Definition of the Scope of Circular Bioeconomy for biowaste management in urban areas

Deliverable D4.1 of WP4

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Contents

Executive summary

The present report constitutes the first deliverable – D4.1 – of Work Package 4 (WP4) of the BioCircularCities (BCC) project. The BioCircularCities project WP4 intends to develop some guidelines facilitating the replication of the approaches defined and experienced in each of the three regional pilots involved in the project, for preparing the transition towards sustainable biowaste management system in compliance with the circular Bioeconomy principles.

The BCC guidelines aim at overcoming the lack of easily accessible tool helping public authorities and private entities to identify the available technologies for such kind of transformation, depending on a set of criteria largely influenced by the surrounding urban or regional context.

The deliverable D4.1. aims at identifying and structuring the principles, concepts, contextual values and parameters of influence for the design of new value chains and biocircular technical pathways for biowaste valorisation and treatment.

The analysis presented in this report D4.1 is focusing in particular on the scope of the BCC regional pilots waste streams, which are the value chains for the valorisation of: (i) organic fraction of Municipal Solid Waste, (ii) organic residues from agro-industrial chain and (iii) residual biomass from forestry and related wood transformation activities.

Deliverable D4.1 first analyses the definition and the scope of the global Circularity and Bioeconomy concepts, the associated European targets and incentives, and the correlations which can be established between them (Section 1). The ultimate purpose of a sustainable, circular bioeconomy strategy for biowaste valorization is to support the transition towards production and consumption systems whose environmental impacts are reduced to a minimum, bringing societal benefits, through the development of economically viable technological solutions. The viability of any sustainable, circular bioeconomy value chain for the reduction or the valorization of biomass waste, as well as the selection of the best technological option(s) to be implemented are sensitive to multiple correlated factors and public and private decision makers must be guided towards the most efficient strategy fitting their targets and interests.

Based on the scope defined in the first part, the best practices for the definition of a Circular Bioeconomy strategy were then investigated, and a review of the existing supporting approaches, guidelines and tools has been performed in order to position the BCC guidelines and clearly define its objectives. This is detailed in Section 2 of the present report. The BCC guidelines will be developed as a supportive tool for the identification of the most suitable value chain, through the identification of the most suitable technological options (bio-circular technologies). To maximize the added value provided by the BCC WP4 guidelines, the guidelines shall address the needs from public and private decision makers along the BCC biomass waste value chains and shall be replicable to different types of biomass waste, given any geographical, political and socio-economic contexts.

The BCC guidelines intend to screen the socio-economic, political and environmental context of the territory in which the value chain shall be implemented, and to evaluate which technological pathway(s) for the biowaste valorization would be potentially compatible with the described surrounding context.

In practice, a portfolio of technologies must be created, and each technology shall be characteri zed according to a list of criteria allowing to identify if the technology is compliant with the characteristics of the context in which it should be implemented. The list of criteria shall reflect the drivers and barriers systematically influencing strategic choices, decisions and operations along the biomass waste value chain.

Hence, a state of the art of the main drivers and barriers towards the development of sustainable circular bioeconomy value chains for biomass waste management was established and is reported in BCC D4.1, Section 3. A literature review was conducted, and seven *"driving forces"* for a successful sustainable, circular bioeconomy strategy have been identified, constituting categories under which the influencing drivers and barriers were grouped:

1. Appropriate and up to date policy framework
2. Shift to more sustainable consumption patterns in support to the market transition towards sustainable circular bioeconomy
3. Cross sectoral cooperation and innovation
4. Development of a skilled and competent workforce at the European level
5. Sustainable management and use of biological resources
6. Funding and investment resources to support the development of a competitive, sustainable, circular bioeconomy
7. Ensuring the transition to a sustainable circular bioeconomy

A list of **influential criteria** has been established (Table 3) from the drivers and barriers that have emerged from the analysis of the literature. These criteria can be intrinsic to the feedstock properties (e.g. composition and quality in terms of content of high-value substances or molecules, presence of contaminants…). The efficiency of technological options for recycling or recovery is also of influence, as well as the potential associated technical constrains. The most convenient pathway towards waste biomass valorisation strongly depends on drivers and barriers related to the local surrounding political and socio-economic context, and on the potential sustainability strategic targets for the local authorities and private stakeholders endorsing the responsibility of waste biomass management.

Both the specific context of the territory or urban area of concern, and the different technologies of potential interest will be characterized according to this list of influential criteria. At the end of the project, the BCC guidelines will be available through a web application, whose operating principles are illustrated in Figure 3. The next deliverable D4.2 of the BCC project WP4 is dedicated to the full documentation of the technology portfolio, of the guidelines' web application operating mode and of the background logic.

List of acronyms

BCC	**BioCircularCities**
CCRI	Circular Cities and Regions Initiatives
EC	European Commission
FAO	Food and Agriculture Organisation
MSW	Municipal Solid Waste
UN	United Nations
WFD	Waste Framework Directive
WBCSD	World Business Council for Sustainable Development

Introduction

More than 113 million tonnes of biowaste are generated in Europe (EU27+ countries) per year, according to estimates based on 2017-2018 statistics (Favoino et al. 2020). Between half and two third of this amount is made of food waste generated along the food waste value chain, corresponding to more or less 20% of all food produced, followed by garden waste.

Since early 2000s, the European Commission creates, adjusts and strengthens several incentives and directives to force the reduction of the amount of biowaste, and to improve their collection, valorisation and treatment. The most significant ones are the Waste Framework Directive (WFD), (European Commission, 2018a), the European Commission Circular Economy Action plan (European Commission, 2020), and the European Commission Bioeconomy strategy (European Commission 2018b). All of them promote the prevention of food waste generation, in compliance with the Sustainable Development Goals (SDG) targets from the United Nations (United Nations 2019) of halving food waste by 2030, and also the separate collection of biowaste in order to maximize its quality for recycling into high added value products and introducing the concept of biorefinery. The level of implementation of separate collection system differs considerably over Europe, and a high proportion of biowaste still ends up in the mixed waste which is landfilled or incinerated. However, biowaste appears as the largest single component of municipal waste in the EU, with a share of 34% (Van der Linden et al. 2020). Hence, recycling of biowaste is key for meeting the EU target to recycle 65% of municipal waste by 2035.

The European Circular Economy strategy is central to the achievement of these targets, with the objectives of ensuring a sustainable use of natural resources, improving resource efficiency, and reducing environmental pressures. Hence, the WFD and the bioeconomy (EUBIA 2019) are articulated in order to avoid landfilling and valorise biowaste as a resource for biorefineries to produce organic fertilisers, soil improvers and growing media, or bio-based products of high value which can all replace fossil-based products (Favoino et al. 2020, Van der Linden et al. 2020).

The D9.2 of the VALUEWASTE H2020 project (EUBIA 2019) reports in their review of the Bioeconomy strategy that priorities of cities' policies are far from being related to bioeconomy principles. In the case of Europe, cities concentrate more than 70% of the European population, and they provide high potential for recovery of bio-nutrients, products, and energy from biowaste. The development and implementation of biowaste management systems compliant with the circular and bioeconomy principles is complex because it depends on a large set of parameters influencing the design of a strategy and planning of new value chains.

Work Package 4 (WP4) of the BioCircularCities project intends to develop some guidelines facilitating the replication of the approaches defined and experienced in each of the three regional pilots involved in the project, for preparing the transition towards sustainable biowaste management system in compliance with the circular

Bioeconomy principles. The present report constitutes the first deliverable of the BCC project WP4 (namely D4.1). It aims at identifying and structuring the principles, concepts, contextual values and parameters of influence for the design of sustainable and circular bioeconomy value chains for the management of biowaste.

The global scope of Circular Bioeconomy is broad and any process in relation to the creation of valuable, sustainable, reusable, or recyclable products from renewable resources could be considered as part of it. However, the analysis presented in this report is restrained to the scope of the BCC project regional pilots, which are the value chains for the valorisation of: (i) organic fraction of Municipal Solid Waste (MSW), (ii) organic residues from agro-industrial chain and (iii) residual biomass from forestry and related wood transformation activities.

This report first analyses the definition of the global Circularity and Bioeconomy concepts, the associated European targets and incentives, and the correlations which can be established among them. Considering this scope, the best practices for the definition of a Circular Bioeconomy strategy were investigated, and the existing approaches and tools for monitoring the implementation of sustainable and circular bioeconomy solutions were then analysed, allowing to position the BCC guidelines and specify its purpose.

Finally, a state of the art of the main drivers and barriers towards the development of sustainable circular bioeconomy value chains for biomass waste management was established, based on the review of the existing literature, keeping the target of alleviating the environmental, social and economic constrains at the core of the analysis. This provided an exhaustive prospect of the criteria that should be considered to support the transition towards Circular Bioeconomy which are aligned and coherent with the main outcomes from the two first BCC living lab sessions organized during the first year of the BCC project, giving its basic structure to the BCC guidelines.

