

Biofuel supply chain management in the circular economy transition: An inclusive knowledge map of the field

Original

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1 **Biofuel supply chain management in the circular economy transition: An inclusive knowledge map**
2 **of the field**

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49 **Abstract**

50 Investment in the production of biofuels, as sustainable alternatives for fossil fuels, has gained
51 momentum over the last decade due to the global environmental and health concerns regarding
52 fossil fuel consumption. Hence, effective management of biofuel supply chain (BSC) components,
53 including biomass feedstock production, biomass logistics, biofuel production in biorefineries, and
54 biofuel distribution to consumers is crucial in transitioning towards a low-carbon and circular
55 economy (CE). The aim of the present study is to render an inclusive knowledge map of the BSC-
56 related scientific production so far. In this vein, a systematic review, supported by a keywords co-
57 occurrence analysis and qualitative content analysis was carried out on a total of 1,975 peer-
58 reviewed journal articles in the target literature. The analysis revealed four major research hotspots
59 in the BSC literature, including, (1) biomass-to-biofuel supply chain design and planning, (2)
60 environmental impacts of biofuel production, (3) biomass to bioenergy, and (4) techno-economic
61 analysis of biofuel production. Besides, the findings showed that the following subject areas of
62 research in the BSC research community have recently attracted more attention: (i) global warming
63 and climate change mitigation, (ii) development of the third-generation biofuels produced from
64 algal biomass, which has recently gained momentum in the CE debate, and (iii) government
65 incentives, pricing, and subsidizing policies. The provided insights shed light on the understanding
66 of researchers, stakeholders, and policy-makers involved in the sustainable energy sector by
67 outlining the main research backgrounds, developments, and tendencies within the BSC arena.
68 Looking at the provided knowledge map, potential research directions in BSCs towards
69 implementing the CE model, including (i) integrative policy convergence at macro, meso, and
70 micro levels, and (ii) industrializing algae-based biofuel production towards the CE transition were
71 proposed.

72 **Keywords:** Biofuel; Supply chain management; Circular economy; Biomass; Anaerobic
73 digestion; Biogas

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88 **Abbreviations**

Abbreviation	Full form
APY	Average publication year
BECCS	Bioenergy with carbon capture and storage
BSC	Biofuel supply chain
CBE	Circular bioeconomy
CE	Circular economy
GHG	Greenhouse gas
LCA	Lifecycle assessment
WoS	Web of Science

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99 1. Introduction

100 The circular economy (CE) with a particular focus on sustainable waste management practices
101 intends to slow, narrow, and close the supply chain loops by returning materials and waste into
102 resources towards making a sustainable and zero-waste environment (Ranjbari et al., 2021a).
103 Implementing CE platforms within the energy sector has been under intense debate due to the
104 potential of the CE in closing energy and material loops by reducing the need to use nonrenewable
105 feedstocks and energy sources (Aguilar Esteva et al., 2021). In this regard, utilizing renewable
106 energy sources has gained momentum worldwide mainly due to the (i) rapid socioeconomic
107 growth and environmental concerns, (ii) depletion of fossil energy resources, (iii) better power
108 quality, and (iv) demand for more reliable and flexible energy sources at lower costs (Craparo et
109 al., 2017; Fadai et al., 2011; Moghaddam et al., 2011).

110 Renewable energy sources, such as wind, solar, and biomass are considered as main players of
111 the future growth in the energy sector to ensure sustainable energy security and mitigate the
112 adverse environmental effects of fossil fuels (Abbasi et al., 2021). In other words, shifting to
113 renewable energy can reduce greenhouse gas (GHG) emissions, and ensure cost-efficient and
114 timely delivery of energy (Ellabban et al., 2014) for societies. Hence, there is a high promotion
115 from governments and their energy policies across the world to force energy systems to utilize
116 more renewable sources (Li et al., 2020a) to support the transition from a linear economy to a CE.

117 The global energy demand is estimated to increase by approximately 28% by 2040 in
118 comparison with the current level (Osman et al., 2021). Today, fossil fuels based on coal, oil, and
119 natural gas, as effective drivers of economic development (Ellabban et al., 2014), are the primary
120 source of energy production and consumption in the global community. However, increasing
121 concerns regarding fossil fuel consumption have attracted much interest in investing in biofuels

122 production to substitute fossil fuels, towards a low-carbon and sustainable circular bioeconomy
123 (CBE). Biofuels produced from biomass feedstock through eco-friendly and carbon-neutral
124 approaches can potentially support future energy supply towards achieving energy security and
125 sustainability (Ambaye et al., 2021). Biofuels are mainly preferred for their (i) carbon-neutral
126 character, (ii) renewability, and (iii) production flexibility in decentralized systems from abundant
127 and versatile resources (Gebremariam et al., 2019).

