

Biomass and organic waste potentials towards implementing circular bioeconomy platforms: A systematic bibliometric analysis

Original

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1 **Biomass and organic waste potentials towards implementing circular bioeconomy**
2 **platforms: A systematic bibliometric analysis**

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42 **Abstract**

43 Over the last decade, the increasing sustainability discourse has pushed interest in
44 investments in the nexus of economy, bioeconomy, and the circular economy (CE). Consequently,
45 the emerging circular bioeconomy (CBE) concept with a special focus on biomass and organic
46 waste valorization to closing the loops of product lifecycle has gained momentum. This research
47 aims at providing a comprehensive map of the body of knowledge in the biomass and organic
48 waste literature with a CBE perspective. To achieve this, a systematic bibliometric analysis is
49 performed employing keywords, co-citation, and bibliographic coupling analyses on a total of 646
50 peer-reviewed articles in Web of Science. As a result, four seminal background research themes
51 building the biomass and organic waste research in the CE were identified as follows: (1)
52 biological conversion technologies, (2) the CE concept and its implementation, (3) environmental
53 studies, and (4) food waste. Moreover, the results revealed that the most recent areas of research
54 in the target literature are clustered in seven categories, including: (1) the biochar industry
55 development in a CE perspective, (2) the role of insect biorefinery in waste management in the CE
56 framework, (3) lifecycle assessment studies for bio-waste treatment systems, (4) the CE
57 implementation in the agricultural sector, (5) spent coffee grounds valorization, (6) organic waste
58 biorefinery applications in a CBE, and (7) municipal bio-waste and food waste valorization *via*
59 anaerobic digestion process. The provided map of the research on biomass and organic waste in
60 the CBE framework can, on the one hand, support scholars in advancing the research and, on the
61 other hand, assist practitioners and local and national authorities in implementing the CE for bio-
62 based waste management.

63 **Keywords:** Biomass, Food waste, Biorefinery, Circular economy, Waste-to-energy, Anaerobic
64 digestion

65 **Abbreviations**

Abbreviation	Full term
APY	Average publication year
CBE	Circular bioeconomy
CE	Circular economy
LCA	Lifecycle assessment
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
WoS	Web of Science

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80 **1. Introduction**

81 Renewable energy resources have become significant players in sustainable global energy
82 strategies to reduce fossil fuels utilization worldwide [1–3]. The sustainable management of
83 renewable resources plays a vital role in transitioning from a fossil-based and linear economy
84 towards a resource-efficient, circular, and bio-based economy [4,5]. In this vein, bioenergy and
85 biomaterial production and applications can support the sustainability of the energy-environment
86 nexus and contribute to a cleaner and low-carbon environment [6,7]. During recent years, the
87 increasing discourse on the necessity of creating sustainable systems for the future has pushed
88 interest in investments in the nexus of economy, bioeconomy, and the circular economy (CE). The
89 CE implies closing, narrowing, and slowing supply chain loops to keep materials in use as long as
90 possible, contributing to a sustainable and zero-waste environment [8]. A bio-based CE, also
91 known as circular bioeconomy (CBE), focuses on the resource-efficient and sustainable
92 valorization of biomass [9].

93 As a carbon neutral-based renewable source of energy that comes from animal and plant
94 materials [6], biomass has been extensively explored by scholars in the context of the CE and BCE
95 establishment. Transitioning towards a CBE requires a comprehensive understanding of the
96 significance of using biomass and its practical implications by stakeholders throughout the whole
97 value chain, from product design to waste management practices [10]. The research in this area
98 has been mainly focused on technological advancements in biomass valorization [11], biomass
99 production for animal feed [12], conversion and application of organic waste biomass [13], energy
100 valuation of agroforestry biomass in the CE [14], renewable energy production employing
101 biomass-based biochar in line with CE principles [15], sustainable biomass production and its
102 function as a feedstock in the CE [10], the contribution of agricultural waste biomass in the CE

103 framework [16], valorization of microalgae biomass to support the CE transition [17], and waste
104 biorefinery towards a sustainable CBE platform [6]. As a result, a huge amount of biomass-related
105 scientific production has been evolving over recent years considering the contribution of the
106 following factors to low-carbon development and the transition from a linear economy to a CBE:
107 (i) biomass and organic waste streams, (ii) biomass valorization approach, and (iii) renewable
108 technologies and biorefinery concept in production and conversion of biomass into bio-based
109 products. Therefore, an inclusive map of the biomass waste research in the CE transition seems
110 lacking in the literature.

111 To fill this gap, the present research aims to characterize and map the body of knowledge
112 on biomass and organic waste in the CBE context. To the best of the authors' knowledge, no
113 systematic bibliometric analysis has been performed on the biomass waste subject area towards
114 implementing the CE and CBE in the literature. In this vein, a systematic bibliometric analysis is
115 conducted considering keywords, co-citation links, and bibliographic coupling networks as the
116 main units of analysis to address the following research questions (RQs):

- 117 • RQ1. How has the scientific production in biomass and organic waste research towards a
118 CE developed over time?
- 119 • RQ2. What are the main research hotspots (keywords) within the biomass and organic
120 waste in the CE literature?
- 121 • RQ3. What are the seminal founders (historical emergence of different perspectives) in
122 biomass and organic waste research in the CE?
- 123 • RQ4. What are the major emergent biomass and organic waste sub-fields of research in the
124 CE in the recent literature?

125 The remainder of this study is organized as follows. An overview of biomass to
126 biorefineries in the emerging CBE is provided in Section 2. The overall research design, including
127 the search strategy and target database to collect data (section 3.1), and bibliometric methods to
128 conduct the analysis (section 3.2), are explained in section 3. The results are presented and
129 discussed in four steps, including (i) descriptive results: performance indicators (section 4.1), (ii)
130 the keyword-based analysis: research hotspots (section 4.2), (iii) co-citation analysis (section 4.3),
131 and (iv) bibliographic coupling analysis (section 4.4). The implications for research, outlining the
132 potential opportunities and prospects for future developments, are proposed in Section 5. Finally,
133 Section 6 concludes the remarks and limitations of the present research.

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135 **2. Biomass to biorefineries in the emerging CBE**

136 Bioeconomy relies on positioning the waste biorefinery as a cornerstone for establishing
137 the CE and a driver for combating resource scarcity, climate change, price volatility, and increasing
138 demand challenges [18]. In this vein, sustainable biomass feedstock, as a promising alternative
139 energy source for biofuel production, in biomass-based biorefineries, plays a significant role in
140 transitioning to a CBE.

141 Biorefineries, as a strategic mechanism for implementing a CBE, are infrastructure
142 facilities for converting various biomass feedstocks to multiple bio-based products, such as
143 biofuels, biochemicals, bioenergy, and other high-valued bio-products [19]. In this regard, the
144 concept of biorefinery using waste has gained momentum among waste management communities
145 over the recent years to facilitate the CE transition. For instance, food waste biorefineries to
146 produce biofuels and bio-based materials have been under intense research due to the convergence
147 of policies and regulations towards achieving sustainable development goals within the 2030

148 Agenda for Sustainable Development [20]. Table 1 provides a list of the most recent reviews on
 149 the potentials of using biomass and organic waste through the biorefinery concept to position the
 150 CE framework.

151 **Table 1.** Recent reviews on using biomass and organic waste towards implementing a CE.
 152

Reference	Year	Type of review	Database	Timespan	Review focus
[21]	2021	Systematic	Scopus	2014-2019	Food waste conversion pathways in the CBE
[22]	2018	Critical	Not specified	Not specified	Adopting biorefinery strategy with an integrated approach through enabling bio-processes for developing a CBE
[23]	2020	Critical	Not specified	Not specified	Sustainable food waste management potentials to achieve a CBE model
[24]	2021	Critical	Not specified	Not specified	Sustainable processing and advanced techniques extended for food waste valorization to produce bio-based products
[25]	2020	Critical	Not specified	Not specified	Upscaling feasibility of bio-waste valorization to close the loop of CBE
[20]	2021	Critical	Not specified	Not specified	Food waste biorefinery and the direction towards CBE
[26]	2019	Systematic	Scopus	2009-2018	Potentials of spent coffee grounds biorefinery in transitioning towards a CE
[27]	2020	Critical	Not specified	Not specified	Food waste valorization in insect production and processing
[28]	2021	Critical	Not specified	Not specified	Implementing biomass-based biorefineries on a large scale focusing on substrates and biotechnologies
[29]	2021	Systematic	Scopus	2009-2020	Lignocellulosic biomass-based biorefineries
[30]	2022	Critical	Not specified	Not specified	Sustainable production of bioenergy and bio-products from bio-waste in a CE

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154 One of the main streams of the generated bio-waste worldwide is food waste [22], which
155 can be used to recover a wide range of energy and materials due to its carbon richness [21]. This
156 waste stream has been widely addressed by research communities seeking pathways towards
157 supporting a CE. Food waste biorefineries for biofuels and platform chemicals production can
158 significantly reduce adverse environmental effects and support sustainable resource management
159 in a CBE paradigm [20]. Conducting a systematic review on food waste conversion pathways,
160 Santagata et al. [21] outlined the opportunities for an emerging CBE as (i) reduced environmental
161 footprint and resource efficiency, (ii) avoided loss of economic value, and (iii) conditioning
162 stakeholders' behavior. The individual bioprocesses in the waste biorefinery approach for food
163 waste, such as fermentation, acidogenesis, and methanogenesis, need to be optimized for
164 generating various bio-based products and better transforming linear economy to a CBE [22].
165 Future technological advances in food waste management are expected to capitalize on the multi-
166 functionality of products, boundaries, trade-offs between resources and food waste, and allocation
167 in a circular system [23].

168 In this regard, although some food waste-valorizing high-end techniques have been
169 established at a laboratory scale, appropriate implementation of these techniques at the commercial
170 level in a sustainable way is still facing critical challenges [24]. Zabaniotou and Kamaterou [26]
171 highlighted the lack of adequate research on spent coffee grounds biorefining approaches and the
172 need for further realistic economic assessment of the mono-process spent coffee grounds break
173 down at higher technology readiness level. Moreover, they showed that efficient conversion of
174 spent coffee grounds in a cascade biorefinery depends on the cost-effective processing schemes
175 and the spectrum of various end-products. Insect-based bioconversions, as a marketable alternative

176 for food waste reduction, can efficiently convert several tonnes of food waste into valuable
177 products, providing an attractive solution for closing the food value chain loop in a CBE [27].

178 Nevertheless, the bottlenecks of bio-waste valorization mainly lie within the technology,
179 highlighting the importance of conducting more research on (i) improving bioenergy density to
180 compete with commodity fossil fuels, (ii) drafting government support and policies for research
181 and development of bio-waste valorization process, and (iii) adopting advanced technologies to
182 generate products with competitive edge and deployment of commercial-scale facilities [25]. In
183 this regard, the role of LCA methods to increase the sustainability of commercial bio-products and
184 biofuels was outlined by Jain et al. [30]. Moreover, the integration of the biomass-based
185 biorefinery with the existing petroleum refinery was proposed by Kumar and Verma [28] as a
186 solution to reduce the overall cost of the process. In this vein, the concept of biomass utilization in
187 the bio-based refineries, such as lignocellulosic biomass-based biorefinery, can serve as an
188 effective model system and archetype for successfully implementing the CBE in the future [28,29].

189 Although various advancements have been recorded in this area, a comprehensive
190 knowledge map of the biomass and organic waste literature to establish a CBE through providing
191 a systematic bibliometric review on the available scientific production is still lacking. Therefore,
192 this research contributes to the existing studies by providing the state-of-the-art of biomass and
193 organic waste potentials in implementing CE and CBE platforms, in particular by (i) presenting
194 the performance indicators of scientific production in the target literature to date, (ii) mapping
195 theoretical and practical developments within the biomass and organic waste research in the
196 context of transitioning from a linear economy to a CE, and (iii) identifying the main areas of
197 research, hotspots, and research tendencies in biomass and organic waste applications in the CBE
198 framework.