1. European context and incentives towards sustainable & circular bioeconomy

The European Commission (EC) released a new version of its Bioeconomy strategy in 2018 (European Commission 2018b). In this essential document, it is estimated that the effects of Circular Bioeconomy would create large economic, social and environmental benefits if Europe's largest cities improve the recycling of organic residue streams. Based on figures from the city of Amsterdam, it is estimated that if the high value organic residue streams from Europe's 50 largest cities would be better recycled, a potential of at least 50 000 jobs could be created in the long term, nearly 30 million tons of carbon dioxide emissions could be avoided annually, and about 7 billion euros in added value could be generated per year (European Commission 2018b).
In order to reach this level of performance, a long process must be initiated for each local specific situation, in order to design a strategy, and then plan and implement circular bioeconomy solution(s) fitting the context (European Commission 2022b).

1.1.1. Bioeconomy definition

The EC established a clear and consensual definition of what Bioeconomy stands for. It " *covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services."* (European Commission 2018b, Robert et al. 2020).

The present report D4.1 of the BCC project focuses on the development of solutions for the valorisation of the biological resources available from the biomass waste (biowaste) of concern for each of the project regional pilot cities or urban areas, namely the organic fraction of Municipal Solid Waste, of agro-industry, and the residual biomass from forestry and related wood manufacturing industry activities. These biowaste streams fall under the type of feedstock the EU member states strategically prioritize for the development of the bioeconomy (Lokesh et al. 2018).
In the case of organic fraction from MSW , the biowaste value chain can be defined as (i) the generation of edible and non-edible food waste and losses by final consumers which are mainly citizens households and restaurants, and the generation of garden waste made of residues from mowing and pruning of private and municipal gardens and parks, (ii) the waste collection and potential sorting applied to the collected waste fraction, and finally (iii) the conversion of the collected feedstock into valuable bio-substances, materials or energy.
The value chain for organic residues from agro-industrial activities include (i) the generation of edible and non-edible food waste and losses by the agro-industries which transform raw agricultural products into food products, (ii) the waste collection and potential sorting applied to the collected waste fraction, and finally (iii) the conversion of the collected feedstock into valuable bio-substances, materials or energy.

The value chain for the wood residual biomass and related wood transformation activities consists in: (i) the lignocellulosic parts generated after forest wood cutting, and the wood shavings and dusts from wood industrial transformation, (ii) their collection and potential pre-treatment, and (iii) their conversion into high value molecules (added value products) or renewable energy sources.

The three value chains can lead to end products of different values, in different volumes. The classification given by Ardolino et al. 2017, based on the ISWA (2015) taxonomy, is interesting to consider. It differentiates:

- Bio-based fine and specialty chemicals, to be used for high technology applications. They are classified as high (economic) value products generally produced in limited quantities.
- Biofuels and bio-based materials – biogas and biomethane, bioplastics, cellulose, and commodity chemicals. They are classified as medium (economic) value, generally produced in medium or moderate quantities.
- Compost and solid digestate, which are considered as low (economic) value but which can be produced in high quantities, locally, and have a high functional value, contributing to improve soil function (structure, microbial diversity, water retention capacity, …) and to store carbon dioxide (Favoino et al. 2019 and Van der Linden et al. 2020).

The EC also claims in its definition that bioeconomy will strongly support industrial innovation and modernization, highlighting that the success of bioeconomy development and implementation relies strongly on the systemic integration of sustainability and circularity, putting the protection of the environment and the enhancement of biodiversity at its heart (European Commission 2018b, Robert et al. 2020).

1.1.2. Generic Pathway towards Circular Bioeconomy

The definition of bioeconomy from the EC is largely used in the existing literature and extended towards Circular Bioeconomy, which fully integrates the circular economy paradigm and sustainability principles with bioeconomy (Bimer 2018, Lokesch et al. 2018, Reim et al. 2019, Ronzon et al. 2020, Angouria-Tsorochidou et al. 2021).

Circular Bioeconomy consists in replacing non-renewable resources with biological resources, also increasing the consideration of residues and wastes as a resource, and in seeking to maximise the functional and economic value of biomass over multiple lifetimes, in a way which contribute to reduce greenhouse gas (GHG) emissions, resource overconsumption, and enhance biodiversity. Maximising biological resources effectiveness induces cascading use of biomass, leading to consider the highest-value biomass reuse or conversion options first, leaving the energy recovery as the last option before landfilling. A strong improvement of the waste collection system is required as aprerquisite to ensure the waste quality can be maintained at its maximum, especially in the case of biowaste (European Commission 2020, Stegmann et al. 2020, Van der Linden et al. 2020, WBCSD 2020, Kardung et al. 2021, Salvador et al. 2021).

The WFD and the associated waste hierarchy (Figure 1) is of course in full agreement with the Circular Bioeconomy principles. It recommends that waste prevention remains the preferred option and waste landfilling should be the last option. In between, in the case waste cannot be avoided, the WFD specifies that Reuse, Recycling and finally Recovery shall be preferred (European Commission 2018a, European Commission 2018b).

Figure 1: Waste Hierarchy from the Waste Framework Directive (WFD)[1].

According to the WFD and other guidance documents for waste management from the EU Commission DG Environment, DEFRA and WRAP, which are reported by Gharfalkar et al. (2015), waste prevention includes reducing the purchase of unnecessary consumable goods by final consumers, extend the products life span, and increase the practice of products' reuse in the consumption habits and set up the infrastructures allowing it. Waste prevention also targets the diminution of adverse environmental impacts induced by waste, and the reduction of harmful substances contained in materials and products.

Prevention of forestry waste generation appears limited, since the parts left from wood cutting cannot be avoided. Indeed, the wood to be cut is selected in prevision of a specific use, which requires a defined level of quality. Then the whole tree to be cut cannot meet these quality criteria, necessarily leading to leftovers. The residues from wood industrial activities are also unavoidable, assuming that industrial processes are already optimized for limiting wood resource losses to a minimum.

On the contrary, prevention is largely applicable to organic waste fraction from agro-industries and from MSW. For MSW, prevention is mainly applicable to food waste while it is more complicated to prevent garden waste generation. Organic waste prevention can be enhanced through communication campaign towards citizens, raising up the economic and environmental burdens induced by over or mis-consumption, and advising on how to change consumption behaviour – e.g. through splitting or better planning the purchase of foodstuffs according to more clearly identified needs, and on how to improve the management of individual organic waste by encouraging selective sorting and, for example, local composting.

The WFD then recommends reusing products or components in order to avoid they become waste, in particular for being used again for equivalent purpose to that for which it was first conceived (Gharfalkar et al. 2015). Hence, in the case of wood biomass residues, reuse makes little sense. Considering the organic waste fraction from agro-industries and from MSW respectively, reuse is also very much constrained. For garden waste, reuse practices are

[1] Scheme taken from the WFD EU Commission website (https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en).

very limited or non-existent. Then the reuse of food waste is much constrained with a number of strict safety regulations at the EU and national levels (Teigiserova D.A. et al. 2019, Angouria Tsorochidou 2021). It could be considered as an option, but it is probably not the option to be developed for the sustainable valorisation of organic waste generated by households and creating the greatest added value. However, considering organic waste from the agro-industrial sector, it could potentially be more feasible than food waste from households since regulations and procedures for the management of edible products already exist.

Recycling is then the next option recommended by the WFD through the principles of cascading use of materials and products. Recycling includes any biological, chemical or physical processing of waste materials into new products, materials or substances for an equivalent or different types of use than that it was initially created for. Composting of organic matter can be considered as a recycling technology by some reference guidance for waste management, while energy recovery from waste feedstock is generally excluded from the recycling definition and constitutes the main approach considered in the "other recovery" category of the waste hierarchy (Gharfalkar et al. 2015).

The technological options existing or under development for recycling or other recovery pathways offer diverse opportunities for the treatment of organic waste fraction from MSW, agro-industrial activities and wood biomass residues, in a way to create new resources with competitive functional and economic values. Each of these opportunities shall be coherent with the principles of circularity and sustainability (European Commission 2018b). Following the waste hierarchy for a better management of biomass waste allows to ensure the compliance of such technological opportunities with the circularity principles, but it does not allow to explicitly address the sustainability pillars that shall be followed in order to minimise the environmental impacts and maximise the socio-economic benefits of any circular bioeconomy strategy (Zhang et al. 2022).

1.1.3. Framework for Circular Bioeconomy actions and sustainable impacts

The European Commission Bioeconomy strategy relies on five main objectives (Robert et al. 2020), each one related to one or more sustainability challenges that are addressed through one or several of the 17 United Nations (UN) Sustainable Development Goals (SDGs), that were adopted in 2015 by all UN Member States as part of the 2030 Agenda for Sustainable Development (United Nations 2019).

The first objective of the bioeconomy strategy is fully aligned with SDG 2, aiming to ensure food and nutrition security while the world population is growing and the nutrition and consumption practices are evolving. This objective induces to pay particular attention to the potential unsustainable use of biomass, to the biowaste prevention, and to the threats climate change can cause on agriculture efficiency. This first priority objective also aims at contributing to sustainable consumption and production (SDG 12).