128 The biofuel supply chain (BSC) comprises biomass feedstock production, biomass logistics,
129 biofuel production in biorefineries, and biofuel distribution to consumers. The supply chain of
130 converting biomass to biofuels has attracted the attention of academic and industrial research as a
131 challenging and complex issue (Ghadami et al., 2021), leading to a huge amount of research. On
132 this basis, BSCs have been extensively explored in the literature from various points of view, such
133 as pricing decisions (Allameh and Saidi-Mehrabad, 2021), optimal design (Zarei et al., 2021),
134 subsidizing (Bajgiran and Jang, 2021), GHG emissions (Daioglou et al., 2017), economic
135 optimization (Ge et al., 2021), network design (Nur et al., 2021), microalgae-based BSCs (Kang
136 et al., 2020), economic viability and environmental impacts (Li et al., 2020b), risk mitigation
137 (Wachyudi et al., 2020), profit allocation (Gao et al., 2019), platforms planning for BSCs (Nugroho
138 and Zhu, 2019), lifecycle assessment (LCA) (Bennion et al., 2015), and strategy selection
139 (Allameh and Saidi-Mehrabad, 2019). Consequently, a significant amount of BSC-related research
140 has been conducted, leading to fragmented literature and scientific production. As a result, a
141 comprehensive knowledge map of the BSC-related studies and their associated research themes
142 and trends seems lacking.

143 To fill the identified gap, the present research aims to provide an inclusive map of the body
144 of knowledge in the BSC domain by identifying its major research hotspots and emergent research

145 tendencies. To this end, a systematic science mapping review, supported by descriptive analysis,
146 keywords co-occurrence analysis, and qualitative content analysis was performed. The results
147 contribute to the existing studies by (i) presenting performance indicators of BSC-related scientific
148 production over time, (ii) identifying BSC research hotspots through conducting a keywords co-
149 occurrence analysis to cluster research articles in the target literature, (iii) capturing BSC subject
150 areas of research which have recently attracted more attention using the average publication year
151 measure, and (iv) proposing potential directions for BSC research towards implementing the CE
152 model. To the best of the authors' knowledge, this is the first attempt in the literature to map the
153 BSC scientific production as a whole, using science mapping analysis through addressing the
154 following research questions (RQs):

155 **RQ1.** What are the past and present states and trends of scientific production in the BSC
156 literature?

157 **RQ2.** What are the seminal research hotspots and tendencies building the BSC background?

158 **RQ3.** Which areas have been recently attracting more attention in the BSC domain?

159 **RQ4.** What are the potential CE avenues ahead for BSC future research?

160 The remainder of the paper is organized as follows. Section 2 presents the adopted search
161 protocol and applied methods. Section 3 provides the main results of the research, including
162 descriptive analysis results, representing performance indicators (Section 3.1), keywords co-
163 occurrence analysis results, representing identified BSC research hotspots (Section 3.2), and
164 qualitative content analysis results, representing emergent BSC research areas (Section 3.3).
165 Potential CE directions for future research within the BSC context are proposed in section 4.
166 Finally, Section 5 concludes the remarks and limitations of the study.

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168 **2. Scope and review methodology**

169 In this research, a systematic review based on the PRISMA statement (Liberati et al., 2009)
170 supported by keywords co-occurrence analysis and qualitative content analysis was carried out to
171 provide a comprehensive knowledge map of the academic production in the BSC literature. The
172 adopted search protocol to collect data (Section 2.1) and analysis methods used in this review
173 (Section 2.2) are explained in the following sub-sections.

174

175 **2.1. Data source and search protocol**

176 In order to assure sufficient coverage of the target literature and reliability of the results within
177 each review process, adopting a well-structured search protocol, clarifying data source, search
178 string, and inclusion criteria seems crucial. On this basis, a structured search protocol was
179 formulated in three steps.

180 First, the Web of Science (WoS) Core Collection database, as the world's most trusted global
181 academic citation database, was chosen as the main data source for the present review.

