known to be contributors to facilitating or accelerating the implementation of CBE practices. Drivers might already be in place or not, that is, they can already exist (e.g., policies) or not (e.g., technological advancement that would allow processing a certain resource into marketable products). The drivers are listed in Table 4.

3.5.1. D-1: alleviating resource supply risks

A CBE helps alleviate risk of resource supply by enabling a shift from non-renewable resources (e.g., fossil fuels) promoting the use of biomass which is renewable and more sustainable.

3.5.2. D-2: reduction of material leakage

The search for reducing material leakage out of the technical system is of utmost importance for a CBE. This means preventing whenever and wherever possible that waste be disposed of into the natural environment.

3.5.3. D-3: more efficient resource use

An efficient use of resources enables optimizing the extraction and use of resources, causing them to cycle for longer, and, consequently, reducing the pace of their leakage out of the system. On top of that, greater efficiency in the use of resources might also mean lower costs or higher profits for companies.

Table 4
Drivers in a circular bioeconomy.

Type of factor	ID	Factor	Supporting literature	Number of mentions from interviews ($n = 32$)
Driver	D-1	alleviating resource supply risks	Lange et al. (2021); WBCSD (2019)	5
	D-2	reduction of material leakage	Awasthi et al. (2019); Dahal et al. (2021); Zecevic et al. (2019)	6
	D-3	more efficient resource use	Awasthi et al. (2019); Barros et al. (2020); Duque-Acevedo et al. (2020b); Hagman and Feiz (2021); Sadhukhan et al. (2020); Zecevic et al. (2019)	7
	D-4	designing out waste	Awasthi et al. (2019); Barros et al. (2020); Lybæk and Kjær (2021)	6
	D-5	circular systems that support revenue streams	Santagata et al. (2021); Salvador et al. (2021b); Zecevic et al. (2019)	6
	D-6	technological advancement	Awasthi et al. (2019); Barros et al. (2020); Gregg et al. (2020); Kapoor et al. (2020); Kardung et al. (2021); Mikielewicz et al. (2020); Pan et al. (2021); Puyol et al. (2017); Salvador et al. (2021b); Sherwood (2020);	6
	D-7	competitive advantage	Banu et al. (2020b); Barros et al. (2020); WBCSD (2019)	11
	D-8	innovation	Barcelos et al. (2021); Bugge et al. (2019); Chowdhary et al. (2021); Donner et al. (2020); Falcone et al. (2020); Gregg et al. (2020); Hansen (2016); Ladu et al. (2020); Leong et al. (2021a, 2021b); Mikielewicz et al. (2020); Näyhä (2020); Reim et al. (2019); Salvador et al. (2021b); UNEP (2017)	5
	D-9	establishment of collaborations and networks	Awasthi et al. (2019); Barcelos et al. (2021); Barros et al. (2020); Bolwig et al. (2019); D'Amato et al. (2020); Donner and de Vries (2021a, 2021b); Donner et al. (2021a, 2021b); Egea et al. (2018); Kapoor et al. (2020); Johnson et al. (2021); Kardung et al. (2021); Marcinek and Smol (2020); Näyhä (2020); Näyhä and Pesonen (2014); Salvador et al. (2021b); Santagata et al. (2021); Toppinen et al. (2017); UNEP (2017)	12
	D-10	open, environment-driven culture	Angouria-Tsorochidou et al. (2021); Björkdahl and Börjesson (2011); Gottinger et al. (2020); Näyhä (2020)	4
	D-11	establishment of public policies/governmental support	Angouria-Tsorochidou et al. (2021); Barcelos et al. (2021); Brandão et al. (2021); Gregg et al. (2020); Imbert (2017); Johnson et al. (2021); Kardung et al. (2021); Kleinschmit et al. (2014); Leong et al. (2021a, 2021b); Mak et al. (2020); Tsai and Lin (2021)	18
	D-12	research and development	Behera et al. (2021); Bugge et al. (2019); Donner et al. (2021a, 2021b); Kapoor et al. (2020); Salvador et al. (2021b); UNEP (2017)	3
	D-13	waste management regulation	Angouria-Tsorochidou et al. (2021); Barros et al. (2020); Donner and de Vries (2021a, 2021b)	2
	D-14	new business models	Donner et al. (2020); Barcelos et al. (2021); Barros et al. (2020); DeBoer et al. (2020); Duque-Acevedo et al. (2020b); Egea et al. (2018); Mehta et al. (2021); Salvador et al. (2021b)	7
	D-15	products with potentially lower environmental impacts	Banu et al. (2020a); Banu et al. (2020b); Barcelos et al. (2021); Barros et al. (2020); Bos and Broeze (2020); Cheng et al. (2020); DeBoer et al. (2020); Duque-Acevedo et al. (2020b); Goswami et al. (2021); Hagman et al. (2019); Johnson et al. (2021); Kang et al. (2020); Kokkinos et al. (2020); Kumar and Verma (2021); Leong et al. (2021a, 2021b); Nagarajan et al. (2020); Paredes-Sanchez et al. (2019); Puyol et al. (2017); Rekleitis et al. (2020); Santagata et al. (2021); Stegmann et al. (2020)	11

3.5.4. D-4: designing out waste

Another driver of a CBE is designing how waste will leave the system, even before its generation. This calls for resilient systems that enable strategizing a waste hierarchy throughout multiple cycles and making waste streams that leave the technical system (into the natural environment) as harmless as possible.

3.5.5. D-5: circular systems that support revenue streams

No business will succeed if there is no stream of revenue. Therefore, it is required that CBE systems and business models support one or a set or revenue streams, proving their financial feasibility. One benefit of (e.g.) waste-based biorefineries is that "waste feedstock", at times, can help balance the initial investments, if it would be the case.

3.5.6. D-6: technological advancement

Technological advancement is another critical factor driving the transition to a CBE. Technologies that allow getting the most value from resources at the lowest cost are preferable. In addition, it should be given priority to technologies that focus on material recovery instead of removal or separation.