199

200 3. Materials, methods, and research design

201 A systematic bibliometric review analysis adopted from Belussi et al. [31] and Ranjbari et
202 al. [8,32] was performed in this study to provide the state-of-the-art of biomass and organic waste
203 potentials and applications in implementing CE platforms. The bibliometric analysis evolved in
204 four steps: (1) descriptive bibliographic analysis to present the publication performance in terms
205 of time distribution, sources, authors, contributing countries and institutions, and funding agencies,
206 (2) keyword-based analysis to identify research hotspots and tendencies, (3) co-citation analysis
207 of the cited references to discover the major research clusters and founders of the studied
208 discipline, and (4) bibliographic coupling analysis of the articles to map the core emergent research
209 sub-fields of the most recent studies within the literature. Figure 1 visualizes the overall research
210 design and employed methods in this study corresponding to the relevant research questions. The
211 defined search strategy to collect the most relevant data as well as methods of analysis are
212 described in the following sub-sections.

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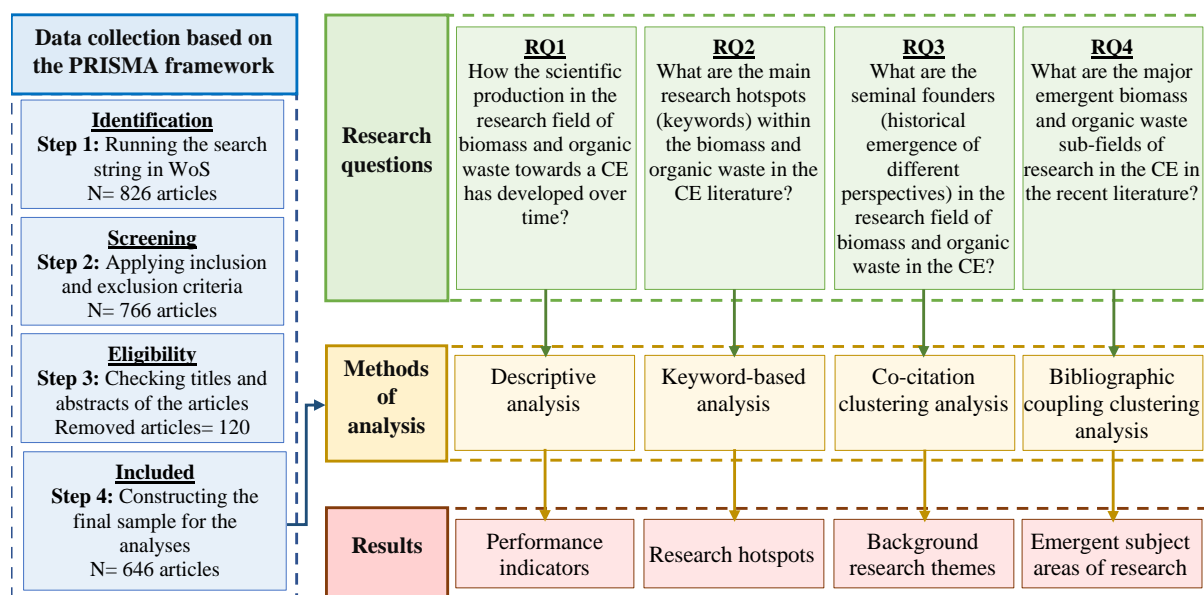


Fig. 1. The research framework.

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216 **3.1. Search strategy and data collection**

217 A search protocol based on the preferred reporting items for systematic reviews and meta-
218 analyses (PRISMA) statement [33] was developed to systematically identify, screen, and select
219 relevant articles from the target literature. In this vein, the Web of Science (WoS) Core Collection,
220 as the world's most trusted global citation database, was used as this research database. Given the
221 main focus of this research, different combinations of the three main keywords "biomass", "waste",
222 and "circular economy" were tested. As a result, the following search string including AND/OR
223 operators was constructed: ("biomass-based waste" OR "biomass waste" OR "waste biomass" OR
224 "waste from biomass" OR "organic waste" OR "organic-based waste" OR "biowaste" OR "bio-
225 waste" OR "bio waste" OR "bio-based waste" OR "food waste" OR "crop residue*" OR "crop
226 waste" OR "wood residue*" OR "wood waste" OR "forest* residue*") AND ("circular economy"
227 OR "circular bioeconomy" OR "circular bio-economy" OR "circular bio economy").

228 The initial run of the search string on the field "Topic: title, abstract, author keywords, and
229 keywords plus" in WoS returned a total of 826 articles. In the next step, the results were limited to
230 only (i) peer-reviewed articles, (ii) journal articles, and (iii) English materials. Nevertheless, no
231 time-period limit was applied to cover all scientific production within the study area.
232 Consequently, 766 articles published from 2011 to 2021 remained for further consideration. To
233 ensure the quality of the studied sample to perform a reliable analysis, the remaining articles were
234 scanned based on their titles and abstracts to exclude irrelevant articles from the analysis. As a
235 result, 120 articles were removed from the data, leading to a total of 646 eligible articles as the
236 final sample for conducting the bibliometric analysis. The details of the search strategy and the
237 article selection process are tabulated in Table 2.

238 **Table 2.** The search protocol to collect data from the target literature.
 239

Search string	("biomass-based waste" OR "biomass waste" OR "waste biomass" OR "waste from biomass" OR "organic waste" OR "organic-based waste" OR "biowaste" OR "bio-waste" OR "bio waste" OR "bio-based waste" OR "food waste" OR "crop residue*" OR "crop waste" OR "wood residue*" OR "wood waste" OR "forest* residue*")
	AND
	("circular economy" OR "circular bioeconomy" OR "circular bio-economy" OR "circular bio economy")
Searched in	Topic: title, abstract, author keywords, and keywords plus
Database	Web of Science
The last update	September 8, 2021
First Result	826 articles
Inclusion criteria	(i) English documents, and (ii) peer-reviewed journal articles
Second result	766 articles
Screening stage	120 articles were removed
Final sample	646 articles

240

241 **3.2. Analysis methods: Clustering and data representation**

242 Researchers have widely employed bibliometric analysis as a quantitative technique and
 243 powerful statistical tool [4] to evaluate the scientific production performance and map a body of
 244 knowledge in various fields and domains. Bibliometric approach to review the literature, with a
 245 special focus on the links among influential articles, contributing authors, main sources,
 246 references, and citation and co-citation networks [34], supports presenting an inclusive overview
 247 of the target literature. Moreover, bibliometric techniques increase researchers' analytical ability
 248 by introducing objective measures for scientific productions assessment that contrast the potential
 249 bias embedded in subjective assessments [35].

250 In this research, a descriptive analysis was carried out on a total of 646 peer-reviewed
 251 articles collected from the WoS database to provide performance indicators of the scientific

252 production in biomass and organic waste from the CBE literature. In the next step, a bibliometric
253 analysis was conducted by following two bibliometric approaches, including (i) the keyword-
254 based approach and (ii) the citation-based approach. The keywords of the articles in the sample
255 were analyzed and mapped based on their occurrence, co-occurrence, and recentness to render a
256 general overview of the research field tendencies and hotspots. Scholars have benefited
257 significantly from keyword-based analysis as a useful knowledge mapping tool for unfolding the
258 conceptual and thematic structure of academic domains and disciplines [36]. Keywords co-
259 occurrence analysis considers keywords as nodes, and the co-occurrence of a pair of nodes
260 represents a link between those nodes in the keywords co-occurrence network constructed. In this
261 context, the number of times that a pair of author keywords (nodes) co-occurs specify the weight
262 of the relevant link [37]. Among the citation-based approaches in bibliometric analysis,
263 bibliographic coupling and co-citation analyses are considered the main and most accurate
264 bibliographic techniques to assess the links between two scientific documents [31]. Therefore, co-
265 citation and bibliographic coupling analyses were used to study the possible relationship between
266 scientific publications in the biomass and organic waste literature in the CE context.

267 The co-citation link strength between two objects (i.e., article, author, journal, etc.) refers
268 to the number of times these two objects have been cited together in another object. On the
269 contrary, the bibliographic coupling link strength between two objects denotes the number of times
270 these two objects have simultaneously cited another object. On this basis, while the co-citation
271 analysis has a backward-looking approach to the target literature, the bibliographic coupling
272 analysis is a forward-looking perspective [31]. Therefore, in this research, co-citation analysis was
273 employed to describe the historical evolution of the biomass and organic waste research in the CE
274 discipline and identify its relevant major research themes. On the other hand, the articles were

275 clustered based on the bibliographic coupling links to identify more recent research sub-fields of
276 the subject in the literature.

277 The VOSviewer software version 1.6.16 [38] was used to perform the analysis. VOSviewer
278 is a computer program developed in the Java programming language that explores and visualizes
279 node-link maps within the documents based on bibliographic data [38,39]. Each node-link in the
280 map denotes a bibliometric network of an object in the database, such as keywords, articles, or
281 references, which extensively assists with better understanding and analyzing the research trends
282 of a specific discipline [39].

283

284 **4. Results and Discussion**

285 In this section, the study results are presented in four separate sections corresponding to the
286 RQs. First, descriptive results, including performance indicators of the target literature, are
287 provided in section 3.1 to answer RQ1. Second, the main findings of the keyword-based analysis
288 are visualized and discussed in section 3.2 to address RQ2. Third, co-citation analysis to cluster
289 the articles and identify the main research themes of the subject are presented in section 3.3
290 corresponding to RQ3. And finally, bibliographic coupling analysis results to map the emergent
291 sub-fields of the research are rendered in section 3.4 to answer RQ4.

292

293 **4.1. Descriptive results: Performance indicators**

294 The provided results in this section address the first RQ:

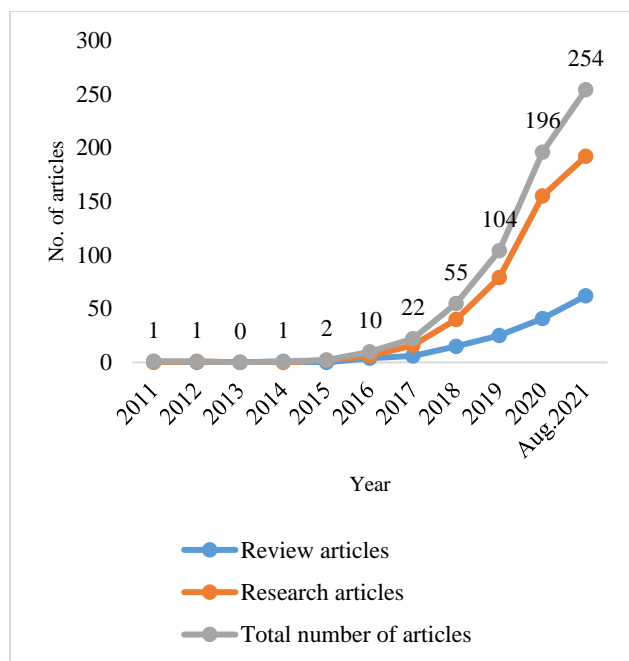
- 295 • RQ1. How has the scientific production in biomass and organic waste research towards a
296 CE developed over time?

297

298 **4.1.1. Publications' evolution over time**

299 To provide an insight into the evolution of publications considering biomass and organic
300 waste from the CE lens over time, the trend of publication of the articles in our considered sample
301 dataset is plotted in Figure 2. Among the overall 646 articles, 155 articles are reviews, constituting
302 approximately 24% of the whole sample. Therefore, the evolution of research and review articles
303 are also plotted in Figure 2. As can be clearly seen from this figure, although biomass has a long
304 history in research, looking at this research field from a CE point of view is a recent phenomenon,
305 starting from 2011 based on the publication date of the oldest paper in our dataset. While from
306 2011 to 2015, only 5 papers in total were published, in 2016, this number tripled, as 10 new articles
307 were published in this domain. The number of publications from 2016 onwards has experienced a
308 drastic increase, such that only after 4 years, the annual publication reach 196 in 2020, and only
309 by August 2021, other 254 new articles are added to the database. The number 254 for the year
310 2021 captures both the articles with the publication year 2021 and also 27 early access articles in
311 our dataset, which have no publishing issue, yet.

312 The growth in the annual number of published articles in the biomass waste domain from
313 the lens of CE is not only true about the overall number of articles, but it is also true about research
314 and review articles, separately. The former with a much faster trend than the latter. While only 6
315 research articles and 4 review articles were published in 2016, these annual numbers increased to
316 155 and 41 in 2020 and 162 and 62 by August 2021, respectively. The significant share of review
317 articles from the total published articles may refer to the mass amount of research in the biomass
318 waste field that has been looked at from the CE viewpoint in research articles in recent years,
319 which has resulted in the recentness of the topic.