182 Second, a search string was constructed aiming to maximize the sufficiency of the extracted
183 documents related to the topic of this research indexed in WoS. In this vein, the two main keywords
184 "biofuel" and "supply chain" were considered as the core of attention for further investigation. To
185 avoid neglecting critical and significant research within the BSC domain as much as possible, these
186 two keywords were divided and carefully scanned to outline the crucial keywords referring to the
187 BSC concept. In this regard, with a similar approach adopted by Pournader et al. (2021), we relied
188 on the supply chain definition by Mentzer et al. (2001) as "a set of three or more entities
189 (organizations or individuals) directly involved in the upstream and downstream flows of products,
190 services, finances, and/or information from a source to a customer". Consequently, we ended up

191 with "supply chain", "supply network", "buyer-supplier", "supplier selection", and "supplier
192 evaluation", as the major keywords covering the concept of the supply chain as a whole. Keywords
193 that implicitly refer to the supply chain, such as "operation management", "inventory management",
194 and "logistics" were excluded from our search string to remain consistent with the main focus of
195 this study. On the other hand, the keyword "biofuel" were searched within the most recent
196 systematic reviews conducted on biofuels (for instance, see Padilla-Rivera et al. (2019), and
197 Chaudhary et al. (2021)) to identify the main keywords and synonyms implicitly addressing the
198 biofuel concept within the scientific production in the literature. To this end, "biofuel", "ethanol",
199 "bioethanol", "biodiesel", "biogas", "biomass", "bio-oil", and "biorefinery" were outlined to be
200 included in the search string. Moreover, due to the presence of "bio" in the keywords, different
201 spelling styles, such as "bio-fuel", "bio fuel", "bio-diesel", and "bio diesel" were also taken into
202 account. As a result, the identified keywords related to "biofuel" and "supply chain" were
203 connected by using the Boolean operators "AND" and "OR" to formulate the following search
204 string for capturing the most relevant documents related to the BSC background: "supply chain"
205 OR "supply network" OR "buyer-supplier" OR "supplier selection" OR "supplier evaluation" AND
206 "Biofuel" OR "bio fuel" OR "bio-fuel" OR "ethanol" OR "bio ethanol" OR "bio-ethanol" OR
207 "bioethanol" OR "bio diesel" OR "bio-diesel" OR "biodiesel" OR "biogas" OR "bio gas" OR "bio-
208 gas" OR "biomass" OR "bio-mass" OR "bio-oil" OR "bio oil" OR "biorefiner*" OR "bio refiner*"
209 OR "bio-refiner*". The initial run of the search string on the topic field in WoS which searches
210 title, abstract, author keywords, and keywords plus returned a total of 2,605 records.

211 Finally, a set of inclusion criteria were set up to limit the initial results to the most relevant
212 and reliable research. In this regard, only peer-reviewed articles published in journals in the
213 English language were included in the final sample and other forms of documents, such as

214 conference proceedings, book chapters, and short communications were excluded from the study.
 215 The rationale behind adopting this approach was to enrich the quality and validity of the collected
 216 data and accordingly analyses and obtained results (Ranjbari et al., 2021c). Besides, due to the aim
 217 of this research to provide a comprehensive science map of the BSC field of research, no time-
 218 period restriction was considered. The continuous process of capturing data was stopped by adding
 219 the last update on December 19, 2021, to the dataset. As a result of this stage, 1,975 peer-reviewed
 220 journal articles met the inclusion criteria and were selected as the final sample for analysis in the
 221 present review. Table 1 summarizes the details of the adopted search protocol.

222 **Table 1**

223 The details of the adopted search protocol to collect BSC-related research.

Search string	"supply chain" OR "supply network" OR "buyer-supplier" OR "supplier selection" OR "supplier evaluation" AND "Biofuel" OR "bio fuel" OR "bio-fuel" OR "ethanol" OR "bio ethanol" OR "bio-ethanol" OR "bioethanol" OR "bio diesel" OR "bio-diesel" OR "biodiesel" OR "biogas" OR "bio gas" OR "bio-gas" OR "biomass" OR "bio-mass" OR "bio-oil" OR "bio oil" OR "biorefiner*" OR "bio refiner*" OR "bio-refiner*"
Database	Web of Science
Searched in	Topic: title, abstract, author keywords, and keywords plus
The last update	December 19, 2021
Initial result	2,605 articles
Inclusion criteria	(i) peer-reviewed journal articles, and (ii) English documents
Final sample	1,975 articles

224

225 2.2. Data analyses

226 To properly answer the RQs of this study, an inclusive approach to assess the research
 227 developments and outcomes in the BSC field was adopted. In this vein, an analytical method
 228 adopted from (Dutra et al., 2022; Ranjbari et al., 2021a, 2022b), combining descriptive analysis,

229 keywords co-occurrence analysis, and qualitative content analysis was applied to render the state-
230 of-the-art of BSC research. To do so, the analyses were performed in three steps as the following.