The second, third and fourth objectives of the bioeconomy strategy are closely linked to each other. The second objective focuses on the sustainable management of natural resources. The third objective relates to the reduction

of society and industry dependence on non-renewable, unsustainable domestic or imported resources. The fourth objective intends to mitigate and adapt to climate change, which makes sense only in parallel of developing pathways towards objectives two and three.
Actions to be taken in order to achieve these two objectives shall be compliant with sustainable consumption and production modes (SDG 12), relying on resilient infrastructure, inclusive and sustainable industrialization and innovation (SDG 9), and shall promote inclusive and sustainable economic growth considering the associated social benefits to the society (SDG 8). That would directly or indirectly ensure access to affordable, reliable, sustainable and modern energy for all (SDG7), and make cities and human settlements inclusive, safe, resilient and sustainable (SDG 11). Then these actions should directly increase food and water security (SDGs 2, 6), which would contribute to regulate land exploitation and protecting biodiversity (SDGs 15) and to adapt and mitigate climate change through GHG emissions reduction and the creation of carbon sinks (SDG 13, 15).

The 5th Bioeconomy strategy objective targets a stronger European competitiveness combined to job creation, through the development of innovative technologies, products and markets. Developing actions in order to reach this objective contributes to fight against poverty (SDG 1) and induces high quality education requirements (SDG 4).

This analysis shows that Circular Bioeconomy potentially contributes to at least 11 out of the 17 UN SDGs. It is aligned with the outcomes of the analysis made by Fritsche et al. (2020) for the EC's knowledge Centre for Bioeconomy, and by Lokesh et al. (2018), as well as with the impact categories identified into the Food and Agriculture Organisation (FAO) report on indicators to monitor and evaluate the sustainability of bioeconomy (Bracco et al. 2019).

As a conclusion of this first section of D4.1,
Table 1 summarizes the concept of sustainable circular bioeconomy in the scope of biomass waste valorisation and treatment, based on the five pillars and objectives of the European bioeconomy strategy, and on the waste treatment categories given by the Waste hierarchy, except for disposal (Section 1.1.2). This simple matrix then integrates actions which are compatible with the principles of circularity and with the associated sustainability targets through the consideration of the SDGs. The generic circular actions provided in the table are identifiable in a large number of existing literature sources. In particular, the arguments provided by Kardung et al. (2021) were considered, as well as those identified in the methodology of the Circular Cities and Regions Initiatives (CCRI), officially released in November 2022 (European Commission, 2022b).

Table 1 shows that the above-described objectives 2, 3 and 4 of the Bioeconomy strategy are central to the development of a sustainable Circular Bioeconomy, as they centralise a majority of circularity principles and actions that could be implemented. This summary table also highlights that SDG 12, fostering sustainable consumption and production, shall be central to any Circular Bioeconomy strategy.

Table 1: Positioning of circularity actions and sustainability targets in the framework of the EU Bioeconomy strategy and the WFD.

<table>
<tr><th></th><th colspan="4">WFD – Waste hierarchy</th></tr>
<tr><th>EU Pillars of Bioeconomy</th><th>Waste prevention / Reduction</th><th>Reuse</th><th>Recycling</th><th>Other recovery</th></tr>
<tr><td>Ensuring food and nutrition Security</td><td>Minimising waste
SDG 12</td><td></td><td colspan="2">Avoid competition of biomass production with food production.
SDG 2 & 12</td></tr>
<tr><td rowspan="2">Reducing dependence on non-renewable and unsustainable resources</td><td>Prioritise renewable resources Minimise use of scarce resources
SDG 12</td><td>Minimise use of scarce resources
SDG 12</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="3">Promote solutions inspired and supported by nature

Extended use & Second-hand market
SDG 12</td><td colspan="2" rowspan="3">Support close loop system *SDG 8 , 9 & 12*
Maximise material intensity and Resource efficiency *SDG 7 & 8*
Design for separation and recovery *SDG 8 , 9 & 12*
Specific waste Collection and sorting *SDG 11*</td></tr>
<tr><td>Mitigating and adapting to climate change</td></tr>
<tr><td rowspan="5">Managing natural resources Sustainably</td></tr>
<tr><td colspan="4">Carbon sequestration in soils connected to use of soil improvers / Biogenic carbon storage
SDG 9 & 13 & 15

GHG reduction *SDG 13*</td></tr>
<tr><td colspan="2"></td><td colspan="2">Minimise use of water and land *SDG 6 & 15*
Protect Biodiversity *SDG 15*</td></tr>
<tr><td rowspan="2">Minimising biowaste
SDG 12</td><td></td><td colspan="2">Cascading use of biomass *SDG 9*</td></tr>
<tr><td></td><td colspan="2">Maximise waste value recovery *SDG 7 & 8*</td></tr>
<tr><td>Strengthening European competitiveness and creating jobs</td><td colspan="4">Local and low impact economies. Employment, Economic development, Linkage between rural and urban economies *SDG 1, 4, 8, 9, 17*</td></tr>
</table>

The viability of any sustainable, circular bioeconomy value chain for the reduction or the valorisation of biomass waste, as well as the selection of the best technological option(s) to be implemented are sensitive to multiple correlated factors and public and private decision makers must be guided towards the most efficient strategy fitting their targets and interests.

2. Setting the goal and scope of the BCC guidelines

The BCC guidelines will constitute the main outcome of the WP4 and will support the exploitation of the project results. The deliverable D4.1 aims at structuring the guidelines framework. Given the context described in Section 1, the next stage is to stand for the clear goals of these guidelines, and to set their scope accordingly.

2.1. Milestones for the development and implementation of a circular bioeconomy strategy

Implementing a new strategy for the management of biomass waste or modifying and improving the existing one is a long process influenced by many factors and parameters and by the stakeholders involved along the value chain. In order to guarantee consistency in the development, implementation and success of such strategy, the methodology released by CCRI constitutes the most recent guide of reference from the EU Commission for the deployment of circular solutions in cities and urban areas (European Commission 2022b). This methodological guidance is generic and transverse to any sector of application. It is not dedicated to the Bioeconomy development, but it is fully in line with the framework and actions demonstrated in
Table 1. It recommends an exhaustive approach following three major consecutive stages – Map-Design-Implement – and allows to address the technological, scientific and governance issues of potential circular solutions. Caldeira et al. 2019 also refers to the "Map-Design-Implement" approach for the development of food waste prevention actions.

The CCRI methodology recommends as a first stage to map the territory in order to get a complete view of the local material and energy metabolism, and to understand the potential for circular economy. It consists in the identification of the most promising economic sector(s) to be targeted (based on resources and waste flows according to the urban metabolism concept and key stakeholders mapping), the statement of the baseline situation in terms of circular solution already implemented or planned, and the identification of the strategic stakeholders to be involved.

Then, the circular systemic solution must be designed in a second stage. The aim is to identify the key circular solution(s) to plan for the implementation depending on the drivers and barriers potentially existing at the country or regional level, influencing the implementation at local or regional level. Then the economic, environmental and social performances of the potential solutions should be assessed. It also includes some planification actions with the consolidation of stakeholders' mobilization and planning of their engagement, as well as the development of an operational planning for the implementation.

The third stage concerns the implementation of the circular systemic solution, including operationalizing the actions after a business model has been established, attracting funds and developing partnerships. Monitoring of sustainable and circular performances in order to ensure the solution long term viability is also part of this stage.

Each stage is estimated by the CCRI to take at least one year to be completed. Each stage is broken down into different phases which should generate the relevant knowledge which is necessary to support decision making processes from the early stages of the process until the implementation of concrete actions.

The scale of such approach induces the need for guidance and tools that can support specifically its different stages and phases. The ultimate goal of the BCC project WP 4 is to release some guidelines supporting the planning of biowaste management solutions (second stage of the CCRI methodology), in compliance with the circular bioeconomy principles.
A review of the existing supporting approaches, guidelines and tools have been performed in order to clearly define the objectives of the BCC guidelines, and to position it well towards the development of solutions and value chains for the sustainable and circular management of organic and/or wood waste.

2.2. Review of existing supporting guidelines and tools

A review of the existing tools and guidelines that can be used throughout the development process of a biocircular strategy has been carried out. The tools cited by the CCRI methodology were considered, as well as those identified through a dedicated literature search, considering the following keywords:

- Tool or Guideline for biowaste management
- Tool or Guideline for Circular Bioeconomy development
- Tool or Guideline for sustainability assessment of biowaste management
- Tool or Guideline for circularity assessment of biowaste management

In total, 19 tools or guidelines have been identified as potentially relevant considering the scope of the BCC project and the scope of the global approach described above. **Error! Reference source not found.** provides an overview of the 19 tools and guidelines specificities.

Three out of the 19 tools and guidelines correspond to web platforms aiming at gathering and sharing knowledge and information about sustainable and circular bioeconomy concepts, approaches and technologies, methods and tools for their assessment, and performances.