320

321 **Fig. 2.** The number of annual published articles in the research field of biomass and organic
 322 waste towards a CE.

323

324 4.1.2. Journals and publishers

325 The 646 articles in the studied dataset were published in 186 journals from 39 publishers.

326 Table 3 provides the list of journals with more than 10 published articles in our dataset, and Figure

327 3 shows the publishers' share from the published articles. Based on Table 3, Journal of Cleaner

328 Production, Sustainability, and Bioresource Technology are the top 3 journals in terms of the

329 number of articles, with 56, 38, and 35 articles, standing for 8.7%, 5.9%, and 5.4% of the articles.

330 From the 14 journals presented in Table 3, the publisher of 7 journals is Elsevier, and the published

331 of 4 journals is MDPI. This ranking is also confirmed by Figure 2, as Elsevier has the highest

332 number of published articles, followed by MDPI, with 301 and 148 articles, respectively.

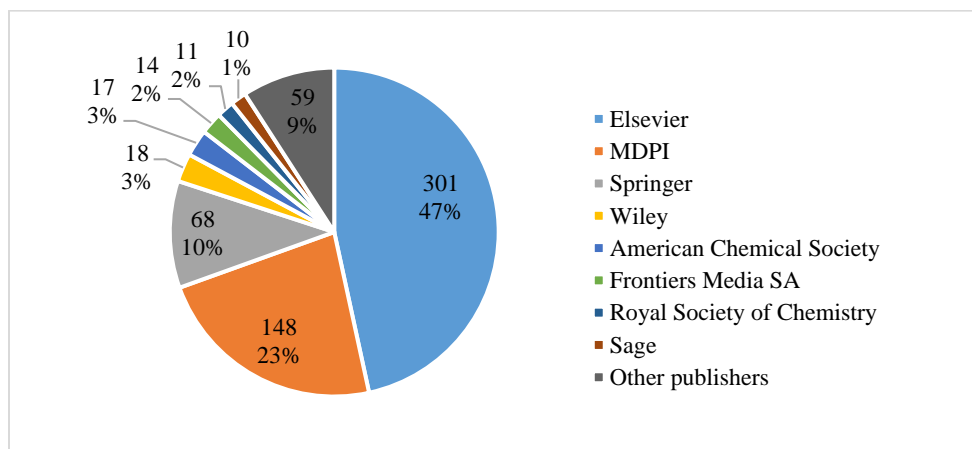
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335 **Table 3.** Top productive journals with more than 10 published articles in biomass and organic
 336 waste research towards a CE.
 337

Journal	Number of articles	Citations to articles	Publisher	Impact factor (2020)	CiteScore
Journal of Cleaner Production	56	1240	Elsevier	9.297	13.1
Sustainability	38	253	MDPI	3.251	3.9
Bioresource Technology	35	1120	Elsevier	9.642	14.8
Energies	28	148	MDPI	3.004	4.7
Science of the Total Environment	28	381	Elsevier	7.963	10.5
Waste Management	26	412	Elsevier	7.145	11.5
Renewable & Sustainable Energy Reviews	22	410	Elsevier	14.982	30.5
Waste and Biomass Valorization	17	152	Springer	3.703	4.2
Resources Conservation and Recycling	15	229	Elsevier	10.204	14.7
Journal of Environmental Management	13	107	Elsevier	6.789	9.8
Molecules	13	186	MDPI	4.411	4.7
ACS Sustainable Chemistry & Engineering	11	75	American Chemical Society	8.198	12
Applied Sciences-Basel	11	35	MDPI	2.679	3
Environmental Science and Pollution Research	11	95	Springer	4.223	5.5

338



339

340 **Fig. 3.** Most productive publishers in the research field of biomass and organic waste towards a
 341 CE (number and percentage of articles are shown on the chart).
 342
 343

344 **4.1.3. Core articles**

345 Considering highly cited articles as more influential in the research field [40], Table 4 and
346 Table 5 present the 10 most influential research and review articles in our dataset, respectively.
347 According to Table 4, the most influential research article with 93 citations in WoS was published
348 by Sheldon [41] in Journal of Molecular Catalysis A-Chemical, highlighting waste lignocellulosic
349 biomass valorization as a key to the sustainable production of chemicals, liquid fuels and polymers
350 in the long term. Three out of 10 highly cited research articles were published in Science of the
351 Total Environment and are ranked 3rd, 7th, and 10th, earning 154 citations in total. This journal
352 was ranked 4th in terms of the number of published articles in Table 3. The second and third highly
353 cited research articles were published by Monlau et al. [42], referring to functional integration of
354 anaerobic digestion and pyrolysis for sustainable resource management, and Sharma et al. [43],
355 addressing waste-to-energy nexus for CE and environmental protection, receiving 78 and 63
356 citations, respectively.

357 As reported in Table 5, the highly cited review articles have received more citations than
358 the top 10 research articles. The most cited review article with 431 citations was published by
359 Mirabella et al. [44] on current options for the valorization of food manufacturing waste. The
360 review articles by Puyol et al. [45], on resource recovery from wastewater by biological
361 technologies, and Dahiya et al. [22], on food waste biorefinery, with 197 and 188 citations,
362 respectively, are the second and third highly cited review articles.

363

364

365 **Table 4.** Ten most cited research articles in the research field of biomass and organic waste
 366 towards a CE.
 367

Reference	Year	Title	Journal	Citation
[41]	2016	Green chemistry, catalysis and valorization of waste biomass	Journal of Molecular Catalysis A-Chemical	93
[42]	2016	Toward a functional integration of anaerobic digestion and pyrolysis for a sustainable resource management. Comparison between solid-digestate and its derived pyrochar as a soil amendment	Applied Energy	78
[43]	2020	Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy	Science of the Total Environment	63
[46]	2018	Techno-economic and profitability analysis of food waste biorefineries at European level	Bioresource Technology	59
[47]	2019	Environmental sustainability of anaerobic digestion of household food waste	Journal of Environmental Management	58
[48]	2017	Farmer perceptions and use of organic waste products as fertilisers - A survey study of potential benefits and barriers	Agricultural Systems	48
[49]	2019	Environmental and economic implications of recovering resources from food waste in a circular economy	Science of the Total Environment	47
[50]	2015	Life Cycle Assessment from food to food: A case study of circular economy from cruise ships to aquaculture	Sustainable Production and Consumption	46
[51]	2016	Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse	Waste Management	45
[52]	2020	Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy	Science of the Total Environment	44

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375 **Table 5.** Ten most cited review articles in the research field of biomass and organic waste
 376 towards a CE.
 377

Reference	Year	Title	Journal	Citation
[44]	2014	Current options for the valorization of food manufacturing waste: a review	Journal of Cleaner Production	431
[45]	2017	Resource Recovery from Wastewater by Biological Technologies: Opportunities, Challenges, and Prospects	Frontiers in Microbiology	197
[22]	2018	Food waste biorefinery: Sustainable strategy for circular bioeconomy	Bioresource Technology	188
[53]	2016	Food waste valorization <i>via</i> anaerobic processes: a review	Reviews in Environmental Science and Biotechnology	113
[19]	2020	Biorefineries in circular bioeconomy: A comprehensive review	Bioresource Technology	111
[54]	2016	New Frontiers in the Catalytic Synthesis of Levulinic Acid: From Sugars to Raw and Waste Biomass as Starting Feedstock	Catalysts	106
[55]	2016	Biological processes for advancing lignocellulosic waste biorefinery by advocating circular economy	Bioresource Technology	99
[56]	2011	International comparative study of 3R and waste management policy developments	Journal of Material Cycles and Waste Management	98
[57]	2017	A roadmap towards a circular and sustainable bioeconomy through waste valorization	Current Opinion in Green and Sustainable Chemistry	93
[58]	2018	Feasibility analysis of anaerobic digestion of excess sludge enhanced by iron: A review	Renewable and Sustainable Energy Reviews	87

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380 4.1.4. Productive and influential authors

381 A total of 2841 authors contributed to the published articles in the domain of biomass and
 382 CE, which are available in the dataset of this research. Among these authors, 317 have at least 2
 383 papers in this dataset. While authors with the highest number of articles in our study were
 384 considered as highly productive authors, authors with the highest number of received citations to
 385 their articles available in our dataset (WoS) were taken into account as highly influential authors.
 386 Table 6 provides the list of the most productive and also the most influential authors in biomass

387 and organic waste research towards a CE. In this regard, Mohan S.V., with 9 published articles, is
388 the most productive author in our dataset. The average publication year of the 9 articles authored
389 by Mohan S.V. is 2018.89, which shows that this author has been active in this field for several
390 years. Irabien, A. and Thomsen, M. come next, each with 8 published articles and the average
391 publication year of 2018.38 and 2020.25, respectively, indicating that the articles published by
392 Thomsen, M. is more recent than the ones published by Irabien, A. within the list of highly
393 productive authors in Table 6, Zabaniotou, A. with the average publication year of 2017.20 for 5
394 articles has the least recent collection of articles.

395 In terms of the citations received by the authors, Sala, S. is the most influential author in
396 the biomass and CE domain. This author has received 490 citations for only 2 papers with an
397 average publication year of 2016. Castellani, V. and Mirabella, N., both with 431 citations to only
398 1 article published in 2014 come next. These two authors have been co-authors in a single review
399 paper titled “Current options for the valorization of food manufacturing waste: a review” published
400 in Journal of Cleaner Production in which Sala, S. is also a co-author [44]. The third rank for the
401 highly influential author refers to Mohan, S.V., who is also the most productive author in our
402 dataset.

403 A comparison between the average citation per article of the highly productive and highly
404 influential authors shows that except for Mohan, S.V., the average citation per article of the most
405 influential authors is considerably higher than that of highly productive authors. This shows the
406 attractiveness of some papers in this research field, most of which are review articles. Besides, a
407 comparison between the average publication year of the highly productive and highly influential
408 authors indicates that the average publication year of the influential authors is mostly lower than

409 that of productive authors. The lower average publication years may be another factor in earning
 410 more citations over time by the articles.

411

412 **Table 6.** The most productive and most influential authors in biomass and organic waste
 413 research towards a CE.

414

Highly productive authors						Highly influential authors					
Rank	Author	Articles	Citations	ACPA*	APY**	Rank	Author	Citations	Articles	ACPA	APY
1	Mohan, S.V.	9	288	32	2018.89	1	Sala, S.	490	2	245	2016
2	Irabien, A.	8	125	15.63	2018.38	2	Castellani, V.	431	1	431	2014
	Thomsen, M.	8	94	11.75	2020.25		Mirabella, N.	431	1	431	2014
3	Taherzadeh, M.J.	7	95	13.57	2020.57	3	Mohan, S.V.	288	9	32	2018.89
4	Awasthi, M.K.	6	95	15.83	2020.50	4	Sarkar, O.	211	3	70.33	2019
	Ok, Y.S.	6	92	15.33	2020.50	5	Hulsen, T.	206	2	103	2018.5
	Zhang, Z.	6	95	15.83	2020.50	6	Puyol, D.	205	3	68.33	2019
5	D'adamo, I.	5	129	25.80	2019.60	7	Dahiya, S.	203	3	67.67	2018.67
	Moustakas, K.	5	114	22.80	2019.40	8	Chatterjee, S.	201	2	100.50	2018
	Song, S.	5	30	6	2020.80		Sravan, J.S.	201	2	100.50	2019
	Tan, H.T.W.	5	30	6	2020.80	9	Astals, S.	197	1	197	2017
	Teigiserova, D.A.	5	83	16.60	2020.40		Batstone, D.J.	197	1	197	2017
	Tsang, D.C.W.	5	88	17.60	2020.20		Kromer, J.O.	197	1	197	2017
	Zabaniotou, A.	5	192	38.40	2017.20		Peces, M.	197	1	197	2017

415 * ACPA: Average citation per article.

416 ** APY: Average publication year.