231 Firstly, a descriptive analysis was conducted on the 1,975 articles collected from WoS to
232 present performance indicators of the scientific production in the BSC literature, answering RQ1.
233 In this regard, for the time period of 1992-2021, the following performance indicators were
234 provided and discussed: (i) publication evolution trends, (ii) contributing publishers and journals,
235 (iii) the geographical distribution of contributions to the field, and (iv) thematic research categories
236 of collected data based on WoS classification.

237 Secondly, based on the co-occurrence algorithm, a keywords co-occurrence analysis was
238 performed on the authors' keywords in our data (4,443 unique keywords within 1,975 articles)
239 using VOSviewer version 1.6.16 (van Eck and Waltman, 2010), addressing RQ2. The main
240 rationale behind adopting this method is linked with the weakness of traditional literature reviews
241 in dealing with mapping a huge amount of articles due to their manual settings. Keywords co-
242 occurrence analysis has been widely used as a useful knowledge mapping tool in theoretical and
243 empirical studies due to its capability in mapping the conceptual and thematic structure of a domain
244 (Krey et al., 2022), representing the cumulative knowledge of the target literature. In keywords
245 co-occurrence analysis, while each author keyword represents a node in the network constructed,
246 each co-occurrence of a pair of author keywords represents a link. The weight of the link
247 connecting the pairs of author keywords denotes the number of times that a pair of author keywords
248 co-occurs in multiple articles (Radhakrishnan et al., 2017). In this regard, data cleaning, as a crucial
249 preparing step for conducting any keyword-based analysis (Ranjbari et al., 2020), was first carried
250 out on the keywords by (i) merging singular and plural forms of the keywords, (ii) combining
251 abbreviations and full forms of the keywords, and (iii) unifying English and American writing

252 styles. Then, the network of the authors' keywords based on the co-occurrence links clusters was
253 constructed to provide a base for unveiling common themes across the articles to understand the
254 thematic structure and knowledge components of the BSC field of research.

255 Finally, in this step, a qualitative content analysis was carried out as a complementary layer to
256 the keywords co-occurrence analysis to (i) obtain a deeper understanding of the extant knowledge
257 and intellectual structures, (ii) enable the identification of the most developed topics within the
258 literature, in particular the most recent subject areas under research, and (iii) better link existing
259 studies to future directions for research. Since the potential of conducting content analysis lies in
260 its combination with other methods (Gaur and Kumar, 2018), it can significantly enrich the results
261 of keyword-based analyses reviews. To this end, combining qualitative content analysis with other
262 review methods has been broadly used in conducting inclusive reviews (S. Chaudhary et al., 2021;
263 He et al., 2020; Piwowar-Sulej et al., 2021). In this regard, a qualitative content analysis was
264 conducted on the articles containing keywords with a minimum average publication year of 2019
265 (i.e., 2019-2022) and at least two occurrences. In this manner, besides the conceptual structure and
266 identified hotspots of BSC research in the previous step, emerging subject areas of research that
267 have recently attracted more attention were also discovered and discussed to answer RQ3. Fig. 1
268 illustrates the overall research framework employed in this study corresponding to the methods
269 applied to answer RQs and expected results.



270

271

Fig. 1. The research framework adopted for mapping BSC research

272 **3. Results and discussion**

273 The obtained results are presented in the following three sub-sections to clearly address the
 274 RQs of the study. In this vein, the performance indicators are presented in Section 3.1 to answer
 275 RQ1 regarding the states of scientific production in the BSC literature. Section 3.2 provides the
 276 major research hotspots and tendencies building the BSC background to address RQ2. And finally,
 277 RQ3 is answered in Section 3.3 through analyzing and discussing the main BSC research areas
 278 that have been recently under debate by research communities.