3.5.7. D-7: competitive advantage

Increased competitive advantage can be achieved through the offer of products with lower environmental impacts when compared to traditional products. Moreover, competitive advantages can also be achieved by taking better advantage of by-products/wastes and turning them into a new revenue stream.

3.5.8. D-8: innovation

Innovation can be technology or business-related. Some companies might be innovative in manufacturing, but not as much in product and business systems, which are crucial for the transition to a CBE.

3.5.9. D-9: establishment of collaborations and networks

Organizational innovation is necessary, which calls for different kinds of expertise, as well as the establishment of collective effort through cooperative organizations and networks, and the creation of consortia, for businesses to seize the benefits of collective efforts. Cooperative organizations (as providers of raw material, investors, or end-users) can ease the commercialization of technologies, as well as help mitigate impacts. On a tactical and operational level, it can be highlighted the advantage of having integrated biorefineries that allow producing a range of products. On a more strategic approach, one can mention the use of joint ventures for the valorization of waste, as well as co-creation and joint research and development.

3.5.10. D-10: open, environment-driven culture

Another crucial aspect is a company's culture, as it needs to allow for the necessary changes to be able to incorporate the aspects of a CBE, whereby support from top management can be decisive to innovation. It requires a culture holding both willingness and belief in change. Furthermore, the commitment to environment-driven conduct could also benefit a CBE.

3.5.11. D-11: establishment of public policies/governmental support

The transition to a bioeconomy, as an emerging sector, could benefit from public policies from both demand and supply sides. The role of the government, working out regulations, and the existence of political initiatives allow for a shift towards a CBE.

3.5.12. D-12: research and development

The work of research institutions, and of private companies on innovation through scientific discoveries and their commercialization also drive a CBE.

3.5.13. D-13: waste management regulation

As addressed in B-5 and C-18, the lack of, excess of, or inadequate regulation might be barriers or pose challenges for a CBE, but when the correct regulations (e.g., for waste management) are in place, they can act as drivers of it. One cannot be certain yet of what the most adequate regulations for a CBE are, though.

3.5.14. D-14: new business models

Willingness to invest in new business models, powered by the perception of new business opportunities, new markets, and the pressure for transitioning to a more sustainable and circular business conduct.

3.5.15. D-15: products with potentially lower environmental impacts

Mainly (but not only) from waste, bioresources bring options with some of the lowest environmental impacts. Greatly due to the use of renewable resources, it can be observed reductions of emissions of greenhouse gases (GHG) (for instance), hence mitigating the effects of global warming, which has been a severe global concern in the last few decades, along with other concerns regarding planetary boundaries.

3.6. Opportunities for a circular bioeconomy

For the purposes of this research, opportunities are considered aspects and/or situations that are already in place and can be taken advantage of to enable implementing CBE practices (e.g., locally available biomass feedstock). A series of opportunities for a CBE is listed in Table 5.

3.6.1. O-1: turning waste into bioproducts

In a CBE, there is the possibility of creating several bioproducts from waste, which would otherwise have been disposed of in a less environment-friendly way and losing its added-value.

3.6.2. O-2: bioenergy production

One of the main paths for the use of bioresources seems to have been the production of energy, mainly via the use of organic waste and consequent reduction of environmental impacts. There remain sufficient opportunities for agriculture in the bioenergy sector, in particular via the utilization of agricultural waste and by-products as well as by harvesting energy crops, thus powering the substitution of non-renewable energy sources. Moreover, also waste and by-product streams from the food and forestry industries, black liquor from the paper industry, can be used for thermal and electrical energy. The bioenergy sector seems to contribute to (i) a decrease in GHG emissions, along with the reduction of risks of environmental damages; (ii) less pressure on non-renewable resources and their energy dependence, and (iii) employment in rural areas by the bioenergy industry.

3.6.3. O-3: lower production costs when using bioresources/biowaste

Using bioresources/waste can (but not necessarily and always will) lower costs for (e.g.) the production of enzymes, bioplastics, and other products of high value. These bioproducts can be produced from by-products from other processes or systems. Moreover, the raw materials might be obtained on less costly operations since they might be produced rather than only extracted or exploited.

3.6.4. O-4: waste recovery

Biowaste, such as food waste, municipal solid waste (MSW) (or the organic fraction of it), animal manure, and other wastes of many systems, can be turned into value-added products. Those can be used to produce (e.g.) biofuels, organic fertilizers, and a range of other products. Nonetheless, the range of existing products can widen upon innovation.

3.6.5. O-5: value recovery

Rather than directly targeting bioenergy, by-products or biowaste can be converted into higher added-value products. The value of these

Table 5
Opportunities in a circular bioeconomy.