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420 4.1.5. Author affiliations

421 The 2841 authors contributing to the studied research domain were affiliated with 995
 422 institutions worldwide. Table 7 provides a list of the most productive organizations based on the
 423 number of times their names have appeared as the authors' affiliations in our dataset. University
 424 of Padua in Italy, with 12 articles, which constitute 1.86% of the total articles in our sample, is the
 425 leading institution in this regard. The National University of Singapore in Singapore and the
 426 University of Milan in Italy, each with 11 articles, are ranked second in terms of productivity,
 427 followed by the National Technical University of Athens in Greece and Northwest A&F University

428 in China, each with 10 articles. Among the 10 institutions listed in Table 7, three institutions are
 429 located in Italy, which shows the high productivity of the Italian institutions in the research in the
 430 biomass and CE domain.

431
 432 **Table 7.** The most productive organizations regarding the number of articles in biomass and
 433 organic waste research towards a CE.
 434

Organizations	Country	Articles	% of total articles	citations
University of Padua	Italy	12	1.86	106
National University of Singapore	Singapore	11	1.70	53
University of Milan	Italy	11	1.70	145
National Technical University of Athens	Greece	10	1.55	169
Northwest A&F University	China	10	1.55	138
Aarhus University	Denmark	9	1.39	95
Consiglio Nazionale delle Ricerche (CNR)	Italy	9	1.39	97
University of Aveiro	Portugal	9	1.39	28
University of Cantabria	Spain	9	1.39	125
University of York	UK	9	1.39	175

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437 **4.1.6. Geographical distribution: Contributing countries**

438 A total of 83 countries contributed to the production of scientific literature on biomass and
 439 organic waste from the lens of CE. The top 10 countries in terms of the number of published
 440 articles are presented in Table 8. As can be seen, Italy, Spain, and China, with 137, 103, and 68
 441 articles, respectively, are the top three productive countries, publishing overall 47.59% of the
 442 articles. These countries also have the highest citation numbers compared to the other countries on
 443 the list. Considering the international collaborations among the contributing countries, Italy with
 444 46 international partner countries and China with 121 international collaborations in their
 445 published articles are the leading countries in international co-authorship.

446 **Table 8.** The top 10 countries in terms of the number of published articles in biomass and
 447 organic waste research towards a CE.
 448

Rank	Country	No. of articles	% of total articles	Total citation	No. of collaborating countries	Total international collaboration	Average publication year
1	Italy	137	21.21	2231	46	103	2019.72
2	Spain	103	15.94	1002	37	84	2019.82
3	China	68	10.53	1012	32	121	2019.91
4	England	55	8.51	905	36	81	2019.47
5	India	39	6.04	638	16	44	2019.92
6	USA	37	5.73	425	36	72	2020.00
7	Poland	35	5.42	360	13	19	2019.89
8	Brazil	33	5.11	240	25	40	2020.15
9	Portugal	32	4.95	236	11	22	2020.19
10	Germany	28	4.33	395	35	65	2019.21
	Sweden	28	4.33	358	22	49	2019.68

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 450
 451 Table 9 provides the most frequent pairs of countries co-authoring articles in the biomass
 452 and organic waste in the CE domain based on the dataset in this research. The most frequent
 453 international collaboration has taken place between China and South Korea, referring to 12
 454 collaborations. This regular collaboration is followed by the co-authorship among China and USA,
 455 China and Italy, and Italy and Spain, each with the frequency of 11. Among the 12 pairs of
 456 countries in Table 9, China has appeared in 7 pairs, England in 4 pairs, and Italy and Spain each
 457 in 3 pairs. These countries are also the top 4 countries in terms of the number of publications,
 458 according to Table 8.

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464 **Table 9.** The most collaborating pairs of countries in the research field of biomass and organic
 465 waste towards a CE.
 466

Country 1	Country 2	No. of collaborations
China	South Korea	12
China	USA	11
China	Italy	11
Italy	Spain	11
India	China	10
Portugal	Spain	10
England	Spain	8
England	Germany	7
England	Italy	7
England	China	7
Malaysia	China	7
China	Sweden	7

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 469 **4.1.7. Funding agencies**
 470 Several funding agencies have supported studies conducted in this field to encourage
 471 research in the biomass and CE domain. Among the 646 articles in this study, 502 articles have
 472 received funding support from at least one funding agency. This number of articles constitutes
 473 approximately 77.71% of the total articles considered in the present research. Table 10 provides a
 474 list of highly supporting funding agencies regarding the number of articles they have supported.
 475 Approximately 10.37% of the total articles (67 out of 646 articles) are supported by European
 476 Commission, leading this organization to be the highest supportive funding agency in this research.
 477 The next ranks refer to UK Research Innovation (UKRI) and Coordenação de Aperfeiçoamento
 478 de Pessoal de Nível Superior (CAPES) with 20 and 19 articles, respectively. As can be seen from
 479 Table 10, European Commission has a significant distance from the other funding organizations

480 in terms of the number of articles supported. The number of articles supported by the European
 481 Commission is more than three times the number of articles funded by its following organizations,
 482 showing the potential of this institution in supporting the research within the biomass and CE
 483 research field.

484
 485 **Table 10.** The most supportive funding agencies in the research field of biomass and organic
 486 waste towards a CE.
 487

Funding Agency	Number of articles	% of total articles
European Commission	67	10.37
UK Research Innovation (UKRI)- UK	20	3.10
Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)- Brazil	19	2.94
Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)- Brazil	18	2.79
National Natural Science Foundation of China (NSFC)- China	16	2.48
Portuguese Foundation for Science and Technology- Portugal	16	2.48
Engineering and Physical Sciences Research Council (EPSRC)- UK	15	2.32
Council of Scientific & Industrial Research (CSIR)- India	9	1.39
European Commission Joint Research Centre	8	1.24
Italian Ministry of Education, University and Research (MIUR)- Italy	8	1.24
Department of Biotechnology (DBT)- India	8	1.24
National Science Foundation (NSF)- USA	8	1.24

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490 **4.2. Keyword-based analysis: research hotspots**

491 The keyword-based analysis results in this section address the second RQ:

- 492 • RQ2. What are the main research hotspots (keywords) within the biomass and organic
 493 waste in the CE literature?

494 To discover the main idea and the scope of articles and identify the research hotspots within
 495 the biomass and organic waste domain in CE, keyword co-occurrence analysis is conducted on the

496 authors' keywords in this section. After a proper data cleaning, as an essential step in conducting
497 keyword-based analysis [59], 1949 keywords were identified, 332 of which had more than 1
498 occurrence. These 332 keywords were used to build the co-occurrence network of keywords in
499 Figure 4 and served as the base for the keywords-based analyses.

500 Figure 4 presents five main categories of information regarding the author's keywords.
501 First, it shows the keywords with at least 2 occurrences in the network's nodes. Second, it reflects
502 the frequency of appearing the keywords through the size of their corresponding nodes, such that
503 a larger node represents a higher occurrence of the targeted keyword. Third, the co-occurrence of
504 the keywords is shown in the network by the lines linking the nodes. Fourth, the thickness of the
505 lines between the nodes indicates the number of co-occurrence of the pair of nodes, such that a
506 thicker line illustrates a more frequent co-occurrence. And finally, the colors of the nodes in this
507 figure show the recentness of the keyword, such that the darker the color of the node, the older its
508 average publication year. The average publication year refers to the mean of the publication year
509 of all articles, including a specific keyword among their authors' keywords.

522 “circular economy”, “circular bioeconomy”, and “bioeconomy” shows that “circular bioeconomy”
 523 is almost a more recent attractive keyword in this domain, followed by “bioeconomy”. A glance
 524 at the other keywords in Table 11 sheds light on the various focal points (e.g., anaerobic digestion,
 525 biorefinery, biochar, etc.) in the studied domain and the concepts and approaches to deal with the
 526 problem (e.g., LCA, resource recovery, recycling, etc.).

527

528 **Table 11.** The most frequent author keywords with at least 10 occurrences.

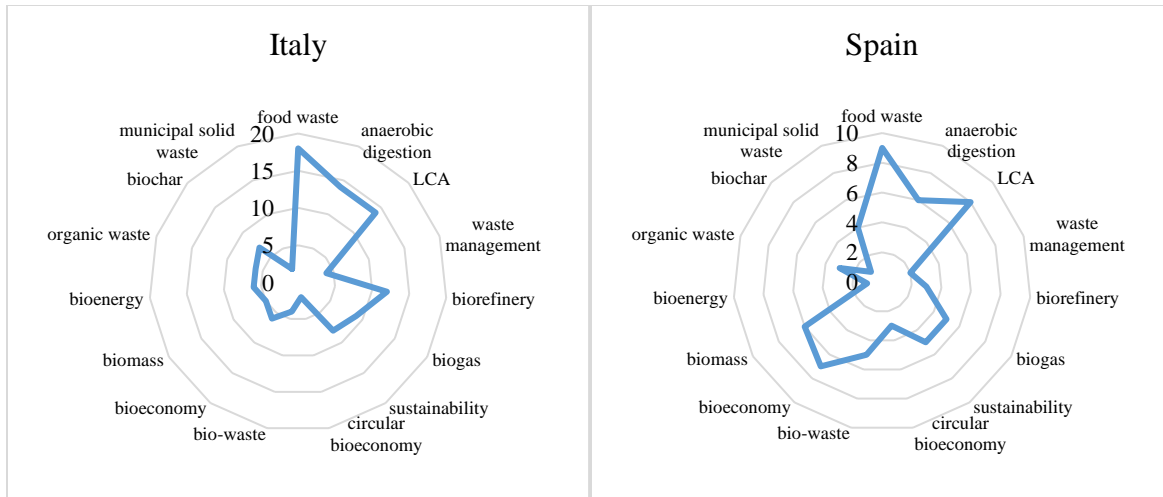
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No.	Keyword	Occurrence	Average publication year	No.	Keyword	Occurrence	Average publication year
1	circular economy	286	2019.91	16	municipal solid waste	21	2019.76
2	food waste	83	2019.66	17	resource recovery	20	2019.85
3	anaerobic digestion	66	2019.79	18	compost	18	2019.78
4	LCA	48	2019.77	19	valorization	18	2020.11
5	waste management	43	2019.88	20	waste valorization	18	2020.22
6	biorefinery	42	2020.02	21	bio-methane	16	2019.94
7	biogas	41	2020.17	22	recycling	15	2019.27
8	sustainability	39	2019.77	23	biofuel	14	2020.14
9	circular bioeconomy	33	2020.36	24	digestate	13	2018.85
10	bio-waste	32	2019.88	25	sewage sludge	13	2019.69
11	bioeconomy	30	2020.07	26	waste	13	2019.39
12	biomass	29	2019.55	27	waste-to-energy	11	2020.27
13	bioenergy	23	2019.52	28	biodiesel	10	2019.40
14	organic waste	23	2020.04	29	pyrolysis	10	2019.30
15	biochar	22	2019.91	30	renewable energy	10	2020.00

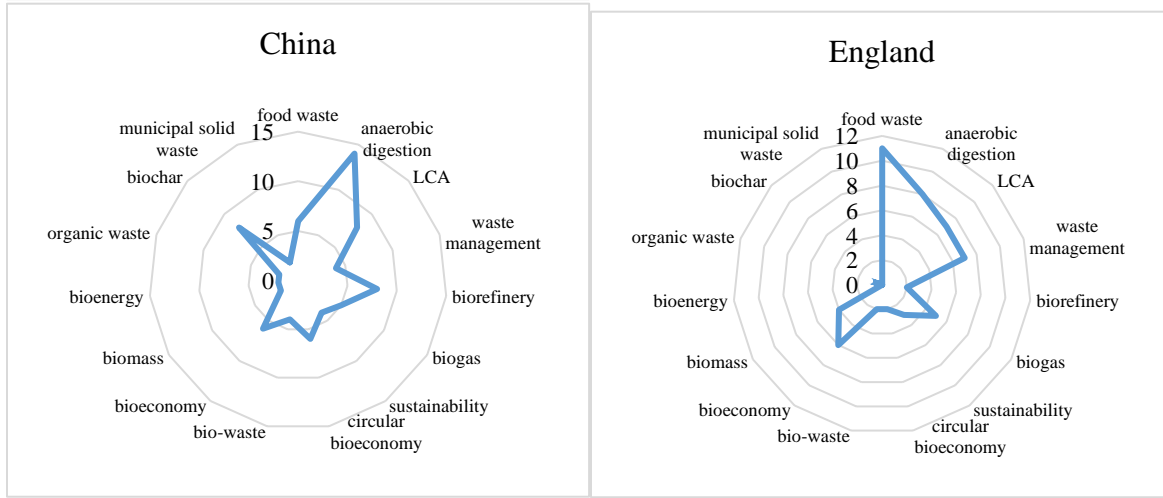
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531 However, the most frequent keywords identified do not necessarily imply that all the
 532 contributing countries to this research domain have the same focal point. Instead, from the CE
 533 viewpoint, each country may focus on a different subject area within the biomass research domain.
 534 In Figure 5, the most frequent keywords with more than 20 occurrences, excluding “circular
 535 economy”, are plotted on a radar map for the identified 6 most productive countries, including
 536 Italy, Spain, China, England, India, and the USA. As can be seen from this figure, any county has
 537 its own research focus, and none of these countries have paid attention to all the subject areas
 538 symmetrically or according to the ranking provided in Table 11. Even “food waste”, the most
 539 frequent keyword after “circular economy”, has not been considered a focal point in the research
 540 conducted by China, India, and the USA within the broad biomass and CE field of research.