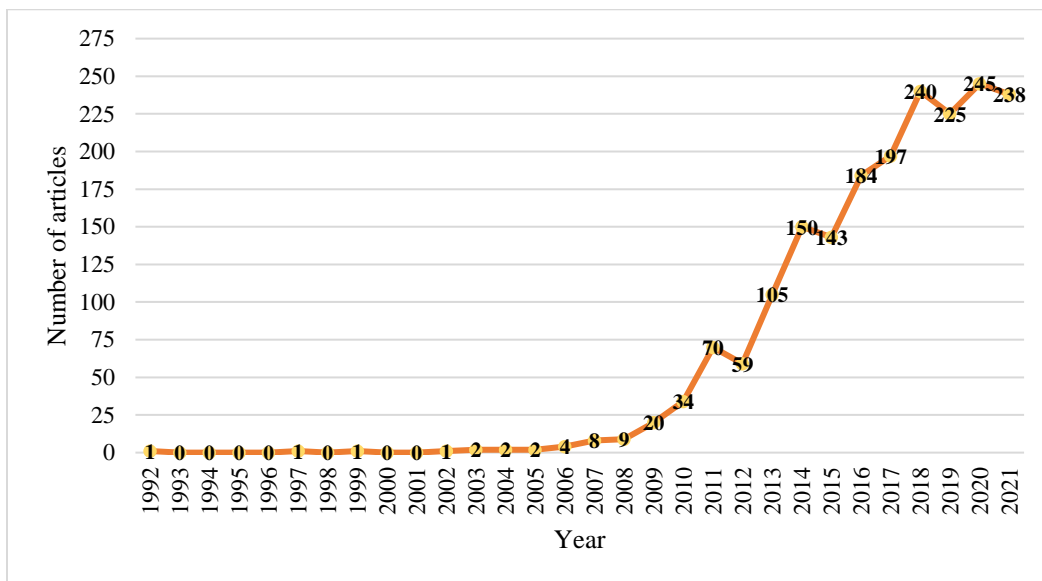
279

280 **3.1. Descriptive analysis results: Performance indicators**

281 **3.1.1. Annual publication evolution over time**

282 A total of 1,975 articles was retrieved from WoS by running the defined search string and
 283 applying the inclusion and exclusion criteria. The oldest identified article within the collected
 284 sample was published in 1992 in the journal "Biomass and Bioenergy". In that article, Mitchell
 285 (1992) provided an overview of a project regarding the wood fuel supply chain under the title

286 "Biomass supply from conventional forestry". As can be seen in Fig. 2, which shows the trend of
 287 annual publication in the field of biomass supply chain based on the articles' publishing date, there
 288 were only 10 articles published in this field of study in the period 1992-2005. However, between
 289 2006-2008 a constant increase was initiated and significant growth took place starting from 2009,
 290 although some minor dints appear in the number of publications between 2009 and 2021. Within
 291 our sample, 26 articles had no publication year, out of which 23 were available online since 2021
 292 and 3 were available since 2020. These articles are not considered in the trend shown in Fig. 2,
 293 however, in order not to lose information and to compute the average publication year of the
 294 keywords more realistically, they have been accounted for in the analysis of the keyword with an
 295 assumption of having the publication year of 2022.



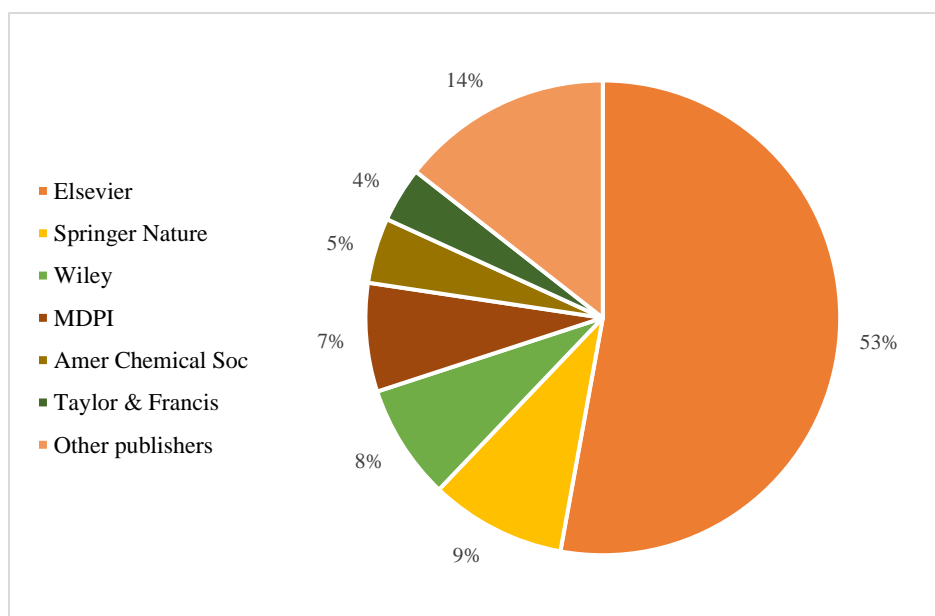
296
 297 **Fig. 2.** The annual publication in the research field of BSC.