Type of factor	ID	Factor	Supporting literature	Number of mentions from interviews ($n = 32$)
Opportunity	O-1	turning waste into bioproducts	Awasthi et al. (2020); Barcelos et al. (2021); Barros et al. (2020); Coppola et al. (2021); Dahal et al. (2021); Duan et al. (2020); Kardung et al. (2021); Leong et al. (2021a, 2021b); Maina et al. (2017); Nagarajan et al. (2020); Santagata et al. (2021); Sadhukhan et al. (2020); Sharma et al. (2021); WBCSD (2019)	11
	O-2	bioenergy production	Amit et al. (2021); Awasthi et al. (2019); Awasthi et al. (2020); Banu et al. (2020b); Barcelos et al. (2021); Barros et al. (2020); Bian et al. (2020); Clauser et al. (2021); Donner and Radić (2021); Duan et al. (2020); Duarte et al. (2021); Duque-Acevedo et al. (2020b); Kang et al. (2020); Kapoor et al. (2020); Kaszycki et al. (2021); Leong et al. (2021a, 2021b); Liu et al. (2021); Lybæk and Kjær (2021); Lybæk and Kjær (2022); Madadian et al. (2021); Moreira et al. (2021); Muscat et al. (2021); Paredes-Sanchez et al. (2019); Puyol et al. (2017); Rekleitis et al. (2020); Santana et al. (2021); Sefeedpari et al. (2020); Sharma et al. (2021); Sherwood (2020); Temmes and Peck (2020); Tsai and Lin (2021); Vanhamäki et al. (2019); WBCSD (2019); Zecevic et al. (2019)	11
	O-3	lower production costs when using bioresources/biowaste	Banu et al. (2020b); Kang et al. (2020); Leong et al. (2021a, 2021b); Vea et al. (2018)	3
	O-4	waste recovery	Awasthi et al. (2020); Barros et al. (2020); Chandrasekhar et al. (2020); Coppola et al. (2021); Dahal et al. (2021); Dahiya et al. (2018); Donner and Radić (2021); Donner et al. (2020); Duque-Acevedo et al. (2020a); Gregg et al. (2020); Kapoor et al. (2020); Kwan et al. (2018); Lange et al. (2021); Loizides et al. (2019); Mpofu et al. (2021); Overturf et al. (2020); Pagliaro (2020); Rekleitis et al. (2020); Sefeedpari et al. (2020); Tsai and Lin (2021); Vanhamäki et al. (2019)	24
	O-5	value recovery	Alexandri et al. (2020); Coppola et al. (2021); Donner et al. (2020); Egelyng et al. (2018); Hagman and Feiz (2021); Lange et al. (2021); Lesage-Meessen et al. (2018); Nagarajan et al. (2020); Salvador et al. (2021b); Sherwood (2020); Stegmann et al. (2020)	23
	O-6	valorization of bioresources	Barros et al. (2020); Berbel and Posadillo (2018); Cheng et al. (2020); Coppola et al. (2021); Donner and de Vries (2021a, 2021b); Donner et al. (2020); Egelyng et al. (2018); Jarre et al. (2020); Konwar et al. (2018); Mohan et al. (2016); Mpofu et al. (2021); Nagarajan et al. (2020); Odegard et al. (2012); Overturf et al. (2020); Santagata et al. (2021); Shirsath and Henchion (2021); Trømborg et al. (2013); Ubando et al. (2020); Zecevic et al. (2019)	24
	O-7	exploring the local economy	Barcelos et al. (2021); Barros et al. (2020); De Laporte et al. (2016); Donner and de Vries (2021a, 2021b); Mengal et al. (2018); Paredes-Sanchez et al. (2019); Salvador et al. (2021b); Santagata et al. (2021); Taffuri et al. (2021); Tsai and Lin (2021)	7
	O-8	developing new markets	Campuzano and González-Martínez (2016); DeBoer et al. (2020); Gyalai-Korpos et al. (2018); Näyhä (2020); Salvador et al. (2021b); WBCSD (2019)	0

resources can be enlarged, by promoting a hierarchy of application pathways to take the best advantage of them, hence targeting the options with the highest values. For instance, wrong-shaped carrots and outer leaves of lettuce, given adequate pre-processing and logistics, can be used in pre-made food instead of ending up in animal feed.

3.6.6. O-6: valorization of bioresources

Valorization of biomass can take place through raw material co-streams and waste. Biomass use reaches its maximum value when used for pharmaceutical purposes (e.g., medicine and fine chemicals for purposes of health and lifestyle), only then food and animal feed, followed by chemicals, biofuel, compost, and lastly energy (electricity and heat), as per the biomass value pyramid of Verburg (2007). One of the options to seek valorization of bioresources is via upcycling. Nonetheless, apart from pursuing pharmaceutical uses, seeking to drive potential by-products into products of human consumption is not automatically the best economic option, since quality requirements for certain labels of pet food might be more rigid than for human food in general (Egelyng et al., 2018).

3.6.7. O-7: exploring the local economy

Bio-based industries seek to locally produce food and feed, on top of materials, chemicals, and fuels from domestic renewable resources. Exportation might not be attractive, greatly due to logistics costs and environmental impacts.

3.6.8. O-8: developing new markets

The possibility of new products might motivate the creation or development of new markets. Within that context, biorefineries can entail the production of several products, to various end markets. Nevertheless, the transition to a CBE business can be given by motivating industry players to invest in such bio-based business while still maintaining their market position with an existing production, while new markets are developed. Developing new markets and reshaping existing ones is important for a CBE, since the development and evolution of the CBE, with new technologies and business approaches, will encourage the transition to bio-based products substituting non-renewable, fossil-based ones, where the need for customer awareness and education will be brought about.

3.7. Drivers and opportunities for regional CBE systems

As drivers and opportunities also sometimes overlap in a practical perspective, they are presented jointly in this section. The *italicized excerpts* are direct quotes from the interviews.

3.7.1. Drivers and opportunities for regional CBE systems in Africa

One of the highlights for Africa is the community support. Good support from local communities and partners has enabled both environmental protection and positive social impacts. Environmental protection is practiced by many local businesses by means of "*agroecology farming*" and "*conservative agriculture*", which also contribute to promoting circular systems by recovering value from waste and (e.g.) making organic products. Positive social impact is seen in activities that aim at contributing to eradicating malnutrition by providing cheaper food alternatives, which is good for the population and good for the business: "*contributing to eradicating malnutrition (insects are a nutritious and cheap type of food). It is cheap to breed and raise insects compared to other livestock farming (such as cattle)*"; and creating jobs:

"*Jobs are created. Like our company* […]*, the number of workers is 150 per year*". Overall, these approaches contribute to a more sustainable development of the country.

Other aspects mentioned as enablers of a CBE in Africa in the future include:

- Raising awareness among the population to make them understand the good foundations of a circular economy;
- The renewal of the economy, allowing Gross Domestic Product (GDP) growth based on a balance between demand, production, and fair income.

3.7.2. Drivers and opportunities for regional CBE systems in America

Public policies, such as "*government subsidies (financial incentives and tax exemptions)*", have been mentioned to help "*promoting more circular practices (although not under this name* [thus, not necessarily using the term circular economy nor bioeconomy]*), benefits such as financial incentives and tax exemption*". Still on the benefits linked to the government, regulation has been pointed as a driver of CBE practices, especially "*regulation of products with more environmentally responsible practices*", such as by demanding reverse logistics.