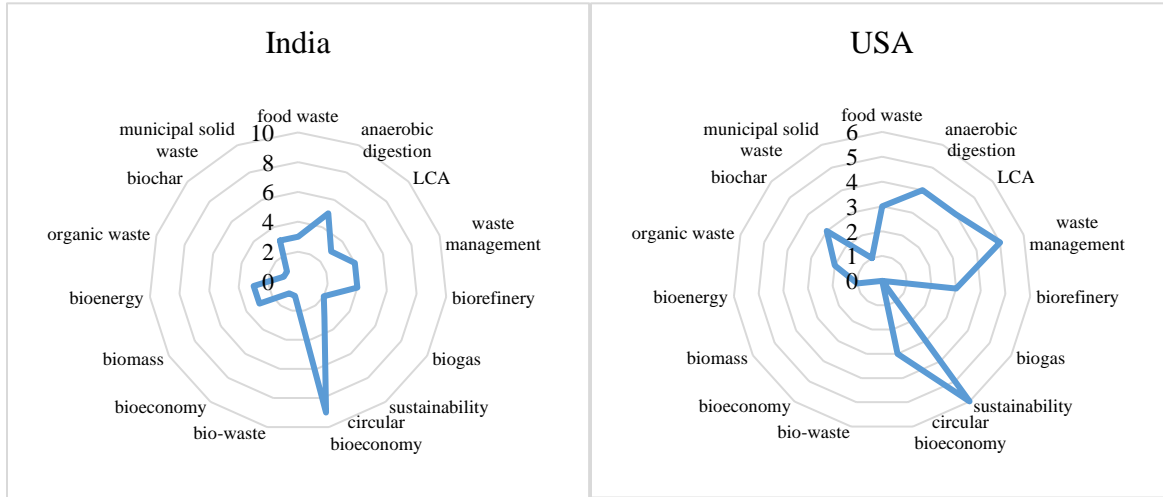
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543



544 **Fig. 5.** Radar map of the most frequent keywords for the 6 most productive countries in biomass
545 and organic waste research towards a CE.
546
547

548 The co-occurrence of the keywords shown in Figure 4 as the links connecting a pair of
549 nodes can deepen the insight about the approaches taken by the authors in the articles. Only 14
550 links in the presented keywords co-occurrence network have more than 10 occurrences. Out of
551 these 14 links, 12 links connect “circular economy” with other keywords, including “food waste”
552 (45 occurrences), “waste management” (25 occurrences), “LCA” (24 occurrences),
553 “sustainability” (23 occurrences), “anaerobic digestion” (22 occurrences), “bioeconomy” (20
554 occurrences), “biogas” (15 occurrences), “biomass” (15 occurrences), “resource recovery” (15
555 occurrences), “bio-waste” (14 occurrences), “biorefinery” (14 occurrences), and “organic waste”
556 (12 occurrences). The appearance of “circular economy” in most of the pairs of keywords with the
557 strongest links points to the highest frequency of this keyword in the sample articles. However,
558 Table 12 presents the most frequent keyword pairs ignoring the ones that include “circular
559 economy”.

560 Based on table 12, whose information is extracted from Figure 4, “anaerobic digestion”
561 and “food waste” have the most co-occurrence (19) in the keywords co-occurrence network. This
562 pair is followed by “anaerobic digestion” and “biogas”, and “biogas” and “food waste” with 17
563 and 10 co-occurrences, respectively. Of the 10 pairs of keywords presented in this table, 6 include
564 “anaerobic digestion” and 4 include “food waste”. Although “food waste” is a more frequent
565 keyword in comparison with “anaerobic digestion” (83 vs. 66 occurrences), more appearance of
566 “anaerobic digestion” in the most frequent keyword pairs indicate that the co-occurrence of “food
567 waste” is with a higher number of keywords but with lower link strength. This can highlight the
568 more general view about the “food waste” in comparison with “anaerobic digestion”, and more
569 flexibility of the “food waste” subject area to be considered with various viewpoints and in
570 different domains from the lens of CE.

571 **Table 12.** Most frequent pair of keywords ignoring the pairs involving “circular economy”.
 572

Keyword 1	Keywords 2	Link strength
anaerobic digestion	food waste	19
anaerobic digestion	Biogas	17
biogas	food waste	10
biorefinery	circular bioeconomy	10
food waste	LCA	8
food waste	Sustainability	8
anaerobic digestion	bio-methane	7
anaerobic digestion	bio-waste	7
anaerobic digestion	LCA	7
anaerobic digestion	organic waste	7

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 574
 575 Referring to the average publication year of the keywords shown with a color range in
 576 Figure 4, the most recent keywords with the average publication year of 2021 refer to the keywords
 577 “energy production”, “hydrothermal carbonization”, “leachate”, “lycopene”, “supercritical fluid
 578 extraction”, “value-added product”, “wastewater”, “agro-industrial residues”, “animal nutrition”,
 579 “bio-methane production”, “biotechnology”, “cellulose”, “fish waste”, “food waste recycling”,
 580 “food waste valorization”, “greenhouse gas”, “greenhouse gas mitigation”, “hydrolysis”, “larval
 581 biomass”, “marine collagen”, “nitrogen fixation”, “nutraceuticals”, “nutrient cycling”, “pig
 582 slurry”, “polyunsaturated fatty acids”, “pomegranate”, “pyrochar”, “sustainable cities”,
 583 “sustainable energy”, “waste reuse”, and “water quality”. These keywords have an occurrence of
 584 between 2 and 4 in the whole dataset, and all of them appear in the articles published in 2021. The
 585 recentness of the articles containing these keywords shows the very recent attention of the
 586 researchers towards looking at these subject areas from the lens of CE.

587 On the other hand, 7 keywords have an average publication year less than 2018. “cradle-
 588 to-cradle” is the oldest keyword with 2 occurrences and an average publication year of 2016,
 589 followed by “levulinic acid”, “sustainable materials”, “waste composition”, “water”, and “water

590 treatment”, each with 2 occurrences and the average publication year of 2017.5. the next old
591 keyword is “carbon footprint” with 3 occurrences and the average publication year of 2017.67.
592 The low average publication year of these keywords indicates weak consideration of these subject
593 areas in more recent research and highlights the potential of considering these research topics in
594 future research.

595

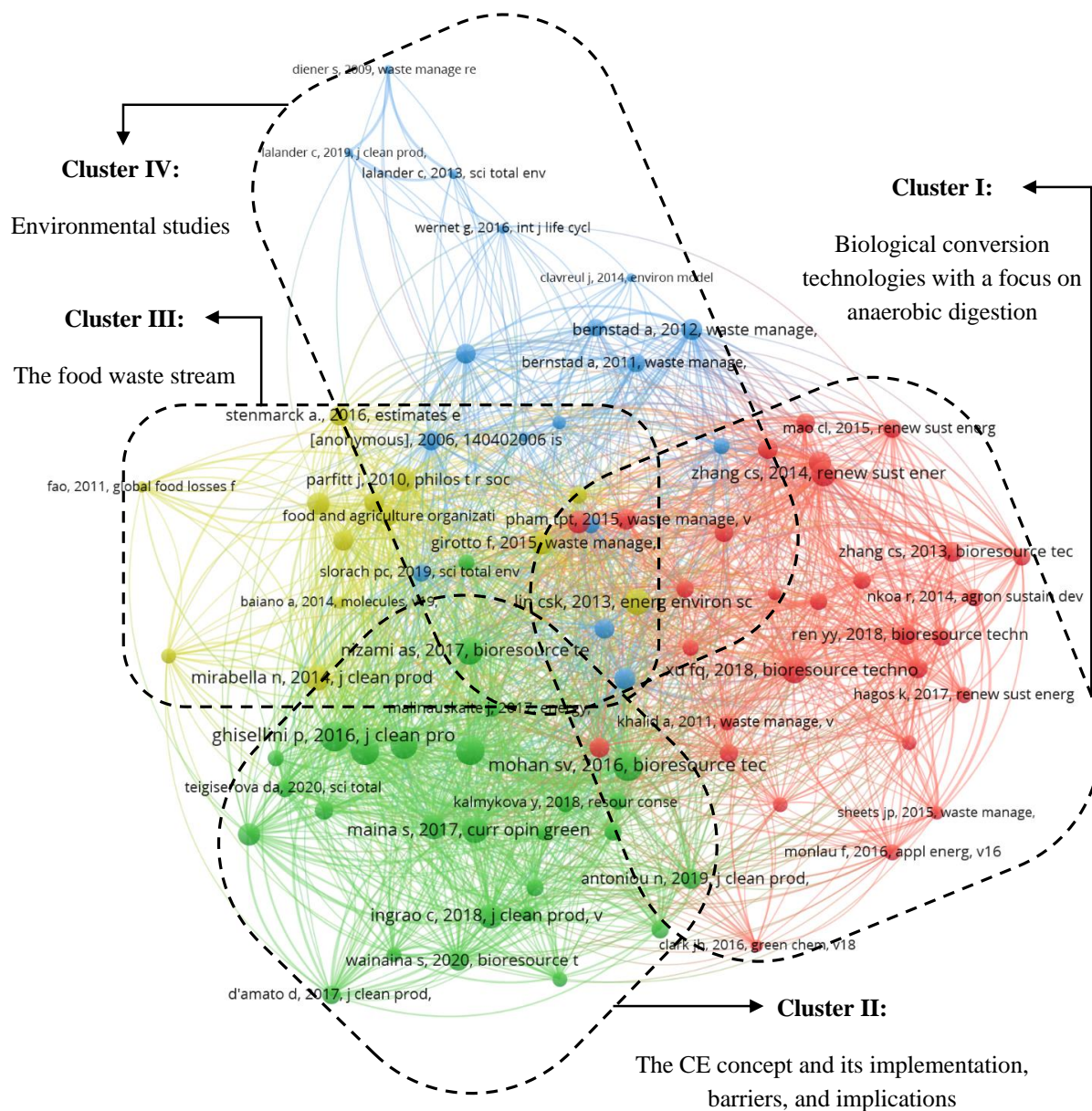
596 **4.3. Co-citation analysis: major research clusters and founders of the studied discipline**

597 The findings of this section address the third RQ:

- 598 • RQ3. What are the seminal founders (historical emergence of different perspectives) in
599 biomass and organic waste research in the CE literature?

600 The co-citation analysis was conducted on the references cited by articles in our data
601 sample. A total of 40,292 references had been cited by 646 articles in our data sample. Due to the
602 high number of cited references, to increase the solidity and interpretability of data clustering, a
603 threshold of a minimum of 10 citations was applied, leading to 86 articles within the co-citation
604 network of this study. As a result, data clustering based on co-citation network revealed four
605 fundamental clusters of biomass and organic waste in the CE research, including (1) biological
606 conversion technologies with a focus on anaerobic digestion, (2) the CE concept and its
607 implementation, barriers, and implications, (3) environmental studies, and (4) the food waste
608 stream. These four main clusters have built the background of the research behind biomass
609 production, utilization, and applications towards implementing CE and BCE platforms. Figure 6
610 visualizes the co-citation network and identified major clusters. Documents within each identified
611 cluster were sorted based on their total link strength, indicating the number of times each document
612 appeared with another document within the list of cited references by the articles in our database.

613 Consequently, ten articles from each cluster with the highest total link strength were selected for
 614 the analysis in this section. Table 13 presents the selected articles and their total link strength and
 615 citation.