298 3.1.2. Core publishers and journals

299 In total, 120 publishers have contributed to the publication of the 1975 articles in our dataset.

300 The six most contributing publishers (i.e. Elsevier, Springer Nature, Wiley, MDPI, American

301 Chemical Society, and Taylor and Francis) account for 85.57% of the published articles (1690
 302 articles of the total), as shown in Fig. 3. Moreover, while the selected sample of articles was
 303 distributed in 426 journals, 42.53% of them (840 articles) were published in only 10 journals. More
 304 than 74.4% of the journals (i.e. 317 journals) published only one or two articles in the studied field.
 305 Table 2 provides the list of 10 journals that have published the highest number of articles in our
 306 dataset. As can be seen in this table, "Journal of Cleaner Production", "Biomass & Bioenergy",
 307 and "Applied Energy" are the three most productive journals with 187, 124, and 123 articles,
 308 respectively. Although these three journals have also received the highest number of citations to
 309 their articles, the highest average citation per article is earned by "Computers & Chemical
 310 Engineering", "Renewable Energy", and "Biomass & Bioenergy", respectively. Furthermore, the
 311 average publication year (APY) reported in Table 2 shows that among the listed journals,
 312 "Sustainability", "Energies", and "Journal of Cleaner Production" have been more active in the
 313 publication of more recent articles rather than the older ones.



314
 315 **Fig. 3.** The main contributing publishers in the publication of BSC-related articles.

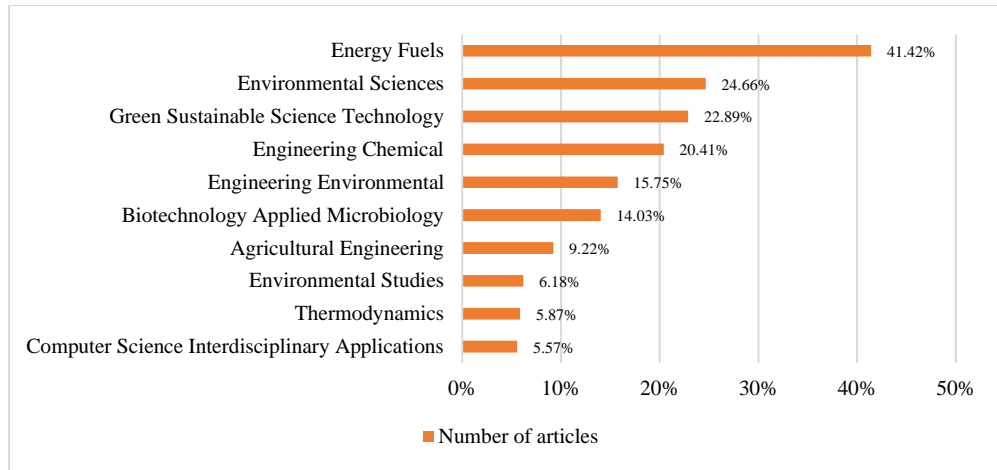
316 **Table 2.** The top 10 publishing journals in the field of BSC research.

Rank	Journal	2020 IF*	2020 CiteScore	No. of articles	Share of the total sample	Citations	AC*	APY*
1	Journal of Cleaner Production	9.297	13.1	187	9.47%	4009	21.44	2018
2	Biomass & Bioenergy	5.061	6.7	124	6.28%	3699	29.83	2014.39
3	Applied Energy	9.746	17.6	123	6.23%	3421	27.81	2017.02
4	Energy	7.147	11.5	84	4.25%	2314	27.55	2016.68
5	Computers & Chemical Engineering	3.845	7.0	74	3.75%	2462	33.27	2016.99
6	Biofuels Bioproducts & Biorefining-Biofpr	4.102	7.2	60	3.04%	1042	17.37	2015.98
7	Sustainability	3.251	3.9	53	2.68%	451	8.51	2018.79
8	Renewable Energy	8.001	10.8	48	2.43%	1439	29.98	2017.06
9	Energies	3.004	4.7	47	2.38%	386	8.21	2018.34
10	Industrial & Engineering Chemistry Research	3.764	5.6	40	2.03%	1141	28.53	2016.03

317 * IF: Impact Factor; AC: Average citation per article; APY: Average publication year

318 3.1.3. Thematic research categories in WoS

319 Based on the WoS classification, the collected articles are published in 99 research categories.
 320 Fig. 4 presents the WoS categories in which more than 100 articles are published, which form the
 321 top 10 research categories containing articles in the BSC study area. Since a single article may
 322 belong to more than one research category, the sum of numbers shown in Fig. 4 exceeds the
 323 number of articles in our dataset. As can be seen in this figure, approximately 41.42% of the articles
 324 (818 out of 1975) are classified in the "Energy Fuels" category. Having "Environmental Sciences",
 325 "Engineering Environmental", and "Environmental Studies" in the 2nd, 5th and 8th ranks highlights
 326 the concern of authors in the BSC field towards the environmental issues linked with this field of
 327 study.