Enablers of CBE practices also have been cost reductions, such as by "*reducing costs with increased circularity* [internalizing flows of resources]*, by recovering waste*". This has also led to lower environmental impacts, such as by reducing GHG emissions, compared to traditional product offers (e.g., renewable energy from waste). This combination also prompts competitive advantage, by often promoting a competitive edge because of more environment-friendly products, which can place a company ahead of competitors and future regulations. Moreover, an elevated sustainable conduct can facilitate financing options, since some financial institutions are open to discuss and support business opportunities linked to (e.g.) renewable alternatives.

Furthermore, consumer awareness is increasing, and the market has been requiring cleaner practices from manufacturers, hence supply chain partners as well as consumers also have been requiring greater transparency, which leads to an accelerated shift.

Other drivers and opportunities for a CBE in America to be explored in the future are:

- Need for increased awareness and education on what a BE and a CBE are, and their benefits, as well as the need for a more sustainable future;
- Need for collaboration (establishing multidisciplinary teams) and symbiosis;
- Need for governmental support in Latin America, by establishing public policies and governmental subsidies that incentivize the adoption of CBE practices (financial incentives, tax exemptions, etc., to reduce initial costs).
- Acknowledging the positive externalities (e.g., contribution to SDGs) derived from renewable and circular alternatives in contrast to non-renewable and circular ones (in monetary terms).

3.7.3. Drivers and opportunities for regional CBE systems in Australia

The main aspects that act as enablers of a CBE in Australia are acceleration programs, policy drivers, and circular procurement. There are "*acceleration programs to start-ups*", which provide "*access to mentors and investors*", helping businesses and ideators to reach a range of stakeholders and seek collaboration. Policy drivers comprise incentives for reducing carbon emissions and climate change impacts, as well as for producing renewable energy. Although not on a "requirement" level, circular procurement has been in place by means of asking suppliers about recovered content and prioritizing the ones with better performance.

Other aspects that were mentioned as enablers of a CBE in Australia in the future (that are not in place at the moment) include:

- Collaboration for solving a problem (e.g., tackling a particular waste);
- Information on material flows (thus tracking materials and finding management and circularity opportunities);
- Finding new markets for novel products (sometimes it might be possible to have a perfectly ready product from a reclaimed stream, but it is necessary to find a market to buy it).

3.7.4. Drivers and opportunities for regional CBE systems in Europe

Regulation favoring environmental protection and regulatory bans (e.g., for plastic bags) and incentives implemented by regulations (e.g., for biofuels) accelerate the uptake of product offers based on renewable sources. This links to public policies, financial incentives, and "*governmental support through financial incentive for R&D*", which take place through government subsidies, incentivizing Research and Development (R&D) for a CE and a BE. These have been making an important contribution to the establishment and development of CBE businesses in Europe. These incentives have been enabling a "*reduction of environmental impacts by replacing the use of fossil fuels*", and by the "*eliminating disposable waste*" (thus closing cycles) and avoiding the use of toxic chemicals.

Although still a challenge in some sectors, in others, "*increasing public awareness* [both internal and external] *and acceptance*" have been promoted by education and sensitization of consumers, which is seen by the demand for sustainable products. "*Market awareness has been increasing*" too in some sectors, which is seen when the "*market asks for sustainable products*" including an Original Equipment Manufacturer "(*OEM) demand for sustainable and circular materials*". This leads to a need for increased collaboration. Lack of collaboration can be a hurdle, but existing collaborations for R&D can be a driver for the uptake of more circular practices. Networking and serendipity, by "*meeting the right people at the right time in the right place*" can also bring opportunities.

Lower costs and competitive advantage have been mentioned as enablers of CBE practices. The use of wastes (in some sectors) as raw materials can have lower costs than virgin materials, which can lead to cost-savings, as can optimizing processes by narrowing the flows of resources, whereas access to new markets can lead to being ahead of competitors ("*first-mover advantage*") and bring a positive image to the business.

Other aspects that were mentioned as enablers of a CBE in Europe in the future (that are not in place at the moment) include:

- Standardization for environmental assessment of circular products;
- Higher taxes on fossil-based resources and lower prices and taxes on waste streams;
- Higher availability of raw materials/bioresources.

4. Discussion

This section presents the main discussions of this study, addressing the reasons why BE companies adopt CBE practices, as well as a synthesis of main aspects preventing and enabling regional CBE systems in practice.

4.1. Main reasons for adopting regional CBE practices

The reasons to adopt CBE practices reported here are drawn from the semi-structured interviews and supported by existing literature, as businesses in different regions have shown differing motivations for engaging in CBE practices. In Africa, the motivation for establishing CBE practices seems to be rooted in social concerns coupled with environmental care, where minimization of costs, such as by recovering value from waste (Mpofu et al., 2021), and optimization of resource use ranks second. A range of reasons have been provided by interviewees, which include providing increased dignity, improving people's living standards by creating jobs and increasing wealth (and thus giving people a chance to put their children in school), growing quality food at an affordable price, and improving people's health by enabling them to eat organic food. Interviewees also mentioned protecting the environment and contributing to lowering GHG emissions, by (e.g.) recycling waste, creating competitive advantage by reducing costs, increasing monetary gains, and diminishing dependence on imports as key reasons.

The reasons for adopting CBE practices in American countries are rooted in cost reductions and monetary gains, and compliance with regulatory requirements coupled with environmental concerns. A few specific reasons include reducing costs and optimizing the use of resources, especially to avoid wastes (Tsegaye et al., 2021), compliance with environmental regulation, and concerns towards increased sustainability, such as less carbon-intensive production (Clauser et al., 2021) and overall reduced environmental impacts (Santana et al., 2021). These have also been the motivation for research on CBE in countries other than the ones participating in the interview, such as Canada (Dahal et al., 2021; Madadian et al., 2021), stressing the focus of CBE interest across the region.

In Australia, the motivation for CBE systems is based on greater sustainability, avoiding the waste of resources, mitigating climate change impacts, enabling access to bioenergy, and saving on costs.