616
 617 **Fig. 6.** Co-citation clustering: Major research clusters and founders of biomass and organic waste
 618 research in the CE context (background research themes).
 619
 620
 621

622 **Table 13.** The top ten documents within each background research cluster in terms of the total link
623 strength.
624

Author(s) and year	Title	Total link strength	Citation	Year	Reference
<i>Cluster I: Biological conversion technologies with a focus on anaerobic digestion</i>					
	Anaerobic digestion of food waste - Challenges and opportunities	128	23	2018	[60]
	Reviewing the anaerobic digestion of food waste for biogas production	115	18	2014	[61]
	Food waste valorization <i>via</i> anaerobic processes: a review	94	13	2016	[53]
	Characterization of food waste as feedstock for anaerobic digestion	93	14	2007	[62]
	Food waste-to-energy conversion technologies: Current status and future directions	89	14	2015	[63]
	A comprehensive review on food waste anaerobic digestion: Research updates and tendencies	83	14	2018	[64]
	Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance	81	17	2011	[65]
	Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse	76	12	2016	[51]
	Inhibition of anaerobic digestion process: A review	76	20	2008	[66]
	The anaerobic co-digestion of food waste and cattle manure	73	12	2013	[67]
<i>Cluster II: The CE concept and its implementation, barriers, and implications</i>					
	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	176	38	2016	[68]
	A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems	175	30	2016	[69]
	Food waste biorefinery: Sustainable strategy for circular bioeconomy	162	32	2018	[22]
	The Circular Economy A new sustainability paradigm?	160	34	2017	[70]
	Conceptualizing the circular economy: An analysis of 114 definitions	148	24	2017	[71]
	Waste biorefineries: Enabling circular economies in developing countries	141	26	2017	[72]
	A roadmap towards a circular and sustainable bioeconomy through waste valorization	137	20	2017	[57]

Food waste recovery into energy in a circular economy perspective: A comprehensive review of aspects related to plant operation and environmental assessment	122	18	2018	[73]
Circular Economy: The Concept and its Limitations	116	23	2018	[74]
Transition towards Circular Economy in the Food System	93	14	2016	[75]
<hr/> Cluster III: The food waste stream <hr/>				
Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective	130	30	2013	[76]
Current options for the valorization of food manufacturing waste: a review	121	22	2014	[44]
Food waste within food supply chains: quantification and potential for change to 2050	106	22	2010	[77]
Food waste generation and industrial uses: A review	105	23	2015	[78]
The food waste hierarchy as a framework for the management of food surplus and food waste	96	12	2014	[79]
Carbon footprint of food waste management options in the waste hierarchy - a Swedish Case study	79	10	2015	[80]
Food wastage footprint, Impacts on natural resources	76	15	2013	[81]
Estimates of European food waste levels	73	15	2016	[82]
Global food losses and food waste – Extent, causes and prevention	65	14	2011	[83]
Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications	44	11	2012	[84]
<hr/> Cluster IV: Environmental studies <hr/>				
Review of comparative LCAs of food waste management systems - Current status and potential improvements	92	13	2012	[85]
Environmental sustainability of anaerobic digestion of household food waste	88	14	2019	[47]
Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040:2006)	81	19	2006	[86]
An environmental analysis of options for utilising wasted food and food residue	80	10	2016	[87]
Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040:1997)	79	19	1997	[88]
A life cycle approach to the management of household food waste - A Swedish full-scale case study	67	13	2011	[89]
Life cycle assessment of energy from waste <i>via</i> anaerobic digestion: A UK case study	61	10	2014	[90]

Environmental and economic implications of recovering resources from food waste in a circular economy	60	13	2019	[49]
Composting of food wastes: Status and challenges	56	16	2018	[91]
Life Cycle Assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches	49	10	2013	[92]

625

626

627 **4.3.1. Biological conversion technologies with a focus on anaerobic digestion**

628 Waste-to-energy conversion technologies have appeared as one of the main background
629 themes of biomass research in the context of CE and implementing BCE platforms. In this regard,
630 among different conversion technologies, including biological, thermal, and thermochemical,
631 biological technologies, particularly anaerobic digestion, have played a significant role [93].
632 Anaerobic digestion is a process in which a consortium of microorganisms breaks down
633 biodegradable materials into biogas in the absence of oxygen [63,94]. Interest in using anaerobic
634 digestion to process source-segregated waste is increasing due to the opportunity of recovering
635 additional value from waste such as nutrient-rich fertilizer products, in addition to biogas
636 production [65,95,96]. Zhang et al. [62], in a study on the characterization of food waste as
637 feedstock for anaerobic digestion, showed that food waste, among other organic substrates, is a
638 highly desirable feedstock for anaerobic digestion due to its high biodegradability and methane
639 yield.

640 Mismanagement of organic-based waste such as food waste has posed significant economic
641 and environmental challenges to the global communities [97]. In this vein, with the promotion of
642 resource recovery, more attention should be paid to biorefinery technologies for producing energy
643 from organic waste and biomass toward a zero-emission economy and production [64]. According
644 to Uçkun Kiran et al. [98], food waste to energy bioconversion to generate ethanol, methane,
645 hydrogen, and biodiesel seems to be economically viable. To properly manage food waste,

646 anaerobic digestion is a promising conversion technology compared with traditional disposal
647 methods, such as landfilling, composting, and incineration [60,61]. However, anaerobic digestion
648 has not been widely used to convert energy from food waste due to economic and technical
649 challenges, such as economic viability and high cost, control process instability, foaming control,
650 and low buffer capacity [60]. To enhance the waste treatment efficiency in anaerobic digestion,
651 the adaptation of microorganisms tolerant to inhibitory substances, co-digestion with different
652 types of biomass, and methods incorporating to counteract or remove toxicants before anaerobic
653 digestion were proposed by Chen et al. [66] and Tabatabaei et al. [96]. In addition, Capson-Tojo
654 et al. [53] suggested trace elements addition and solid digestate recirculation to effectively stabilize
655 the anaerobic digestion process. Moreover, the efficient direct use of digestate generated during
656 converting organic waste into biogas through anaerobic digestion as a substrate and stand-alone
657 fertilizer for processing organic waste into new food was proposed by Stoknes et al. [51].

658

659 **4.3.2. The CE concept and its implementation, barriers, and implications**

660 Transitioning from a traditional linear economy with a take-make-dispose business model
661 towards a CE with closed loops of materials has gained momentum among scholars and research
662 communities in the last decade. This is proved by the booming publications on the CE subject in
663 scientific databases. For instance, 3152 articles, including "CE" in their title, have been published
664 in WoS up to September 2021, while this number was 194 articles by 2010. The CE as an economic
665 system intends to replace the "end-of-life" concept with 4Rs strategies, including reducing,
666 reusing, recycling, and recovering within production and consumption patterns [71]. In this
667 context, the main focus is on the closing-the-loop production processes to (i) increase resource
668 efficiency, (ii) minimize generated amount of waste, in particular urban and industrial streams,

669 and (iii) achieve better harmony and balance among society, economy, and the environment [69].
670 Hence, the CE contributes to (i) high-quality material cycles and high value and (ii) incorporating
671 the possibilities of sustainable production and sharing economy to promote a more sustainable
672 production-consumption culture [74].

673 However, the CE and sustainability concepts seem interconnected with similarities and
674 differences. In this vein, Geissdoerfer et al. [70] highlighted their main differences as (i)
675 sustainability aims at benefiting society, economy, and the environment at large, while the CE
676 mainly benefits the economic actors that implement the system, and (ii) sustainability performs
677 based on shared responsibility, while governments, policy-makers, regulators, and private
678 businesses are mainly responsible for transitioning from a linear to a CE. Due to the increasing
679 attention worldwide to the CE implementation in a wide range of disciplines and domains, a huge
680 amount of research has been done in different industries and businesses. Overall, the CE research
681 background has mainly focused on defining and conceptualizing the concept [54,58,77],
682 implementing strategies, and enabling the transition towards a CE in general [57,68,73,75] and
683 with a focus on developing countries [72]

684

685 **4.3.3. The food waste stream**

686 Food waste representing a massive market inefficiency has posed a severe challenge to the
687 global economy, food supply chains, agricultural and industrial systems. Approximately 1.3 billion
688 tons/year represents one-third of all food produced is never eaten and lost or wasted globally [99],
689 which calls all waste management sectors from collection to disposal to explore sustainable
690 solutions [78]. Households and processing are the most contributing sectors to food waste
691 generation, accounting for more than 70 percent of the European Union's food waste [82].

692 Moreover, the carbon footprint of food loss and waste is estimated to be 3.3 Gtonnes of CO₂,
693 which makes food wastage rank as the third top emitter after the USA and China in the world [81].
694 The first step towards a more sustainable resolution to properly manage food surplus and food
695 waste is adopting a sustainable production and consumption culture [79]. The food waste
696 generation covers all the food lifecycle from agriculture at the beginning to industrial
697 manufacturing and processing, retail, and household consumption [44]. Although such an
698 enormous amount of waste has raised serious waste management issues, it has brought some
699 potentials and opportunities to be treated, valorized, and reused into other production systems
700 through biorefinery platforms [44,100,101]. In this regard, food waste, as a valuable resource with
701 a high possibility to be used as a raw material for the production of chemicals, materials and fuels
702 [76], need to be paid attention to more intensively by waste-management authorities. Galanakis
703 [84] highlighted food waste as a cheap source since the conversion technologies allow the recovery
704 of high added-value components from food waste inside food chains as functional additives in a
705 wide range of products.

706

707 **4.3.4. Environmental studies**

708 This cluster highlights the role of environmental concerns in the wake of improper waste
709 management, increasing the amount of waste generated worldwide and using fossil fuels to direct
710 research towards establishing a CBE. The main focus of research in this area has been assessing
711 the potential environmental impacts of various treatment methods for bio-based waste streams. In
712 this regard, LCA methods and tools based on the ISO14040-44:2006 standard [86] have been
713 widely applied. However, the outcomes of LCA methods can vary due to differences in system
714 boundary setting, methodological options (for instance, evaluating global warming potentials to

715 biogenic carbon emissions), and input data variations [85,102]. Righi et al. [92] showed that the
716 anaerobic co-digestion of organic fraction of municipal solid waste and dewatered sewage sludge
717 with composting post-treatment in small plants might propose an environmentally sustainable
718 choice for waste management in small communities. In another study, Slorach et al. [49] denoted
719 that anaerobic digestion has the lowest environmental impacts per tonne of waste treated.
720 According to their research, among incineration, in-vessel composting, anaerobic digestion, and
721 landfilling, in-vessel composting was the least environmentally sustainable option.

722 Moreover, in a comparative full-scale case study, Bernstad and la Cour Jansen [72] showed
723 that both anaerobic and aerobic treatment methods result in net avoidance of greenhouse gas
724 emissions. Still, compared with incineration, they contribute more to nutrient enrichment and
725 acidification. Evangelisti et al. [90], in a study based on lifecycle inventory data of the Greater
726 London area, outlined that when energy and organic fertilizer substitute non-renewable electricity
727 and inorganic fertilizer, anaerobic digestion is the best treatment option considering total CO₂ and
728 total SO₂ saved. They introduced incineration as the most environmentally friendly option for
729 photochemical ozone and nutrient enrichment potentials. For wasted food and food residue
730 utilization in the CBE, among four waste management options, including minimization, anaerobic
731 digestion, composting, and incineration, the lowest environmental impact and best carbon return
732 on investment was obtained by anaerobic digestion [87]. Nevertheless, although anaerobic
733 digestion has lower environmental impacts, it may lead to higher marine eutrophication, terrestrial
734 acidification, and particulate matter formation compared with incineration and landfilling due to
735 the application of digestate to land and the release of ammonia and nitrates [47].