328
329

Fig. 4. The top 10 WoS thematic research categories containing BSC research.

330 3.1.4. Geographical distribution of contributions

331 A total of 85 countries were identified to have contributed to the publication of articles in the
 332 BSC field of research. The top 10 productive and influential countries based on the number of
 333 published articles and the number of received citations, respectively, are listed in Table 3.
 334 According to this table, the USA, England, and Italy with 575, 176, and 166 articles and 15410,
 335 5147, and 3289 citations, respectively, are both the top productive and the top influential countries.
 336 Furthermore, among the institutions within the contributing countries, the U.S. Department of
 337 Energy (DOE), Imperial College London, and Iran University of Science & Technology with 97,
 338 55, and 48 articles, respectively, are the top three contributing institutions to the topic.

339 **Table 3.** The top 10 contributing countries in terms of no. of articles and no. of citations.

Top 10 contributing countries in terms of the no. of articles				Top 10 contributing countries in terms of the no. of citations		
Rank	Country	Articles	Share of the total sample	Rank	Country	Citations
1	USA	575	29.11%	1	USA	15,410
2	England	176	8.91%	2	England	5,147
3	Italy	166	8.41%	3	Italy	3,289
4	China	157	7.95%	4	Canada	2,832

5	Canada	131	6.63%	5	China	2,504
6	Germany	104	5.27%	6	Netherlands	2,242
7	Netherlands	93	4.71%	7	Spain	1,880
8	Iran	86	4.35%	8	Germany	1,836
9	Malaysia	85	4.30%	9	Austria	1,667
10	Brazil	84	4.25%	10	Malaysia	1,644

340

341 **3.2. Keywords co-occurrence analysis results: Discovering BSC research hotspots**

342 A total of 4,664 author keywords were recognized in the dataset at the initial stage. This
343 number was reduced to 4,443 unique keywords after cleaning the data. In order to provide a clear
344 picture of the main keywords forming the core of BSC research, a threshold of a minimum of 20
345 occurrences was considered for the keywords to be analyzed in-depth in this section. The
346 considered threshold resulted in the selection of 38 keywords, which were used to build the clusters
347 in Fig. 5. These clusters reflect the main research focuses in the field of BSC. In the keywords co-
348 occurrence network illustrated in Fig. 5, each node stands for a keyword, its size shows the
349 occurrence of the keyword in our dataset, and its color shows the cluster it belongs to. Moreover,
350 the links between the pair of nodes show the co-occurrence of the two keywords in a single article
351 and the thickness of the links reflects the repetition of this co-occurrence in different documents.

352 Table 4 provides details about the keywords in the built clusters, including their (1)
353 occurrence, (2) average publication year (i.e. mean of the publication year of the articles in which
354 a specific keyword appears), (3) average citation (i.e. mean of the citations received by the article
355 containing a specific keyword), (4) number of links (i.e. the number of keyword with which a
356 specific keyword co-appear in a single article), (5) total link strength (i.e. the sum of all co-
357 occurrences of a specific keyword), and (6) the five most co-occurring keywords with a specific
358 keyword and their number of co-occurrences. Furthermore, for each cluster, the average

368 **Table 4.** Major research hotspots within the BSC literature.