In European countries, the main reasons for adopting CBE practices have been reported to be primarily related to environmental care (mainly driven by the reduction of environmental impacts by replacing the use of fossil resources), which has also been reported elsewhere, across different countries, such as Sweden (Hagman and Feiz, 2021) and Ireland (Shirsath and Henchion, 2021). That is followed by saving on costs and optimizing the use of resources, which can be achieved by, for instance cascading the use of resources (Lybæk and Kjær, 2022). Gaining competitive advantage (having a competitive edge), such as by setting into practice innovative business models (Donner and de Vries, 2021a, 2021b), and complying with regulation (e.g., extended producer responsibility), also have been signaled as further reasons.

4.2. Synthesis of main aspects preventing and enabling regional CBE systems in practice

The greater number of participating organizations based in Europe shows the belief on both a bioeconomy and a circular economy. That is likely greatly influenced by the role played by the European Union, in incentivizing and subsidizing BE and CE initiatives. On the other side of the spectrum, there is a perceived difficulty of American companies to dialogue and discuss their practices openly. It is still unknown the reasons why companies, especially in America but also in other continents, are not as willing to partake in CBE initiatives or share their knowledge and perception on the positive and negative aspects encountered in their paths, which could contribute to designing auto sufficient and resilient business models for a CBE. Overall, there is a need for greater awareness about what a bioeconomy, a CE, and a CBE are among organizations in America.

Based on the results achieved, from a practice-based perspective, the barriers and challenges most frequently addressed by the stakeholders interviewed should be prioritized when formulating public policies and also when designing and adapting business models, for they represent the most common hardships for CBE systems to emerge and develop. The same can be said of drivers and opportunities, as they represent the factors that more commonly boost CBE systems.

Overall, the key barrier (see Table 2) as pointed out by stakeholders was lack of financial resources/capital (B-4) ($n = 14$), which was mentioned many times jointly with low technology-readiness level. On the contrary, the least concerning barrier was the seasonality of feedstock (B-8) ($n = 2$). Regarding challenges, the main challenge (see Table 3) has been price competitiveness (C-12) ($n = 14$), which once again was mentioned many times together with lack of adequate technology, which needs to be both technically and economically feasible. The least concerning challenges were maintaining a uniform product (C-2) ($n = 0$), motivating production of low-priced products (C-3) ($n = 0$), final product quality/efficiency (C-13) ($n = 0$), and lack of standardization of inputs (C-19) ($n = 0$).

When it comes to drivers, the main aspect perceived as a driver (see Table 4) by the participating stakeholders was establishment of public policies/governmental support (D-11) ($n = 18$), which many times help to overcome barriers and lessen the burdens of challenges. The least contributing driver was waste management regulation (D-13) ($n = 2$). The most prominent opportunities (see Table 5) were waste recovery (O-4) ($n = 24$) and valorization of bioresources (O-6) ($n = 24$), which go alongside value recovery (O-5) ($n = 23$). On the contrary, developing new markets (O-8) ($n = 0$) was not seen as an opportunity for developing businesses in a CBE.

Therefore, advancing CBE systems would require, primarily, setting strategies to overcome the lack of financial resources/capital, by means of (for instance) financing options and incentives offered by either public or private organizations with the intent of offsetting the initial hardships of new business practices. Another highlight would be the need to develop and/or make locally available, adequate technology, meaning that the technology needs to be economically accessible and the necessary chain of supply to maintain such technology in operation in the long term needs to be developed jointly. Moreover, price competitiveness with traditional (linear and non-renewable-based options) needs enabling. To make it happen, along with developing the adequate technology, it is recommended that the incentives long given to fossil-based products be switched to renewable-based ones, and that taxes on non-renewable alternatives be raised and benefits be ceased. Moreover, establishing public policies and strategies for governmental support that enable value recovery (especially from waste) and valorization of bioresources can more easily foment CBE systems.

On the more specific aspect of this research, identifying regional aspects of CBEs enables tailoring initiatives to accelerate the adoption of circular practices and the transition to an economy that is more circular and based on renewable resources. Therefore, it can help in building and advancing regional CBE systems. Furthermore, there might be trade-offs both among barriers and challenges as well as among drivers and opportunities. Some of the factors presented and discussed here can have more than one effect on businesses, that is, some barriers can be both barriers and challenges at the same time. A few barriers can, on top of preventing businesses from starting circular practices, also withhold and/or slow down the development of the business, thus becoming challenges for BE businesses (and this logic applies to challenges too). Similarly, some drivers can be both drivers and opportunities at the same time (and this logic applies to opportunities too).

4.3. Managerial and policy implications

It has been reported elsewhere in the literature (Salvador et al., 2021b) that rebound effects in the CBE have not been given a great deal of attention. Nonetheless, it needs to be highlighted that the establishment of BMCBEs can be followed by rebound effects. Those same authors mention two possible rebound effects in the CBE scenario: wastes being turned into commodities (thus becoming mainstream feedstock), and bioproducts being introduced to the market on low-price strategies, thus triggering increased consumption. Other rebound effects might be possible depending on the specific characteristics of the CBE system and the business model in place.

Linking to the issue of rebound effects, the pricing of circular products would also be important to be investigated. As the CBE is developing and its benefits are being unveiled, the relevance of premium pricing for CBE products increases too. Existing research has found that consumers were willing to pay less for second-hand products than they were for a first-hand one; however, they were willing to pay more for a bio-based product compared to a traditional one (Colasante and D'Adamo, 2021). It is also argued that certification can play a major role in premium pricing (Morone et al., 2021), since certified products go through a verification process and are accredited by relevant stakeholders.

Regarding technological development, there are many technologies available that can be used in the context of a CBE, such as for making value-added use of waste (upcycling it) (Usmani et al., 2020). However, on top of that, technology needs to be accessible, in a way that it is available locally and within economic reach. That also regards building a supply chain that supports the business in the use of that technology, such as by allowing access to parts and maintenance for equipment. Nonetheless, new technological developments also need to have their environmental performance assessed (Tsalidis and Korevaar, 2022), for they must be optimized with respect to energy and material efficiency (Ranjbari et al., 2022) if they are to contribute to a more circular BE.