736

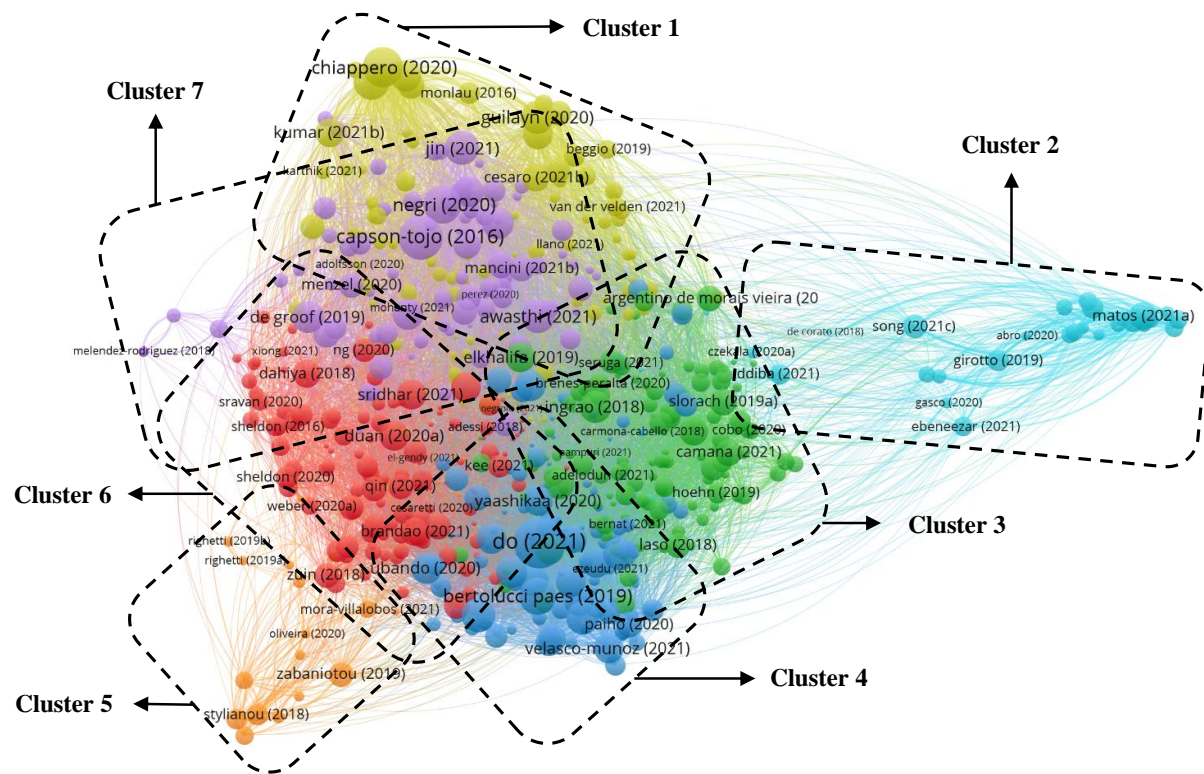
737 **4.4. Bibliographic coupling analysis: discovering emergent research areas**

738 The results obtained from bibliographic coupling analysis in this section address the fourth
739 RQ:

- 740 • RQ4. What are the major emergent biomass and organic waste sub-fields of research in the
741 CE in the recent literature?

742 To provide a map of the emergent research themes, the bibliographic coupling analysis was
743 conducted on the articles in our sample. In this regard, articles were clustered based on the number
744 of references they shared. Among the 646 total articles in our sample, 11 articles shared no
745 references with other articles, and therefore, they were removed from the clustering process. As a
746 result, the remaining 635 articles formed seven clusters, as illustrated in Figure 7 and reported in
747 Table 14. These seven clusters represent the major emergent sub-field of research in biomass and
748 organic waste research towards transitioning to a CBE, including (1) the biochar industry
749 development in a CE perspective, (2) the role of insect biorefinery in waste management in the CE
750 framework, (3) LCA studies for bio-waste treatment systems, (4) the CE implementation in the
751 agricultural sector, (5) spent coffee grounds valorization, (6) organic waste biorefinery
752 applications in a CBE, and (7) municipal bio-waste and food waste valorization *via* anaerobic
753 digestion process. The aforementioned research areas are the most recent subjects in the target
754 literature, with the total average publication year of 2019.87, as shown in Table 14.

755



- Cluster 1:** The biochar industry development in a CE perspective
- Cluster 2:** The role of insect biorefinery in waste management in the CE framework
- Cluster 3:** LCA studies for bio-waste treatment systems
- Cluster 4:** The CE implementation in the agricultural sector
- Cluster 5:** Spent coffee grounds valorization
- Cluster 6:** organic waste biorefinery applications in a CBE
- Cluster 7:** Municipal bio-waste and food waste valorization *via* anaerobic digestion process

756

757 **Fig. 7.** Bibliographic coupling clustering: Emergent research areas in biomass and organic waste
 758 research towards the CE (the most research themes).

759

760 **Table 14.** Bibliographic coupling clusters details.

761

Cluster name	Number of articles	Average publication year	Oldest article publication year	Sample articles
Cluster 1: The biochar industry development in a CE perspective	109	2019.87	2012	[103–109]
Cluster 2: The role of insect biorefinery in waste management in the CE framework	37	2020.05	2017	[110–116]
Cluster 3: LCA studies for bio-waste treatment systems	128	2019.85	2015	[47,117–123]
Cluster 4: The CE implementation in the agricultural sector	116	2019.86	2017	[124–129]

Cluster 5: Spent coffee grounds valorization	22	2020.13	2018	[26,130–135]
Cluster 6: organic waste biorefinery applications in a CBE	133	2019.85	2014	[20,22,46,57,136–142]
Cluster 7: Municipal bio-waste and food waste valorization <i>via</i> anaerobic digestion process	90	2019.84	2016	[53,143–147]

762

763

764 **4.4.1. The biochar industry development in a CE perspective**

765 The main focus of this cluster is on biochar as a biomass-derived material and its
766 applications to enable CE platforms. This cluster includes 109 articles with an average publication
767 year of 2019.87, representing a hot research topic in this area. Biochar is a carbonaceous material
768 produced *via* biomass waste thermochemical conversion [107,148,149] and can be used as a cost-
769 effective and environmentally friendly solution to remove a wide range of organic and non-organic
770 pollutants [150]. As a by-product produced during gasification or pyrolysis of waste biomass in
771 biorefineries, biochar has a great potential to support transitioning towards the CE, reduce the
772 environmental impacts, and mitigate the climate change crisis [106]. The research in this cluster
773 has been mainly focused on investigating biochar utilization in the anaerobic digestion of food
774 waste and loss in line with CE principles *via* digestate treatment and biogas upgrading [104],
775 biochar role as an additive in anaerobic digestion processes [108], coupling biochar with anaerobic
776 digestion in a CE perspective to promote sustainable energy and agriculture development [103],
777 and biochar integration with anaerobic fermentation as a win-win strategy in a closed-loop
778 approach [109]. Besides serving as a stability enhancer, CO₂ adsorbent for biogas, and
779 improvement agent for digestate quality in anaerobic digestion, biochar can be used as a soil
780 conditioner and bio-adsorbent [151]. Nevertheless, despite the promising potential uses of biochar

781 as activated carbon, construction material, and agriculture and horticulture sectors, the research on
782 its benefits remains significantly debated [106].

783

784 **4.4.2. The role of insect biorefinery in waste management in the CE framework**

785 This subject area highlights the contribution of insects to waste management according to
786 the CE objectives regarding valorizing waste as much as possible. Research in this cluster is recent
787 and limited, as the first article published goes to 2017, and compared to the other clusters, this
788 cluster has the second-fewest articles (N=37). Besides, the average publication year is 2020.05,
789 denoting the recentness of the research. The global increasing protein consumption to feed humans
790 and animals has drawn significant attention to insect rearing [115]. Insect biorefineries produce
791 biofuel and protein and transform organic waste into insect biomass [152]. In this vein, insects are
792 mainly used as a feed source for monogastric animals, supporting the sustainability of meat/fish
793 production systems and reducing environmental effects [115]. Moreover, using animals in waste
794 processing to recover materials and renewable energies, such as biofuels, indicates a suitable fit
795 with the regenerative nature of CE systems [114]. For instance, Jagtap et al. [113], in a research
796 work contributing to the design of a food system based on a CE model, identify black soldier fly
797 larvae as a bioreactor that converts food waste into high-value feed materials. The core research
798 in this cluster have highlighted the potential of bioconversion of animal manure using fly Larvae
799 to promote a CE in agricultural systems [112], the *Hermetia illucens* insect applications in food
800 waste management [111], and organic wastes upcycling for biodiesel production from *Hermetia*
801 *illucens* based on a CE framework [110]. Insect biorefineries are economically feasible at both
802 small and large scales [153]. However, the concept of insect biorefinery to address the CE

803 essentials still needs to be better elucidated regarding safety practices and regulations when making
804 a chain including waste, insects, and feed/food [114].

805

806 **4.4.3. LCA studies for bio-waste treatment systems**

807 This cluster stands as the second-largest cluster of our bibliographic coupling analysis in
808 terms of the number of articles (N=128). Although LCA methods and tools have been employed
809 in environmental studies for a long time, their usage in bio-waste treatment systems has appeared
810 as an emergent research area with an average publication year of 2019.85. From a circular
811 bioeconomy viewpoint, applying the LCA method that considers a cradle-to-grave system
812 boundary to have a sound design of a biorefinery is crucial [19]. In the CE transition, waste
813 management as a central activity with a high potential of environmental impacts must be assessed
814 from the environmental performance point of view [119]. On this basis, LCA methods have been
815 widely used for environmental evaluation of waste management practices and waste treatment
816 scenarios, such as residual bio-waste management strategies [117], biological treatments of bio-
817 waste in the lifecycle perspective [118], comparison of different organic fractions of municipal
818 solid waste collection systems [120], lifecycle environmental sustainability of recovering energy
819 and fertilizers from household food waste [47], and food waste-to-food strategies corresponding
820 to the CE model [122]. Sridhar et al. [136] believe that LCA and bioeconomy models show
821 promising approaches to support effective decision-making. However, since the boundary
822 selection significantly affects LCA outcomes [154], different waste systems should be properly
823 integrated to avoid temporal or spatial shifts of environmental impacts [123].

824

825 **4.4.4. The CE implementation in the agricultural sector**

826 The agricultural sector as one of the most potential sectors in contributing to the CE
827 transition has been investigated by sustainability and CE researchers and practitioners.
828 Agricultural residues or lignocellulosic biomass constitute a part of the second generation of
829 biofuels [155]. A total of 116 articles belong to this cluster included in the seven identified
830 emergent subject areas of research with an average publication year of 2019.86. The CE supports
831 a sustainable and regenerative agriculture system, mainly through proposing suitable strategies for
832 agricultural waste valorization. In this regard, integrated valorization of fruit by-products to
833 achieve CE objectives [125], developing a CE framework for sustainable agri-food supply chains
834 [128], and bio-energy production [124], are some recent subjects of study. Nevertheless, although
835 a huge amount of research has been conducted on implementing the CE in the agriculture sector,
836 theoretical CE models and frameworks have not yet been adopted in the agriculture field [126].

837

838 **4.4.5. Spent coffee grounds valorization**

839 The fewest number of articles belongs to this cluster (N=22). The research in this area
840 based on our sample data is very recent, with the first paper published in 2018 and the average
841 publication year of 2020.13. Coffee is the second most traded commodity after petroleum [156],
842 highlighting the key role of coffee industries in the global economy due to job creation and income
843 reporting [26]. Consequently, the global coffee industry generates a huge amount of bio-waste and
844 by-products, such as coffee spent grounds, and coffee silverskin that are incinerated, composted,
845 or mainly thrown away for landfilling without recycling for other purposes[157]. As a result,
846 sustainable management of the coffee industry and its associated by-products/wastes and value
847 addition seems crucial in transitioning towards a CBE. The continuously increasing coffee

848 consumption has generated massive quantities of solid residues in return in the form of spent coffee
849 grounds, which is considered as a low-cost and promising feedstock with huge valorization
850 potentials for the production of bio-syngas, compost, electricity, green composites, and biodiesel
851 through biorefineries [135]. The focus of studies in this cluster has been principally on the
852 valorization of spent coffee grounds for biodiesel production [133], utilization of spent coffee
853 grounds in packaging development in the CE context [132], the potential of spent coffee grounds
854 as a second-generation feedstuff and an alternative ingredient in dairy cattle [131], and converting
855 environmental risks to benefits [130]. Although mono-process extraction methods of spent coffee
856 grounds have been widely studied, biorefining approaches are still at an early research stage [26].
857 In this regard, implementing a biorefinery to valorize spent coffee grounds highly depends on
858 characteristics of the residues and economic interest and availability of the obtained products
859 [134].