Among the 16 remaining tools and guidelines identified, 12 are tools, 3 are raw scientific models without dedicated software tool or specific user interface, and 1 is a methodological approach recommended for the sustainable assessment of waste management solutions.
The majority (75%) of these 16 instruments are dedicated to the assessment of the circularity or sustainability performances of circular or biocircular pathways or actions. Among these 12 instruments, three deal purely with the assessment of environmental performances of biocircular scenarios, supported by Life Cycle Assessment (LCA). Three deal with urban metabolism characterization, supported by Material Flow Analysis (MFA), and two out of the three also combine MFA with LCA. The other six adopt multicriteria sustainability assessment approaches.

Among the 16 tools, models and method, five are addressing circularity or sustainability issues for all type of waste, including biomass waste. Only four are focusing specifically on the management of biowaste. Five others were developed focusing on the circularity and sustainability of material and/or energy flows, which can address the management of primary and secondary resources and waste based resources, being of bio or fossil origin.

Only 4 out of the 16 instruments are dedicated to the identification of circular or sustainable actions or pathways. These tools and guidelines generally allow the identification of generic solutions but they do not reach the step of providing support in the identification of concrete technological options to be implemented, except for the tool developed by Delgado et al. 2019, materialized through the DELIGES software application. This tool intends to go in this direction, but its development seems stopped at the academic level and the tool is not distributed.

Table 2: Overview of the 19 tools and guidelines analysed

	Authors	Type of supporting instrument	Scope (product/process, value chain, territory)	Type of resources / Sector of concern	Bio-circular strategy development stage supported by the tool or guideline	Targeted public
EU Framework for Bioeconomy monitoring	European Commission JRC. Giuntoli et al. 2020	Web platform	All	All	Transverse to Map – Design – Implement stages	Industrial, researcher and public stakeholders
The Biowaste Hub	SCALIBUR H2020 project. 2022	Web platform	All	Biowaste	Transverse to Map – Design – Implement stages	Industrial, researcher and public stakeholders
TECH4BIOWASTE database	H2020 project Tech4Biowaste.	Web platform	Process and product description	Food waste and Garden waste	Transverse to Design and Implement stages	Technology providers and users
EASETECH	Technical University of Denmark. 2015 Clavreul et al. 2014	Tool	Process Value Chain Territory (City or larger area)	Environmental technologies applied to all types of waste.	Assess and evaluate the pathways or solutions	Researchers, consultants, public authorities as well as technology developers.
LCA-IWM	J. den Boer. 2007	Tool	Municipality Waste value chain / management systems	All type of waste	Assess and evaluate the pathways or solutions	Policy makers/ Public Authorities, Industrial stakeholders
MSW-DST	US EPA and RTI International. RTI International. 2012	Tool	Waste value chain	All type of waste	Assess and evaluate the pathways or solutions	Policy makers/ Public Authorities, Industrial stakeholders
BioMonitor tool	H2020 project BioMonitor. Van Leeuwen et al. 2021	Tool	Product / value chain / market (>> territory)	Agro-food, bio-based products, forest resources, wood based products, bioeconomic sectors	Assess and evaluate the pathways or solutions	Policy makers/ Public Authorities, Industrial stakeholders
DECISIVE	H2020 project DECISIVE. 2021	Tool	Process and Urban area	Urban biowaste	Assess and evaluate the pathways or solutions	Local authorities and environmental service companies
Food waste prevention calculator	De Lorentiis et al. 2020	Tool	Food waste value chain.	Food waste	Assess and evaluate the pathways or solutions	Policy makers/ Public Authorities
DELIGES	Delgado et al. 2019.	Tool	Value chain including waste collection, pre-treatment, treatment and application.	Biowaste in general	Assess and evaluate the pathways or solutions	Public and private stakeholders making decision along biowaste value chain
ReSOLVE framework	The Ellen MacArthur Foundation, 2017.	Tool	Product / process / value chain	Generic to material and energy flows	Identify solutions and actions	Companies – Industrial stakeholders
Urban Opportunity Framework – Circle City scan tool	Circle Economy. 2020	Tool	Territory: Urban and cities territory	Focus on circularity for several urban themes: water, solid waste, energy, organics, buildings, consumables.	Identify solutions and actions	Cities' decision makers / Public local Authorities / Local authorities / Urban planners
Causal Loop Diagrams (CLD)	Bassi et al. 2021	Tool	Territory	Generic and not limited to bio-resources. Focus on circularity development for material and energy flows.	Assess and evaluate the pathways or solutions	Industrial, researcher and public stakeholders

Value Chain Approach	UNEP. 2021	Tool	Value chain	Not dedicated to bioeconomy. Focus on circularity for Food flows, and also construction and textile.	Identify solutions and actions	Policy makers and industrial decision makers
Circular Strategies Scanner	CIRCit NORDEN. 2020	Tool	Product / Service.	Generic and not limited to bio-resources. Focus on circularity development for material flows.	Identify solutions and actions	Manufacturing industries
SWOLF – Solid Waste Optimization Life-Cycle Framework	Stanisavljevic et al. 2017	Raw scientific model	Value chain: Solid Waste Management Process: Individual technology	Solid waste (bio and other)	Assess and evaluate the pathways or solutions	Policy makers and industrial decision makers
Urban Metabolism Analyst – UMAn	Rosado et al. 2017.	Raw scientific model	Product / Territory.	Generic and not limited to bio-resources. Focus on circularity development for material flows.	Assess and evaluate the pathways or solutions	Cities' decision makers / Public local Authorities / Local authorities / Urban planners
Urban Circularity Assessment (UCA)	CITYLOOPS H2020 project. 2022	Raw scientific model	Product / Territory.	Generic and not limited to bio-resources. Focus on circularity development for material flows.	Assess and evaluate the pathways or solutions	Cities' decision makers / Public local Authorities / Local authorities / Urban planners
MCDA	Pieratti et al. 2019	Methodological approach	Value Chain	Forest wood chain as a case study – replicable to other biowaste value chain	Assess and evaluate the pathways or solutions	n.n

2.3. Objectives and positioning of the BCC guidelines

Considering the state of the art together with the scope and objective of the BCC project, the BCC guidelines will be developed as a supportive tool for the identification of the most suitable value chain, through the identification of the most suitable technological options (biocircular technologies).

In order to maximise the added value provided by the BCC WP4[2] guidelines, the guidelines shall target any decision makers from the BCC biomass waste value chains and shall be replicable to different types of biomass waste, given any geographical, political and socio-economic contexts.

Therefore, this type of guidelines positions itself in support of the design of circular solutions (second stage of the CCRI methodology, Section 2.1), supporting the identification of the key circular solution(s) matching with the specific city or urban area potential for circular bioeconomy. The BCC guidelines shall be applicable once the phase of "setting the ambition" of the circular bioeconomy strategy currently designed is already initiated. According to the CCRI methodology, "Setting the ambition" significates to set some targets or performance objectives to be reached through the implementation of one or several suitable biocircular technologies (European Commission 2022b).

Hence, it is assumed that issues from the first stage of the approach recommended by the CCRI – the identification of the most promising economic sector(s) to be targeted, statement of the baseline, identification of strategic stakeholders to be involved (see Section 2.1) – were clarified on top the BCC guidelines consultation, and that phases to be developed for the further implementation (stage 3, see Section 2.1) are not covered by the guidelines and would be addressed below the BCC guidelines consultation.

The BCC guidelines intend to screen the socio-economic, political and environmental territorial context in which the value chain shall be implemented, and to evaluate which technological pathway(s) for the biowaste valorisation would be potentially compatible with the described surrounding context. The goal is to support the stakeholders' decisions for setting some priorities for potential actions to move forward with sustainable, circular bioeconomy implementation for biowaste management.
In practice, this means that a portfolio of technologies must be created, and each technology shall be characterized according to a list of criteria allowing to identify if the technology is compliant with the characteristics of the context for implementation. The list of criteria according to which each technology shall be characterized will be established based on the analysis of drivers and barriers systematically influencing strategic choices, decisions and operations along the biomass waste value chain.

[2] The content of the project and the description of the different WPs are available at: https://biocircularcities.eu/

The technologies of concern for the three BCC pilots will be integrated in priority in the portfolio, but it could be expanded in order to also consider additional innovative biorefineries technologies of relevance (e.g. those identified in the Tech4bioWaste H2020 project). This extension would provide a significant added value to the guidelines, because biorefinery processes are at the core of the development of sustainable and circular bioeconomy, but due to their novelty, those technologies are low integrated in the existing guidelines and tools supporting decision making.

3. Identification of drivers and barriers towards sustainable, circular bioeconomy.

The aim of Section 3 is to analyse the driving forces and the potential barriers towards the development of a sustainable and circular economy, in order to understand which are the criteria of influence to be considered for the choice of a technological pathway, considering a specific urban or territorial context.