That also relates to the different roles of companies from the different economic sectors in a CBE. The primary sector is the main responsible for providing the virgin feedstock for the many ramifications of the supply chain in a CBE and has a more traditional role (Salvador et al., 2022). Organizations in subsequent steps in the value chain are often stewards of more innovative initiatives, such as in manufacturing (Pérez et al., 2019), provision of service/experience (Burneo et al., 2020), for value recovery/waste-related activities (Jimenez-Lopez et al., 2020), and bioenergy (Marangon et al., 2021). Thus, the organizations in these different environments (primary sector and organizations in downstream activities) can also face the reported aspects (barriers, challenges, drivers, and opportunities) in different ways.

In the context of a CBE, it has been identified that pilot projects and early-stage demonstrations can contribute to the diffusion of knowledge (Hedeler et al., 2020) and technology (Lettner et al., 2020). Furthermore, innovators lead the development of and might influence the terms upon which policies are built (Karp et al., 2021). Nonetheless, that holds true not only with regards to policies but also market requirements and competitive advantage (Koytsoumpa et al., 2021), be it in traditional ways, for material-based products and systems, or in digital platform industries (Watanabe et al., 2019).

Moreover, a number of policy implications can be drawn from the results of this research. Especially governments but also other stakeholders can use the findings about the barriers and challenges for the advancement of a CBE in the different regions to establish incentive policies to accelerate the transition to a CBE. These incentive policies can take the form of monetary incentives, such as tax exemption or funds for financing CBE initiatives. Policies can help build complete supply or value chains for businesses in a CBE to succeed, i.e., create specific incentives for businesses to build long-lasting partnerships in order to ensure that their business initiative will not be cut short for lack of suppliers or wholesalers/retailers that sell the products they offer.

4.4. Limitations of this study

This study neither claims to be exhaustive nor exempt from limitations. The results of the literature review were based on the searches conducted using the specific terms and databases described in the methods section, and the results of the semi-structured interviews were based on a convenience-based selection of stakeholders. For the practice review, the sampling was done by convenience and no companies whose activities were located in Asia responded to our invitation to participate in the semi-structured interviews. Therefore, no results could be drawn for Asian countries.

Moreover, the companies that participated in the practice review were found using the strategies described in Section 2.2. The organizations who were contacted had participated in BE-based projects, had made their information available on websites and reports linked to BE, or were known by the researchers who are authors of this manuscript. Organizations outside of this reach were not contacted. Therefore, should the organizations contacted differ, the results with regard to the specific barriers, challenges, drivers, and opportunities for the various regions might have been different too.

In addition, the barriers, challenges, drivers, and opportunities for businesses in a CBE were presented on a general approach. Each of those aspects might take place (or not) differently depending on the context, and their definition and perceived need might also vary depending on the stakeholder (e.g., business, consumer, or government) and region. The regional assessments help draw more specific characteristics of CBE across different continents, but they are also based on the overall report of all companies that accepted to participate in the interviews, thus one specific aspect (barrier, challenge, driver, or opportunity) might not be applicable to any one specific organization surveyed.

Furthermore, even though regional conclusions could be drawn for the four different regions, the aspects for the CBE at a local level can vary. It is unlikely that any two geographical areas will account for a CBE system with the exact same characteristics, even within the same region. Therefore, even though the aspects drawn here are representative of the region it describes, one specific organization might not have experienced one singled-out aspect (barrier, challenge, driver, or opportunity) identified in this research. The same is true for the different countries. The occurrence of those aspects can vary across the different countries in the same continent.

5. Conclusions and future outlook

This paper has provided a synthesis of the existing barriers, challenges, drivers, and opportunities for businesses in a CBE both from a theoretical and a practical perspective. The barriers and challenges reported here relate primarily to the lack of financial resources for transitioning to more circular practices, and difficulties related to logistics, lack of adequate technology, lack of awareness, and inadequate policies/regulations. The drivers and opportunities are primarily related to subsidies and financial incentives (either private or from governments), the advancement of or access to technology, and the chance to optimize operations while increasing value for the business. Moreover, on the one hand, there seems to be more academic interest in circular practices from food and feed, new products derived from wood, and bioenergy systems, whereas on the other hand, on a practice-based perspective it seems that CBE practices raise greater interest among organizations in the bioenergy, and food and feed sectors.

The main suggestion for further research left here is to investigate the barriers, challenges, drivers, and opportunities for businesses in a CBE in Asian countries. Furthermore, those aspects could also be further investigated to show specific difficulties and enablers for a CBE in different sectors in the same region. Moreover, the investigation of synergies among the aspects that were presented in this research are left as suggestions for future research as well. There might be barriers and/or challenges that will take place concomitantly. The same is true for drivers and opportunities. Moreover, there might be drivers and/or opportunities that when coming into place at the same time might offset a challenge or a barrier. In addition, there might be barriers and/or challenges that might prevent businesses from seizing certain opportunities or taking advantage of drivers.

Drawing on the existing synergies that there are among the aspects, the very drivers and opportunities can be used to overcome many of the barriers and challenges encountered when transitioning to a CBE. Those potential synergies are left to be investigated in future research endeavors, as are the reasons that explain the existing differences for barriers, challenges, drivers, and opportunities for CBE systems across continents. Also building on the results of this research, business models for a CBE could be proposed taking into consideration specific characteristics of a CBE and the challenges and barriers faced by existing businesses, along with possibilities for taking advantage of drivers and pursuing opportunities. Furthermore, by studying various existing business strategies and models that overcame barriers, management recommendations can be developed.

Moreover, other topics that we identified to be worth of further investigation include:

- Development and application of quantitative methods to account for circularity assessment;

- Investigating what technological advancements would enable an accelerated transition to a CBE;
- Investigating what the specific hardships for transitioning to a CBE are for micro, small, and medium-sized enterprises;
- Investigating specific solutions and practical examples on how particular barriers and challenges can be overcome, and how specific drivers and opportunities can be identified for companies of different sizes and in different sectors;
- Investigating the effects of circular premium, i.e., whether consumers would be willing to pay more for a product coming from a chain of circular processes, and to what extent that would hold true.