860

861 **4.4.6. Organic waste biorefinery applications in a CBE**

862 The highest number of articles (N=133) have appeared in this cluster, with the average
863 publication year of 2019.85, highlighting the applications of biorefinery systems for organic waste
864 from a CBE perspective. Due to the global attention to shift towards sustainable development, food
865 waste biorefineries have recently gained momentum because of their capabilities in producing
866 biofuels and bio-based materials from food waste valorization [20]. Hence, many research
867 activities have been carried out to study the characteristics, applications, and implications of food
868 waste biorefineries for implementing a CBE. The food waste biorefinery approach should be
869 optimized regarding the cascade of individual bioprocesses for transitioning from a linear economy
870 to a CBE [22]. In this regard, the major topics of research have been resource recovery and

871 biorefinery potential of organic waste in the CBE [141], refining biomass residues for sustainable
872 energy and bio-products [140], conversion of food waste to energy with a focus on LCA and
873 sustainability [136], high-value food waste and food residues biorefineries focusing on
874 unavoidable wastes from processing [142], biorefinery approach for organic solid waste derived
875 from agriculture, industry and urban [139], techno-economic and profitability analysis of food
876 waste biorefineries [46], and sustainable approaches for conversion and reutilization of food
877 wastes to valuable bio-products [137]. In this vein, adopting suitable technical and economic
878 strategies within a multi-disciplinary approach can support developing a sustainable biorefinery of
879 food waste based on CBE principles and bridging the gap between waste remediation and product
880 recovery [22].

881

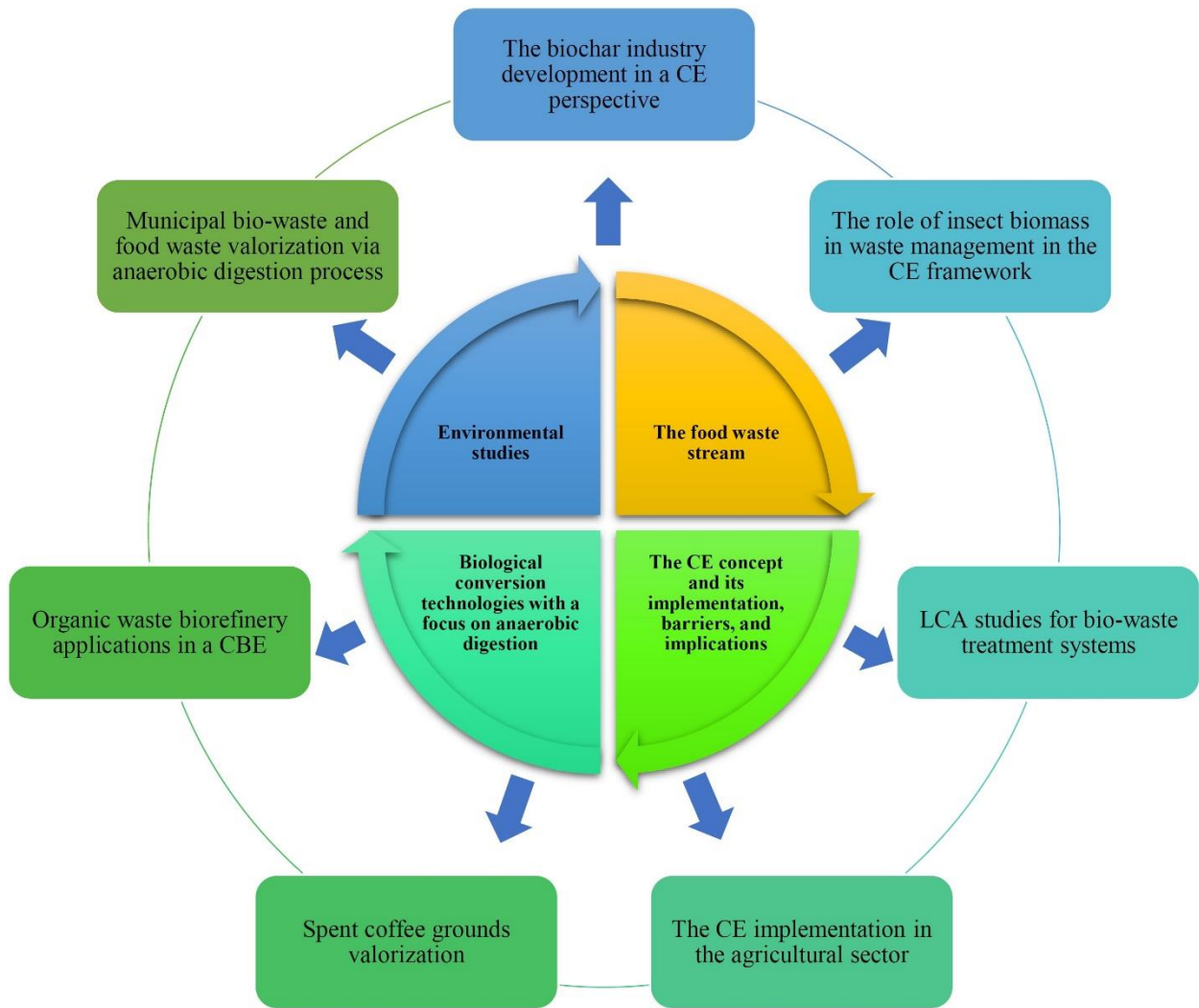
882 **4.4.7. Municipal bio-waste and food waste valorization *via* anaerobic digestion process**

883 Valorization of municipal bio-based and food waste streams through applying anaerobic
884 digestion as a biological conversion technology has constructed the focal point of this research
885 cluster. This cluster included 90 articles with an average publication year of 2019.84. Anaerobic
886 digestion as a recent subject of research had been also appeared as one of the main identified
887 background research themes from the co-citation clustering analysis in the previous section. Apart
888 from the aforementioned applications of anaerobic digestion in the previous section, anaerobic co-
889 digestion of food waste and rendering industry streams for biogas production [143], anaerobic co-
890 digestion of sewage sludge and wine vinasse in a two-stage process [158], food waste anaerobic
891 digestion for bio-energy production [147], identification of variables and factors that affect
892 municipal bio-waste and food waste anaerobic digestion [146], and food waste anaerobic digestion

893 impacts on biogas production and environmental impacts [145] are among recent research topics
894 within this cluster.

895 Finally, Figure 8 illustrates the general map of the results obtained from the co-citation and
896 bibliographic coupling analyses, representing the main background research themes and emerging
897 subject areas of research in biomass and organic waste literature in the CE context.

898



899

900 **Fig. 8.** The main background research themes and emerging subject areas of research in the
901 research field of biomass and organic waste towards the CE.

902

903

904 **5. Implications for research: opportunities and prospects**

905 To follow both the waste hierarchy and the CE principles, reducing the waste from the
906 source should be prioritized [159]. The biomass and organic waste source can be the food loss
907 generated at any part of the food supply chain, food waste generated by the end consumers, or
908 other biomass and organic wastes produced in the agricultural, horticultural, and industrial sectors.
909 In any of these cases, proper strategies should be designed and adopted to inform and train waste
910 generators about waste treatment methods, the ways to reduce waste reduction, and the benefits
911 and opportunities of converting waste to energy. In this regard, special attention should be devoted
912 to (1) designing guidelines and rules for the agricultural and industrial sectors to encourage them
913 to follow and promote CE principles in their activities to minimize waste and support them to feed
914 their waste to a waste-to-energy process, (2) increasing the social awareness about the negative
915 effects of waste generation and at the same time, informing them about the efficient food waste to
916 energy conversion, (3) promoting the usage of biofuels and bio-fertilizers and increase the research
917 and funding supports towards increasing the share of biofuels in the energy basket.

918 Besides the several applications of the biofuels derived from biomass and organic waste,
919 the role of using biofuels in the decarbonization of transport systems has been highlighted in
920 several research works [160]. On the other hand, the mobility restrictions during the COVID-19
921 pandemic shed light on the role of fossil-fuel-based transport systems on atmospheric pollution in
922 urban areas [161]. Therefore, the current pandemic, with its effects on the economic, social, and
923 environmental aspects of human lives [162,163], has provided an opportunity to promote the
924 transition towards using greener energy sources, such as electricity and biofuels, in the transport
925 sector. Using biofuels in the transport sector can be a potentially favorable solution, as it can lead
926 to the elimination of waste and the replacement of fossil fuel at the same time, resulting in positive

927 environmental outcomes [164]. Although biofuels have been used in the transport sector [165],
928 more research, market analysis, and funding are required to commercialize alternative-fuel
929 vehicles and encourage biofuels in transportation.

930 Using bio-wastes in the biorefineries to recover energy and material can be considered a
931 clear step towards implementing CE [8]. Environmental, economic, and social impacts of using
932 waste in this process align with the three pillars of sustainability [19] and support sustainable
933 development in rural areas [30]. However, a holistic view and systems thinking approach
934 [166,167] to capture the interconnections among the variables and address the system complexity
935 must be considered when assessing the sustainability and CE transition [168] in the activities
936 linked with the waste-to-energy conversion practices. This systems thinking approach can also be
937 coupled or supported by agent-based modeling [169] or data-driven approaches such as machine
938 learning [170] and artificial neural networks [171] to support decision-making towards process
939 and product improvement and optimization. Data-driven technologies can also help establish and
940 develop key performance indicators and baselines to better evaluate the performance at each stage
941 of the waste-to-energy process [136]. Adopting a multi-disciplinary approach seems to be crucial
942 in this regard to design proper and inclusive strategies.

943

944 **6. Research limitations**

945 The present research was conducted with limitations that can provide future directions for
946 further development by scholars involved in this domain. First, the article clustering was
947 performed based on two bibliometric methods, including bibliographic coupling and co-citation
948 analyses. Using other types of data clustering methods, such as text mining-based methods and
949 tools, is recommended for more investigations on the same topic. Second, although we tried to

950 cover all aspects of biomass and organic waste research in the CE context, our data was extracted
951 only from the WoS database. Hence, considering other citation databases, such as Scopus, for
952 extracting more relevant data should be carried out in future research. Moreover, incorporating
953 materials from secondary data, gray literature review, and snowballing techniques is highly
954 encouraged to enrich the present research findings. And finally, defining separate research projects
955 to comprehensively and systematically analyze and review each of the clusters identified in our
956 research (i.e., the four co-citation clusters and the seven bibliographic coupling clusters) would be
957 a valuable potential future avenue for researchers.

958

959 **7. Conclusions**

960 This research was the first attempt in the literature applying a systematic bibliometric
961 analysis to render an inclusive image of the body of knowledge in biomass and organic waste
962 research towards implementing a CE. To this end, two bibliometric methods, supported by co-
963 citation and bibliographic coupling clustering techniques, were used to uncover the main research
964 backgrounds and emergent subject areas of research, building the target literature.

965 The findings showed that the main founder research themes that have built the core
966 background of the scientific production in biomass and organic waste applications in the CE had
967 been mainly focused on (i) biological conversion technologies, (ii) conceptualizing the CE and its
968 associated implementation strategies, (iii) environmental studies, and (iv) food waste management
969 practices. On the other hand, seven emergent research areas that research communities have
970 recently focused on were identified and discussed, including (1) the biochar industry development
971 in a CE perspective, (2) the role of insect biorefinery in waste management in the CE framework,
972 (3) LCA studies for bio-waste treatment systems, (4) the CE implementation in the agricultural

973 sector, (5) spent coffee grounds valorization, (6) organic waste biorefinery applications in a CBE,
974 and (7) municipal bio-waste and food waste valorization *via* anaerobic digestion process.

975 The identified research themes through co-citation analysis with a backward-looking
976 approach to the target literature and also uncovered subject areas through bibliographic coupling
977 analysis with a forward-looking perspective provide a comprehensive portrait of biomass and
978 organic waste research in the CBE context. In the end, potential directions for further research in
979 the future were proposed to facilitate the CBE transition. The insights provided by the present
980 bibliometric analysis are expected to help researchers and scholars to capture a general overview
981 and landscape of the research conducted to date. Besides, it can be used as a guideline for policy-
982 makers and industrial practitioners to advance recent developments within the field.

983

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