3.1. Methodological approach

A literature review was conducted, focusing first on the documents resulting from the analysis carried out by the European Commission and its research centers and institutes, as well as on the documents resulting from reference institutes such as the FAO from the United Nations, or the World Business Council for Sustainable Development (WBCSD).

This state of the art has been consolidated considering publications from scientific journals, which were selected because they carry a global or transversal analysis of the sustainable circular bioeconomy frameworks, of the factors of success or of potential improvement. The selected scientific articles provide a generic or case-study related analysis of the political context at the territorial level (cities, localities or regions) and highlight the possibility for developing circular bioeconomy business models, raising up the associated challenges, drivers and barriers, from the value chain perspective.

Also, the results of the literature review reflect and complement the outcomes from the two BCC living lab and peer review sessions that were organized during the first year of the project and the policy framework analysis on circular bioeconomy carried out both at EU and pilot level. The content and results on drivers and barriers coming from the living lab and peer review sessions and the policy framework analysis are reported and analysed in detail in the BCC deliverable 3.2., then it was chosen to not expand on in this D4.1 deliverable.

3.2. State of the art

The ultimate purpose of a sustainable, circular bioeconomy strategy for biowaste valorisation is to support the transition towards production and consumption systems whose environmental impacts are reduced to a minimum, bringing societal benefits, through the development of economically viable technological solutions. This has been extensively described in the first section of this report. These perspectives are closely correlated, through common or complementary vectors (drivers) and brakes (barriers). Based on the literature review that was performed, seven *"driving forces"* for a successful sustainable, circular bioeconomy strategy have been identified, constituting categories under which the influencing factors can be grouped.

Error! Reference source not found. summarizes and classifies the drivers and barriers identified in a SWOT matrix. Each colour corresponds to one of the seven driving forces. Arguments classified under **Strengths** and **Opportunities** constitute drivers towards sustainable, circular bioeconomy. Strengths were identified from some actions or facts already implemented, or conclusions from the analysis of some existing systems. Opportunities constitute the added value or the advantages that the further development of sustainable and biocircular value chains would bring. **Weaknesses** and **Threats** both gather the existing barriers to the development of such value chains. Weaknesses highlight arguments and facts slowing down the design and implementation of biocircular solutions, and Threats gather the elements and facts that could cause problems or undermine the development of biocircular value chains. Looking at **Error! Reference source not found.**, the equilibrium between drivers and barriers is unbalanced, the number of barriers identified being almost twice the number of identified drivers.

Depending on each specific context in which bioeconomy would be developed at the local or regional scale, the influence of one or the other driving force may prove to be significant and predominant compared to the others. The driving forces are presented in this report without considering any priority given to one or the other, the objective being to understand the scope of each of them, the potential obstacles associated, and the influence they could have on each other.

Strengths

- Demand driven development enhances the market to adapt and manage the transition more efficiently.
- Awareness-raising activities and providing good information to consumers .
- Targets on municipal waste recycling are set at 55% for 2025, 60% for 2030 and 65% for 2035.
- Rural development policies are a crucial component to be integrated into the implementation of Bioeconomy.
- WFD 2018 targets for recycling induce to limit the presence of contaminants among collected waste.
- Separate collection of biowaste will become mandatory on 01/01/2024.
- Succes stories (already achieved developments) can enhance innovation and cooperation between public and private sectors, and mutualising initiatives from the private sectors.
- Promising alternative routes for biorefining, compatible with rural development, resilience, and system efficiency.
- Food wastes can be an important feedstock for small-scale biorefineries.

Weaknesses

- Mobilisation of private investments.
- Further investments for transfer knowledge into innovation.
- Engage citizenships is a long process.
- Lack of understanding of concepts, choices and co-benefits by the stakeholders along the value chain (businesses, citizenships, final user).
- Inadequate awareness and participation of consumers/citizens.
- The consumer behavioural change can significantly influence decision making.
- Consumers rooted consumption habits and patterns can be a limitation.
- Lack of acceptance of waste-based products.
- Missing framework to seize and communicate about sustainability to different stakeholders,
- Need for clear rules on labelling.
- Lack of standardisation.
- Lack of a long-term policy pull.
- Lack of regional CE policy formulation and coordination.
- Lack of targets and objectives related to the implementation of policies.
- The environmental and economic costs of the biowaste valorisation can be beneficial or not.
- Transformative land use practices are not well addressed.
- Impacts of the bioeconomy at the regional or local level are not well adressed.
- Need to cover the "valley of death" of bioeconomy innovation.
- Infrastructure capacity can be limited.
- Matching the treatment capacity to the volume of the collected waste can be critical.
- Low TRL of circular innovations.
- There is a gap between laboratory research and its transfer to industrial-scale commercial application.
- Too low collaboration between researchers, industries and governments.
- No comprehensive statistics on the socio-economic performances of bio-based industries is available.
- A change of paradigm is required, the focus of Member States is not enough on the development of bioeconomy considering the biowaste value chain.
- Better understanding of potential synergies and trade-offs of technology and policy options is necessary.
- Sustainability evaluation and monitoring need to be further developed and strengthened (models and metrics).

Opportunities

- Shift towards more sustainable consumption patterns.
- Well-being, health and resilience need to be seen as necessary co-drivers of market interactions.
- Strong engagement of citizen and young people.
- Give active roles to people
- The development of biomaterials and ecosystem services will gain significantly
- Economic incentives for bio-waste collection and treatment.
- Need to face the projected 'biomass gap' between supply and demand of biomass for food, materials and energy.
- The continuous or improved provision of Ecosystem services shall get an economic value.
- Promote short domestic sustainable bioeconomic supply chains.
- Sustainable and inclusive business models.
- Separation of bio-waste at source is a basic condition for achieving high-quality outputs.
- Investing for the creation of skills, quality jobs and opportunities
- Sustainable regional economic development.

Threats

- High upfront investment costs & Financing risks related to long and uncertain payback times.
- Time lags between making an investment and starting operation.
- Resource price distortion
- Market and demand risks
- The interaction between food & feed, fibre, chemicals, energy etc. is currently driven by markets and prices, with few policy interventions.
- Difficulties in balancing and coordinating economic development and environmental regulation.
- Lack of long term vision related to CE return investments.
- Innovation outside the bioeconomy sphere could be more competitive than bioeconomy solutions/products.
- EU biorefinery activities are dominated by large-scale projects to achieve cost-effectiveness and high efficiencies.
- Efficiency and viability of new business model can induce some technological and/or logistic deficiencies.
- Technical feasibility of biowaste processing faces limitation and challenges, mainly related to the supply chain of biomass waste.
- The conventional bioenergy pathways are under threat.
- Biophysical limitations of the natural resources value chain are under consideration.
- Lack of knowledge of procedures in businesses.
- Lack of experience and skills among public authorities.
- Success of biocircular models depend strongly on the joint consideration of cross-cutting issues, multiple objectives, and competition between the different (industrial and energy) sectors of the bioeconomy.

Figure 2: SWOT analysis of the drivers and barriers towards sustainable, circular bioeconomy. Each colour corresponds to one driving force: Red ⇔ 3.2.6 Funding and investment resources to support the development of a competitive, sustainable, circular bioeconomy – Green ⇔ 3.2.2 Shift to more sustainable consumption patterns in support to the market transition towards

sustainable circular bioeconomy – Blue ⇔ 3.2.1 Appropriate and up to date policy framework – Yellow ⇔ 3.2.3 Cross sectoral cooperation and innovation – Black ⇔ 3.2.5 Sustainable management and use of biological resources – Purple ⇔ 3.2.4 Development of a skilled and competent workforce at the European level – Brown ⇔ 3.2.7 Ensuring the transition to a sustainable circular bioeconomy.

3.2.1. Appropriate and up-to-date policy framework

Any biocircular solution will be driven by the necessity to adjust the existing policies and regulation. The first driving force towards sustainable circular bioeconomy has been identified as an *"Appropriate and up-to-date policy framework"*. Policies and regulations set some targets to be reached by the public and private stakeholders along the sector and value chain of concern and intend to provide the framework and the directives that shall be followed to reach these targets. For a concept like circular bioeconomy, this is challenging, first because the scope is large and complex. Even in case the scope is restrained respectively to the organic food waste or to the wood residual waste management value chains, of concern in the BCC project, the scope remains broad and complex because for each of these value chains, the waste stream, quantities, embedded materials and management systems induce to involve various economic sectors, each having its own specificities leading to the need for some dedicated policy frameworks, and for the definition of adapted objectives. This also induces that policies that do not target directly the bioeconomy can as well have some effects (Kardung et al. 2021, D'Adamo et al al. 2022). The challenge also comes from the fact that circular bioeconomy implementation started one to two decades ago, and since then the techno-economic context in which it happens is evolving fast, inducing the continuous emergence of new issues to be integrated in the global and in the specific policy frameworks at the same time. The global policy framework is given at the EU level mainly through the Bioeconomy strategy (EU Commission 2018b) and the WFD (EU Commission 2018a). Kardung et al. 2021 complete with citing the European Commission Circular Economy Action Plan (European Commission 2020), the European cohesion policy and the Regional Innovation Strategies for Smart Specialisation as significant influential policies.