In summary, as a major take-away of this research, for CBE systems to succeed there needs to be further technological development (in terms of local availability and economic feasibility) and greater connection among the actors in the value chain, converging in resilient circular business models for a CBE.

Declaration of competing interest

The authors declare that they have no known conflict of interest.

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Appendix A. Literature reviews from the final portfolio

Table A.1
Literature Reviews from the Final Portfolio.

Source	Title	Context of Research Gap	Research Aim	Focus/Caveat
Brandão et al. (2021)	Circular bioeconomy strategies: From scientific research to commercially viable products	Knowledge of technologies that use biowaste as a resource for diverse industrial sectors	Providing an overview of the current scientific, technological and commercial trends on valorization of agri-food and forest wastes	Agri-food and forest wastes
Shirsath and Henchion (2021)	Bovine and ovine meat co-products valorisation opportunities: A systematic literature review	There are significant non-food/non-edible valorisation opportunities available	Providing an overview of all relevant feedstocks and all existing and potential food and non-food valorisation opportunities originating from offal and meat co-products	Offal and meat co-products
Menon and Lyng (2021)	Circular bioeconomy solutions: driving anaerobic digestion of waste streams towards production of high value medium chain fatty acids	The value of anaerobic digestion is well accepted, however using it merely for methane production has its own drawbacks and questions have been raised on biogas being the main driver for this process	Analyzing the state-of-the-art of the production of medium chain fatty acids (MCFAs) from organic wastes by adapting the conventionally methanogenic process of anaerobic digestion (AD) for the production of volatile acids and the subsequent chain elongation, as well as for the production of hydrogen, and discussing the modifications involved, the bottlenecks, challenges and opportunities	Methods of inhibition of methanogenesis
Catone et al. (2021)	Bio-products from algae-based biorefinery on wastewater: A review	Critical factors for large-scale development and deployment of microalgae that can achieve targeted levels of algal biomass productivity and composition and conversion efficiencies	Discussing the potential bio-products that may be gained from microalgae grown on urban wastewater	Microalgae grown on urban wastewater
Clauser et al. (2021)	Biomass Waste as Sustainable Raw Material for Energy and Fuels	Challenges in technology and economics to achieve acceptable yields and product costs to compete with fossil product	Describing the emerging biorefinery strategies to produce fuels (bio-ethanol and γ-valerolactone) and energy (pellets and steam), compared with the currently established biorefineries designed for fuels, pellets, and steam	Biofuels and energy production and environmental factors
Jain et al. (2022)	Bioenergy and bio-products from bio-waste and its associated modern circular economy: Current research trends, challenges, and future outlooks	Valorization of biowaste into other value-added products such as biofuel is essential	Examining how microbial profiles have transformed treasured bioenergy and bioproducts aspirations into mechanical bioproducts marvels discovered through cutting-edge microbial analyses of biowaste	Chemicals derived from biowaste
Mpofu et al. (2021)	Anaerobic treatment of tannery wastewater in the context of a circular bioeconomy for developing countries	The current economy of tanneries in developing countries is mainly linear	Exploring the anaerobic digestion of tannery wastewater for the advancement of a bio-based circular economy	Anaerobic treatment of tannery wastewater
Pan et al. (2021)	Anaerobic co-digestion of agricultural wastes towards circular bioeconomy	The effect of feedstock and operating conditions on biogas production from an anaerobic co-digestion process has not been critically evaluated	investigate the effects of factors related to feedstock (organic wastes), including particle size, C/N ratio, and pretreatment options, on the anaerobic co-digestion performance	Anaerobic co-digestion of agricultural wastes
Mehta et al. (2021)	Advances in Circular Bioeconomy Technologies: From Agricultural Wastewater to Value-Added Resources	The valuable resources in agricultural wastewater should be recycled and reused for environmental sustainability	Describing and evaluating the performances of different circular technologies for converting agricultural wastewater into value-added resources	Agricultural wastewater
Khoshnevisan et al. (2021)	A critical review on livestock manure biorefinery technologies: Sustainability, challenges, and future perspectives	Apart from technologies for recovering energy, there are other manure treatment alternatives such as composting and vermicomposting, which are widely used	Reviewing the most frequently employed technologies for livestock manure management from different points of view (i.e., energy recovery, nonenergy route and	livestock manure management

Table A.1 (*continued*)

Source	Title	Context of Research Gap	Research Aim	Focus/Caveat
		mostly in developing countries due to their simplicity and low capital cost	nutrient recovery)	
Lange et al. (2021)	Developing a Sustainable and Circular Bio-Based Economy in EU: By Partnering Across Sectors, Upscaling and Using New Knowledge Faster, and For the Benefit of Climate, Environment & Biodiversity, and People & Business	Defining the new bioeconomy vision	Giving a brief introduction to the history and development of the modern bioeconomy in Europe	Circular Bio-Based Economy in EU
Leong et al. (2021a, 2021b)	Waste biorefinery towards a sustainable circular bioeconomy: a solution to global issues	The production of bioenergy and biomaterials can sustain the energy–environment nexus as well as substitute the devoid of petroleum as the production feedstock, thereby contributing to a cleaner and low carbon environment	Highlighting the waste biorefinery as a sustainable bio-based circular economy, and, therefore, promoting a greener environment	Waste biorefineries
Sarma et al. (2021)	Valorization of microalgae biomass into bioproducts promoting circular bioeconomy: a holistic approach of bioremediation and biorefinery	Due to low biomass productivity and high harvesting cost, microalgae-based production have not received much attention	Providing the state of the art of the microalgae based biorefinery approach to define an economical and sustainable process	Microalgae based biorefineries
Sharma et al. (2021)	Sustainable processing of food waste for production of bio-based products for circular bioeconomy	Food waste valorization opens new horizons of economical growth, bringing waste as an opportunity feedstock for bio processes to synthesize biobased products from biological source in a circular loop	Abridging merits and demerits of various advanced techniques extended for food waste valorization and contribution of food waste in revenue generation as value added products	Food waste
Liu et al. (2021)	Sustainable blueberry waste recycling towards biorefinery strategy and circular bioeconomy: A review	Addressing the blueberry waste valorization for a sustainable circular bioeconomy	Addressing the availability of blueberry crop residues, applications of this feedstock in bioprocess for obtaining range of value-added products, to offer economic viability, business development and market potential, challenges and future perspectives	Blueberry crop residues
Qin et al. (2021)	Resource recovery and biorefinery potential of apple orchard waste in the circular bioeconomy	Assessing an industrial bioeconomy at apple farms	Discussing the apple orchard potential for generating sustainable and efficient energy	Apple orchard waste
Goswami et al. (2021)	Microalgae-based biorefineries for sustainable resource recovery from wastewater	Wastewaters from different sources contain enormous amounts of nutrients such as carbon, nitrogen, and phosphorus. Thus, the recovery of these nutrients via appropriate sustainable process becomes a necessity	Providing the knowledge about the potential of low-cost microalgae-based integrated biorefinery for wastewater treatments and resource recovery	Microalgae-based biorefineries
Salvador et al., 2021b	Key aspects for designing business models for a circular bioeconomy	Summarizing the key aspects that need to be considered when designing, implementing and managing businesses in a CBE	(i) Revealing key aspects for implementing and managing business models for a circular bioeconomy; and (ii) pointing out the issues that lack further research on the theme, based on the existing literature	Aspects for designing business models based of a linear approach (traditional Business Model Canvas)
Behera et al. (2021)	Integrated microalgal biorefinery for the production and application of biostimulants in circular bioeconomy	Microalgae are underrated compared to other microbial counterparts, due to inappropriate knowledge on the technical, enviro-economical constrains leading to low market credibility	Discussing the biostimulatory potential of microalgae interactively combined with circular bio-economy perspectives	Microalgal biorefinery
Tsegaye et al. (2021)	Food Waste Biorefinery: Pathway towards Circular Bioeconomy	Comprehensive studies on the recovery of multiple products are mandatory to tackle the current challenges of food waste biorefinery	Exploring the state of the art of food waste biorefinery and the products associated with it	Food waste biorefinery
Coppola et al. (2021)	Fish Waste: From Problem to Valuable Ressource	About two-thirds of the total amount of fish is discarded as waste, creating huge economic and environmental concerns. For this reason, the disposal and recycling of these wastes has become a key issue to be resolved	Underlining the enormous role that fish waste can have in the socio-economic sector	Fish waste
Amit et al. (2021)	Food Industries Wastewater Recycling for Biodiesel Production through Microalgal Remediation	Use of wastewater microalgae to replace fossil fuels in energy production	Discussing prospective routes for the production of value-added compounds (polysaccharides, amino acids, biofuels, and biopigments) along with the bioremediation of food industry wastewater	Food industry wastewater

Appendix B. Profile of Participating Organizations

Table B.1
Profile of Participating Organizations.

Organization ID	Type of organization	Country	Position	How long in the position (years)	Main sector/activity	Size of Organization	Duration of interview (min)
1	Cluster	Denmark	Team Leader	1	Bioeconomy	Large	28
2	Individual	Netherlands	Specialist/Consultant	1	Recycling	Small	22

(continued on next page)

Table B.1 (*continued*)

Organization ID	Type of organization	Country	Position	How long in the position (years)	Main sector/activity	Size of Organization	Duration of interview (min)
	Company						
3	Cluster	Greece	President/Director	5	Bioeconomy	Large	21
4	Individual Company	Portugal	Engineer	13	Bioenergy	Large	15
5	Individual Company	Portugal	Manager	7	Engineering	Large	16
6	Individual Company	Portugal	President/Director	1	Food and Feed	Medium	17
7	Individual Company	Mexico	Business Owner	3	Bioenergy	Micro	25
8	Individual Company	Portugal	Manager	3	Consulting	Medium	35
9	Individual Company	Finland	Manager	2	Forestry	Large	32
10	Cluster	Spain	Researcher/Analyst	1	Bioeconomy	Large	35
11	Individual Company	Netherlands	President/Director	3	Engineering	Large	18
12	Individual Company	Norway	Manager	3	Engineering	Small	29
13	Individual Company	Germany	Engineer	10	Bioenergy	Small	26
14	Individual Company	France	Business Owner	2	Engineering	Small	20
15	Individual Company	Spain	President/Director	15	Chemical Products	Large	23
16	Individual Company	Rwanda	Business Owner	3	Food and Feed	Small	21
17	Research Institute	Spain	Manager	7	Textile	Large	15
18	Individual Company	Rwanda	Business Owner	5	Food and Feed	Medium	25
19	Individual Company	Kenya	Business Owner	6	Biochemical	Small	14
20	Cluster	Kenya	Team Leader	12	Biochemical	Large	24
21	Individual Company	Burundi	Business Owner	9	Biochemical	Medium	27
22	Cluster	Burundi	Business Owner	13	Food and Feed	Large	16
23	Individual Company	Australia	Business Owner	2	Bioenergy	Small	11
24	Research Institute	Brazil	Researcher/Analyst	6	Livestock	Large	22
25	Cluster	Brazil	President/Director	10	Pharmaceutical	Large	22
26	Individual Company	Argentina	Manager	3	Bioenergy	Large	19
27	Individual Company	South Africa	Specialist/Consultant	1	Bioeconomy	Small	23
28	Individual Company	Netherlands	President/Director	0.33	Digitization	Small	20
29	Individual Company	Australia	Manager	1	Bioenergy	Large	20
30	Individual Company	Brazil	Researcher/Analyst	0.25	Bioenergy	Medium	20
31	Individual Company	United States of America	Business Owner	4	Food and Feed	Small	25
32	Individual Company	Brazil	Manager	12	Biochemical	Large	25

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