The global objectives given by the WFD target the recycling of 65% of municipal waste in 2035, including biowaste. This constitutes a central driver for the development of biocircular value chains, leading to optimizing the separation and collection of the different waste fractions and foster the development of technological solutions to limit the presence of contaminants among the collected waste, ensuring high quality feedstock. To this purpose, the separate collection of biowaste will be mandatory for municipalities from the 01/01/2024 (European Commission 2018a, European Commission 2019, Favoino et al. 2019).

Also, the implementation of economic incentives such as taxes on residual waste (e.g. polluters pay principle, carbon tax, etc.) that make cheaper the biowaste collection and treatment than the landfill, can enhance the development of biowaste valorisation systems (Favoino et al. 2019, Van der Linden et al. 2020), considering in parallel the risk that Caldeira et al. 2019 pointed out on the possibility that environmental performances of any new biocircular value chain could be weakest than those of biowaste final disposal.

However, the lack of long-term policy incentives (European Commission 2022a), the lack of policy formulation and coordination at the regional level (Philip et al. 2018, Fritsche et al. 2020), the lack of clear and quantified targets adapted per value chain (Angouria Tsorochidou et al. 2021, European Commission 2022b) and the weak intervention of policy in the regulation of interactions between the different sectors involved in the development of circular bioeconomy (Ladu et al. 2017, Fritsche et al. 2020), can potentially hinder its development and implementation. Ladu et al. 2017 also point out the lack of regulatory support instruments at the European level that would foster the competitiveness of biorefineries for plant-based chemicals or materials production, while it is central to the development of the bioeconomy. Angouria Tsorochidou et al. 2021 also highlight the importance to account for environmental performances of biowaste valorisation in the regulations supporting the local

initiatives, and the barriers induced by the lack of a clear framework establishing responsibilities for the implementation and operation of value chains and the bioconomy in general.
The full D3.2 of the BCC project is dedicated to the identification of policy drivers, barriers and good practices, based on European and national policies and best practices review, and based on the outcomes of the first and second living labs implemented in the framework of the BCC project. The main outcomes from the literature review which are highlighted in this section are coherent with the outcomes reported in the D3.2 report.

3.2.2. Shift to more sustainable consumption patterns in support to the market transition towards sustainable circular bioeconomy

According to Fritsche et al. 2020, the regulation of interactions between the different sectors involved in the bioeconomy is mainly driven by the market, which itself is largely driven by the consumers or clients demand. Hence, the second driving force identified is the *"Shift to more sustainable consumption patterns in support to the market transition towards sustainable circular bioeconomy"*. The link between consumption patterns and market orientation is pointed out by the recent Bioeconomy strategy progress report from the European Commission, which also mentions the importance of the strong engagement of citizens and young people in the process of developing new economic models such as the bioeconomy related ones (European Commission 2022a). Giving active roles to people would make them able to engage and express themselves about their willingness to transform societal interests and consumption patterns towards more sustainability (Fritsche et al. 2020, D'Adamo et al. 2022). Well-being, health issues and resilience capabilities shall be seen as co-drivers of market interactions (Fritsche et al. 2020, Salvador et al. 2021, Caldeira et al. 2022), since human well-being should be progressively influenced by the creation and regeneration of ecosystem services, rather than by material and energy consumption. This indeed points out how powerful societal choices and beliefs can be on decision-making and on the orientation of markets (Fritsche et al. 2020, Kardung et al. 2021, European Commission 2022a). This is also raised by Verkerk et al. (2021), which recommend the integration of consumer behavioural change as a central parameter in the modelling of circular bioeconomy systems and their sustainability assessment.
Also, it must be pointed out that the significant reduction of biowaste generation is an essential target of the WFD and SDGs, and the involvement of population towards bioeconomy development shall also contribute to raise awareness on waste prevention.

Despite these drivers, a number of bottlenecks slow down the shift to more sustainable patterns. First, the risk of distortion of resources price which is influenced by the ratio of supply and demand, could lead to non-competitive secondary resources like biowaste compared to primary resources counterparts, especially petroleum feedstock. This could compromise the profitability of any new bioeconomy value chain, from the very first step of its design (European Commission 2022b, Lokesh et al. 2018). In addition, a weak and fragmented demand for secondary resources would also constitute a risk for the socio-economic sustainability of the circular bioeconomy value chain to be developed.
It proves again that the further development and consolidation of the bioeconomy market is required, through the involvement of the society, fostering the demand for products and resources from the bioeconomy. But

considerable efforts and long-lasting processes are required to involve citizens in any action and make the consumption habits from consumers evolving. The low acceptance for waste-based and/or bio-based products is a significant factor of this inertia, potentially induced by the low awareness and understanding of circular bioeconomy concepts, approaches and benefits (WBCSD 2020, European Commission 2022b). This shall be supported by public authorities with the development of information campaign and communication supports, such as standards or labelling, in order to raise awareness and build trust about the added value, the quality and the benefits of end products resulting from biorefineries and other biowaste valorisation pathways, in compliance with the sustainability pillars and the circularity principles (Lewandowsky 2018, Philip et al. 2018, Reim et al. 2019, Van der Linden A. et al. 2020, Angouria Tsorochidou et al. 2021, Kardung et al. 2021, European Commission 2022a, European Commission 2022b). This shall be made based on common rules to be established, in order to frame consensual quality and labelling frameworks, which are essential to avoid the proliferation of various labels that could induce risks of confusion on the markets and for the final consumers (Van der Linden et al. 2020).
Also, the risk subsists that despite the potentially limited environmental benefits, the potential expensive nature of the bio-based products, their potential limited functionality and durability still hinder their acceptance (Lokesh et al. 2018).

3.2.3. Cross sectoral cooperation and innovation

The observations from 3.2.1 and 3.2.2. lead to raise up the next driving force, which is the importance of *"Cross sectoral cooperation and innovation"*. Changes in consumption patterns would support the transition towards biocircular systems at the territorial scale, but the transition could not be effective without the engagement of the different stakeholders playing a role along the biocircular value chain (WBCSD 2020, European Commission 2022a), and without the consideration of the horizontal and vertical interconnectedness of the value chains (Kardung et al. 2021). Horizontal interconnectedness refers to the several businesses operating at the same level of the value chain in a similar or different industry, while vertical connectedness refers to the different and subsequent parts of the supply chain.
Four main categories of key stakeholders for the development of circular systemic solutions, identified in the CCRI methodology (European Commission 2022b), are transposable to the case of biocircular solutions development in urban areas. First, the local authorities are active in stimulating the debate, providing insights and expertise, and promoting the initiative. Second, the industry and businesses are central because they constitute the essential part of local and regional economies, and because they can bring expertise and knowledge in support to decision-making. Industry and businesses can be of different economic sectors, including rural economy which is essential to the bioeconomy. Third, as highlighted in the previous driving force, the consumers can provide highly valuable feedback and advice. Also, consumer organizations and NGOs can be efficient intermediaries to reach, inform and engage consumers. Finally, universities and research institutions can bring supportive knowledge and know-how on some specific aspects of the value chains to be developed.
The development of biocircular value chains and business models shall be inclusive, involving and empowering resources producers, rural actors depending on the feedstock sources, and supply chain actors in order to turn climate change and biodiversity challenges into opportunities which would then lead to diversify incomes and create new types of employments (European Commission 2022a, Lasarte-Lopez et al. 2022). It is of primary

importance to characterize the value chain technological requirements and to identify which business, industry, research institution could respond (Lokesh et al. 2018, European Commission 2022b).

In regard to the BCC project scope and value chain of concern, industry, businesses and local public authorities have the highest interest and the highest influence on decisions made for the biocircular valorisation of organic waste and wood residual waste. However, the stakeholders to be involved would be specific to each business model and each regional or local value chain, of which one of the determining factors is the type of feedstock available and its quality.

For feedstock issued from biowaste, the feedstock availability and quality strongly depend on the collection and separation methods implemented (Caldeira et al. 2019, Favoino et al. 2019, Van der Linden et al. 2020). The willingness to obtain high quality feedstock for valorisation into high value products through biorefineries, which is at the top of the waste hierarchy, can of course be discerned as a driver. But this requires a more complex biowaste collection and separation system, which can induce considerable logistic and economic constrains. This is especially the case for organic food waste, due to the sanitary conformities to be respected. Some specific transport and storage conditions are required in order to avoid the degradation of the feedstock and maintain its physico-chemical properties and added-value (Angouria Tsorochidou et al. 2021, Caldeira et al. 2019, European Commission 2019).

From this statement it is understandable that there is a risk of irregularities for the biowaste feedstock supply chain, in term of quantity and quality, that must be integrated in the development of effective and resilient value chains and associated business models (Lokesh et al. 2018). Then, this can be critical for the socio-economic and environmental sustainability of the treatment infrastructure (Caldeira et al. 2019). Indeed, the uncertainty about the stability of the feedstock supply chain is particularly critical for the correct dimensioning of the infrastructure capacity, in particular when dealing with the transition to a larger scale facility of biorefineries or with any new recycling processes that are mostly available until now at low TRL (Van der Linden et al. 2020, European Commission 2022b).

This conducts to Fritsche et al. (2020) critical view on projects that aim to achieve large scale, cost-effective and highly efficient biorefineries infrastructure, which is not compatible with the (food) biowaste feedstock supply chain. The authors argue that biorefinery technological concept and facilities shall remain at small scale to ensure their efficiency, their sustainability, and their contribution to regional and rural development (see also below the driving force "sustainable management and use of biological resources").

Given the numerous parameters influencing the sustainability of each specific biorefinery project, its planification shall be supported with a comprehensive techno-economic analysis (Caldeira et al. 2019). Statistics in the field could be helpful to gauge the new projects of bio-based industries, but these studies are unfortunately lacking in the literature (Lasarte Lopez et al. 2018). Hence, the lack of mid to long term vision related to the biorefinery efficiency and return on investment inhibits the companies to change their organisational structure and move forward of the established technologies. It could also limit the willingness to develop collaboration and partnership between stakeholders along the value chain while it is a key factor of success (Lewandowsky 2018, Reim et al. 2019, European Commission 2022b). This is closely linked to another critical aspect for the development of the bioeconomy, which is the exploitation of the innovation potential (Reim et al.2019, Kardung et al. 2021, Salvador et al. 2021, European Commission 2022a). Despite this and the socio-economic benefits of the development of sustainable, circular bioeconomy value chains could bring, it leads to technological developments with a level of innovation lower that what could be expected, and to a gap between research and industries which is difficult to fill in (Van der Linden A. et al. 2020). The governments and public authorities could certainly better support the overcoming of these barriers, by changing their focus priorities to enhance a more cross-sectoral approach, by investing in public research on bioeconomy. Both private and public actors shall contribute to the creation of regional industry clusters that can support the creation of regional integrated network of industries (Lewandowsky et al. 2018, European Commission 2019 and European Commission 2022b).

This is potentially critical for the competitiveness of the biocircular solutions compared to innovations from other emerging sectors (Fritsche et al. 2020). Like in section 3.2.2, here again the lack of experience and skills, expertise and technical know-how on biocircular concepts and approaches from businesses and public authorities leads to a limited understanding of the associated sustainability benefits (European Commission 2022b) and hinder the cross-sectoral cooperation.

3.2.4. Development of a skilled and competent workforce at the European level

To tackle this issue and more globally to contribute to the 5th objective of the EU bioeconomy strategy (EU 2018) which is to strengthen the European competitiveness and create jobs, the next driving force is *"the development of a skilled and competent workforce at the European level".* The need to strengthen the professional training offer inside European Member States, through further appropriate investments, is pointed out as an essential vector for dynamizing and developing further the bioeconomy sector, to ensure its competitiveness at the international level and to create skilful and qualitative jobs (Lasarte Lopez et al. 2018, European Commission 2018b, Caldeira et al. 2019, European Commission 2022a and European Commission 2022b). As highlighted previously, this is required for actors from both the private and public sectors, and governments should invest in order to support education and professional training (Lewandowsky 2018, Caldeira et al. 2019, Angouria Tsorochidou et al. 2021).

However, as long as the bioeconomy would remain a niche sector or represent a small share of the market, the need for these specific competences and know-how development would remain limited, making it more difficult for the public authorities to invest and prioritize education in the field (Philip et al. 2018), bringing back to the need for strengthening the bioeconomy market, identified in section 3.2.1.

In addition to enhancing the interactions between the value chain stakeholders (section 3.2.3.), the creation of industry clusters at the national, regional or local level can also effectively support the development of skills and competitiveness, contributing to create an integrated bioeconomy network of related industries that can provide inputs and support to each other, and can foster some collaborations and mutualizing competences (Reim et al. 2019, Philip et al. 2018, Lewandowsky 2018).

3.2.5. Sustainable Management and use of biological resources

The development of a skilled and competent workforce would also largely contribute to the next biocircular economy driving force which is ***"the sustainable management and use of biological resources"***, corresponding to the 2nd objective of the EU bioeconomy strategy (Section 1). This is a tricky challenge which is essential to tackle to ensure sustainability of the circular bioeconomy. Indeed, the demand of biomass for food, material and energy production is growing significantly, given the growing population and the current consumption patterns. Transforming the economy towards bioeconomy would be beneficial only if the consumption and production models converge through the consideration and the respect of the regenerative capacity of the planet (Fritsche et al. 2020, WBCSD 2020). The increasing demand for biomass from additional sectors and markets, such as pharmaceuticals, textiles, building materials, packaging (WBCSD 2020), can place some sectors under threat, like the electricity and heat production which are the major sectors using biomass in Europe, and it can induce pressure on the management of land transformation, causing indirect damages on the biodiversity and climate change (Fritsche et al. 2020, Verkerk et al. 2021, European Commission 2022a.).

Circular bioeconomy value chains relying on biowaste valorisation would contribute to alleviate the existing pressure, but still the balance between supply and demand of biowaste feedstock for different purposes should be central to the development of sustainable business models. The development of global value chains (multi-regional or multi-national) could present some advantages like facilitating the implementation of bioeconomy with harmonized practices. But then, the sustainability of such global systems, in regard to their contribution to climate change mitigation, maintaining biodiversity and ecosystem services, and their socio-economic benefits like job creation and diversification of the rural economy, could be questioned (Lokesh et al. 2018, Kardung et al. 2021).

The needs for the regional development of circular bioeconomy through biorefinery, energy recovery and composting are put forward in the literature, rather than global and large scale industrialisation, as it is the case for the fossil based economy.
Short domestic supply chains allow to identify in an easier way the potential conflicts and pressure existing for the supply of biomass and its demand for various local purposes (Lasarte Lopez et al. 2018, Caldeira et al. 2019, Fritsche et al. 2020, Verkerk et al. 2021, European Commission 2022a). Kardung et al. (2021) also point out that regional development allows to estimate more precisely the investment requirements, each region having specific attributes, strengths, and opportunities. Through its case study on decentralized small scale biowaste treatment plant, Angouria Tsorochidou et al. (2021) demonstrate the benefits of local value chains, in terms of environmental and socio-economic benefits, with the production of high-quality products inducing limited investment for the treatment infrastructure and the waste collection.

3.2.6. Funding and investment resources

The five driving forces exposed so far lead to a new driving force, namely *"the funding and investment resources to support the development of a competitive, sustainable, circular bioeconomy"*. As pointed out earlier, economic funds and investment are required to strengthen the bioeconomy workforce competences and skills to handle and develop the concepts and technologies associated to a sustainable, circular bioeconomy. Increasing the target for the amount of biowaste to be recycled and recovered constitutes an incentive for investment, especially for the development of additional or new infrastructures and technologies (European Commission 2019). The bioeconomy offers the opportunity to develop new value chains, with the biorefinery concept at its heart, inducing need for research and development and offering significant opportunities for innovation (Lewandowsky 2018, Philip et al.

2018, Kardung et al. 2021). The Strategic Innovation and Research Agenda formulated by the Bio-based Industries Consortium aims at supporting the identification and prioritization of the technological and innovation challenges to address. To support those requirements, the economic and human resources public investment from governments are the most determining factors (Angouria Tsorochidou et al. 2021), but the potential for innovation shall also attract private investments along the value chain (Lewandowsky 2018, Kardung et al. 2021). This is also raised in the Bioeconomy strategy progress report from the European Commission, warning the insufficient funding sources available to foster innovation into the bioeconomy, and the too weak mobilisation of private investments (European Commission 2022a). This reluctance from the private sector is certainly due to the uncertainty of the payback time, while the upfront investment remains significant (European Commission 2019, European Commission 2022b). The level of investments will determine the capacity of progress and innovation in the EU member states, and how fast innovative solutions can be developed, implemented and become competitive (Kardung et al. 2021).

3.2.7. Ensuring the transition to a sustainable circular bioeconomy

Finally, *"Ensuring the transition to a sustainable circular bioeconomy"* is of primary importance and constitutes the seventh driving force popping up from the literature review, somehow wrapping up several arguments already highlighted in the description of the other driving forces and pointing out the need to deepen the understanding and assessment of sustainability performances of the new business models and value chains.

The consideration of the cross-cutting issues and of the multiple objectives of the transition towards circular bioeconomy in the evolutive policy context, as well as of the competition between the different sectors of the bioeconomy, is central to the modelling and assessment of sustainability performances, to better support policy making, industrial decision making and market development and stabilization (Ladu et al. 2017, Verkerk et al. 2021, European Commission 2022a).
A better understanding of the potential synergies and trade-offs of technology and policy options must also be considered in the assessment (European Commission 2022a). It is pointed out that comprehensive tools and metrics for the evaluation and monitoring of circular bioeconomy systems' sustainability are missing, but such tools and studies would strengthen the confidence of policy makers, public authorities and private businesses to invest further for the transition towards bioeconomy development (Loiseau et al. 2016, Caldeira et al. 2019, Fritsche et al. 2020, Verkerk et al. 2021, European Commission 2022a, European Commission 2022b).

In addition, sustainability assessment shall be considered not only for the value chains but also for end products. Indeed, bio-based products can present better carbon footprints than functionally equivalent fossil-based products, but they can be sensitive to a number of other environmental impacts such as water and land use, ecotoxicity and eutrophication (Fiorentino et al., 2017, Kardung et al. 2021, Caldeira et al. 2022).
The consistent pathway proposed by the FAO from the United Nations (Bracco et al. 2019) for monitoring and evaluate bioeconomy implementation at the product/value chain level and at the territorial level, shall be considered, as well as the set of indicators proposed by Kardung et al. (2021) in the framework of the BioMonitor H2020 project.

The drivers and barriers identified in the case studies presented by Ghosh et al. (2018), Demichelis et al. (2019), and Taffuri et al. (2021) match with those presented through the seven driving forces in this report.

3.3. Criteria for the selection of suitable technological pathways

The need to carry out predictive sustainability assessment of new circular bioeconomy business models and value chains was identified in the literature review. To be consistent, such assessment shall rely on complex modelling in the background. To do so, the most exhaustive approach would certainly be to use the results of Integrated Assessment Models. That would allow the integration of the short to long term policy changes planned or assumed in the assessment, as well as their effects on the whole socio-economic and environmental system. And that would also allow to account for interlinkages and feedback effects characterizing the potential synergies and trade-offs between industrial sectors and technologies (Fritsche et al. 2020, Panoutsou et al. 2020, Verkerk et al. 2021, European Commission 2022a).

Such modelling approaches are out of scope of the purpose of the BCC guidelines, whose goal is to guide the choice of the most appropriate biocircular solution(s) depending on the specificities of the territory or urban area concerned. A list of influential criteria has been established (Table 3) from the drivers and barriers that have emerged from the analysis of the literature carried out in Section **Error! Reference source not found.**. Both the specific context of the territory or urban area of concern, and the different technologies of potential interest which will be integrated in the BCC guidelines technology portfolio (see Section 2.2), will be characterized according to this list of influential criteria. In the case features of one or several technologies match with the specific context characteristics, the technology(ies) will be identified as suitable, and some information on the sustainability performances of these technology(ies) will be provided, based on literature sources available for each technology. The BCC guidelines will be available through a web application, which operating principles are illustrated in Figure 3. The next deliverable D4.2 of the BCC project WP4 will be dedicated to the full documentation of the technology portfolio and of the guidelines web application operating mode and background logic.

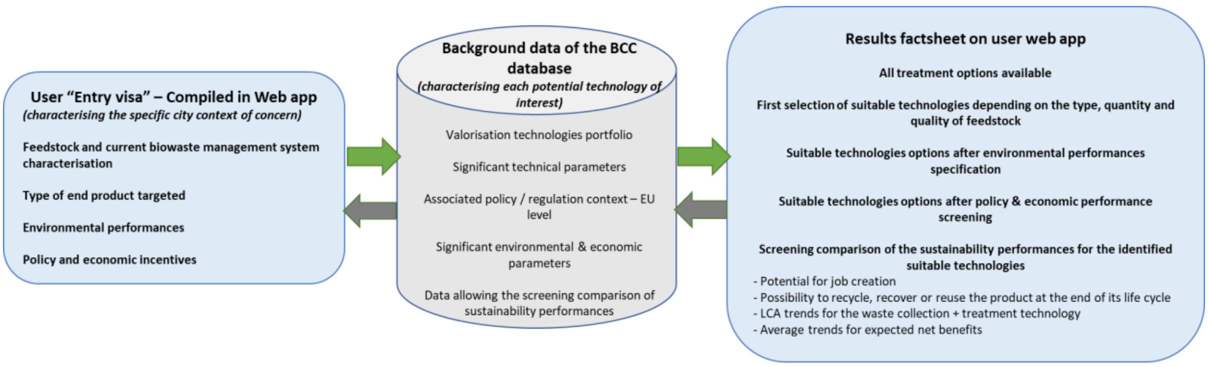

Figure 3: Operating principles of the BCC guidelines web application

Table 3: List of influence criteria for the choice of a suitable bio-circular technology for the valorisation of organic and wood based biowaste, depending on cities and urban areas specific context, and on specific characteristics from technologies.

Criteria to be specified by the web application user in regard to the context of the waste stream under consideration at city or regional level. On the background BCC database (Figure 3), each technology will also be characterised according to these criteria.	
1. Feedstock and current system characterisation	Compatible feedstock
	Continuous and regular availability of feedstock
	Sorting at source / Separate collection system
	Specific sorting after collection in order to separate the organic fraction
	Non-hazardous contaminant acceptance / High quality feedstock
	Capacity (in terms of feedstock acceptance) for one average single plant
	Price and price stability of feedstocks at the end of waste state compared to landfill tax
	Compatibility with multi-regional vs. local supply chain
	Waste hierarchy category (Recycling (high value), Recycling (medium and low value), Recovery (Energy and heat), Disposal)
	Potential contribution to EU targets for energy recovery from biowaste
	Potential contribution to EU biowaste recycling targets
2. Type of end product targeted	Category of the economic value of the end product
	Capacity (in terms of feedstock acceptance) for one average single plant
	Existing regulation regarding the product output (EU quality and safety standards…)
	Social acceptance of a new product
	Competitiveness compared to conventional products / market price for the bio-based products
3. Environmental performances	Conventional product counterpart / Substitution potential
	Target for CC Impact reduction (%) compared to conventional counterpart
	Process energetic yield (CED produced *vs.* CED consumed)
	Reduced land surface used compared to conventional counterpart bio-based resource
	Other significant sources of environmental impacts (toxicity, air emissions, waste…)
4. Political and economic incentives	Need for developing specific competences
	Additional specific equipment required (for any of the various processing steps) compared to the current situation
	Available subventions from the EU Commission /national or regional entities (Yes / No–- Which conditions?): taxes, fees, economic incentives, or subsidies
	Net benefits (Value added vs. life cycle costs, considering available subsidies)
Sustainability performances of technologies – Information provided by the tool for each technology identified as suitable for the specific city / region context	
Indicators provided for the potentially suitable technologies identified	Potential for job creation
	Purpose of the end product
	(When relevant) Possibility to recycle, recover or reuse the product at its end of its life
	LCA trends for the waste collection + treatment technology–- relevant indicators

Conclusion

The D4.1 of the BCC project allowed to set the framework and the structure of the BCC guidelines, aiming at supporting the design and the development of sustainable and circular solutions fostering the development of bioeconomy value chains for biowaste management at the territorial scale, focusing in particular on the selected biowaste in the investigated pilot areas (organic fraction of MSW, agro-industrial biowaste and wood residual biomass streams).

The work has been conducted following three main stages. First, the definition and the scope of sustainable, circular bioeconomy was analysed and specified. Second, the purpose of the BCC guidelines to be developed was defined more specifically, providing a more specific framework, considering the scope defined in the first stage and the review of already existing tools. Third, the drivers and barriers towards sustainable and circular bioeconomy solutions development were identified through a literature review, in order to understand the criteria of influence that shall be considered to characterize both the potential technological solutions and the surrounding political, environmental and socio-economic context in which the solutions shall be implemented.

The ultimate purpose of a sustainable, circular bioeconomy strategy for biowaste valorisation is to support the transition towards production and consumption systems whose environmental impacts are reduced to a minimum, bringing societal benefits, through the development of economically viable technological solutions. It was demonstrated that numerous correlated driving forces can push forward the development and implementation of sustainable biocircular solutions, but also significant barriers hinder this development or restrain the potential for environmental and societal benefits that the development of bioeconomy should provide.

This conducted to the identification of a set of almost thirty criteria of influence for decision making regarding the design and development of sustainable circular bioeconomy value chains and associated technological solutions. These criteria can be intrinsic to the feedstock properties (e.g., composition and quality in terms of content of high-value substances or molecules, presence of contaminants…). The techno-economic efficiency of the technological options for recycling or recovery of biowaste is also of influence. Finally, the most convenient pathway towards waste biomass valorisation strongly depends on the local surrounding political and socio-economic context, and on the potential sustainability strategic targets for the local authorities and private stakeholders endorsing the responsibility of waste biomass management. Related drivers and barriers leading to the set of criteria are detailed in the third section of this report.

Considering this set of criteria, the BCC guidelines intend to screen the socio-economic, political and environmental urban or regional context in which the value chain shall be implemented, and to evaluate which technological pathway(s) for the biowaste valorisation would be potentially compatible with the described surrounding context. The goal is to support the stakeholders' decisions for setting some priorities for potential actions to move forward with sustainable, circular bioeconomy implementation for biowaste management.

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