Cluster 1: Biomass-to-biofuel supply chain design and planning (APY*: 2016.90)						
Keyword	Occurrence	APY	AC*	Links	TLS*	The five most co-occurring keywords
Optimization	223	2017.21	21.02	34	350	Supply chain (51); Biomass (36); Biofuel (35); Bioenergy (20); Uncertainty (20)
Sustainability	130	2016.99	30.02	32	169	Biofuel (17); LCA (17); Biomass (14); Multi-objective Optimization (13); Renewable energy (9)
Multi-objective optimization	63	2017.56	33.62	28	84	Sustainability (13); Supply chain (11); Biofuel (5); BSC (5); LCA (5)
Uncertainty	59	2017.22	29.02	25	93	Optimization (20); Biofuel (10); Supply chain (10); Stochastic programming (7); BSC (5)
Mixed integer linear programming	58	2016.76	26.66	26	90	Optimization (18); Biomass (9); Supply chain (9); Bioethanol (4); Biorefinery (4)
Biomass supply chain	56	2016.68	22.71	19	51	Optimization (10); Bioenergy (5); Biorefinery (4); GHG emission (4); LCA (4)
Biodiesel	49	2016.35	18.02	18	49	Supply chain (13); Optimization (8); Biofuel (3); LCA (3); Uncertainty (3)
Supply chain management	42	2016.12	28.57	21	56	Optimization (9); Biomass (8); Bioenergy (4); Bioethanol (4); Sustainability (4)
BSC	40	2017	38.2	18	46	Optimization (7); Multi-objective optimization (5); Uncertainty (5); GHG emission (4); Sustainability (4)
Stochastic programming	27	2017.11	35.37	13	33	Uncertainty (7); Optimization (5); Biofuel (4); Biomass (4); Supply chain (4)
Supply chain design	24	2015.96	33.13	16	28	Biofuel (4); Mixed integer linear programming (3); Optimization (3); Biodiesel (2); Bioenergy (2)
Facility location	23	2015.78	26.52	16	38	Biofuel (5); Optimization (5); Supply chain (5); Sustainability (4); Biomass (3)
Switchgrass	23	2015.26	33.74	21	43	Biofuel (6); Supply chain (5); Sustainability (4); Bioenergy (3); LCA (3)
Sustainable development	22	2017.64	38.32	17	28	Biomass (5); Multi-objective Optimization (3); Supply chain (3); Bioenergy (2); BSC (2)
Cluster 2: Environmental impacts of biofuel production (APY: 2017.15)						
Keyword	Occurrence	APY	AC	Links	TLS	Most co-occurring keywords
LCA	170	2017.21	22.11	34	209	GHG emission (19); Sustainability (17); Bioenergy (16); Biomass (15); GHG (10)
Renewable energy	66	2017.67	20.55	19	73	Biomass (15); Optimization (11); Sustainability (9); Biofuel (6); Supply chain (6)
Greenhouse gas emission	56	2017.07	18.89	25	81	LCA (19); Bioenergy (6); Biomass (6); Supply chain (6); Biofuel (4)
Bioethanol	49	2016.39	16	21	70	Optimization (13); Supply chain (10); LCA (8); Sustainability (6); Mixed integer linear programming (4)
Biogas	45	2017.04	13.98	19	56	Anaerobic digestion (11); Supply chain (11); Optimization (7); Bioenergy (4); Biofuel (2)
Environmental impact	28	2017.79	14.21	15	40	LCA (13); Biofuel (5); Supply chain (5); Bioenergy (2); Bioethanol (2)
GHG	24	2015.83	23	15	38	LCA (10); Biofuel (5); Bioenergy (4); Biomass (4); Energy (3)
Anaerobic digestion	23	2018.44	13.78	11	28	Biogas (11); Optimization (4); Bioenergy (3); LCA (3); Biorefinery (1)
Energy	22	2016.5	21.45	14	34	Biomass (7); Supply chain (4); GHG (3); LCA (3); Optimization (3)
Cluster 3: Biomass to bioenergy (APY: 2016.29)						

Keyword	Occurrence	APY	AC	Links	TLS	Most co-occurring keywords
Supply chain	267	2016.28	20.54	33	383	Optimization (51); Biomass (43); Biofuel (42); Bioenergy (32); Biorefinery (18)
Biomass	205	2016.32	26.02	33	310	Supply chain (43); Bioenergy (39); Optimization (36); Biofuel (19); Logistics (17)
Bioenergy	156	2016.29	28.03	34	238	Biomass (39); Supply chain (32); Optimization (20); Biofuel (17); LCA (16)
Logistics	57	2015.95	26.14	22	105	Biomass (17); Bioenergy (16); Supply chain (15); Optimization (13); Geographic information system (7)
Geographic information system	45	2015.89	22.11	23	74	Logistics (7); Optimization (8); Supply chain (8); Biomass (7); Biofuel (6)
Torrefaction	40	2016.93	34.05	15	45	Biomass (10); Bioenergy (8); Supply chain (7); LCA (5); Logistics (4)
Transportation	37	2016.16	19.57	15	63	Supply chain (12); Biomass (9); Biofuel (7); Optimization (6); Logistics (5)
Forest biomass	34	2016.83	14.44	20	48	Supply chain (10); Bioenergy (9); Biofuel (5); Optimization (5); LCA (2)
Forest residue	20	2016.25	21.5	14	23	Bioenergy (5); LCA (3); Biomass (2); GHG emission (2); Torrefaction (2)

Cluster 4: Techno-economic analysis of biofuel production (APY: 2017.13)

Keyword	Occurrence	APY	AC	Links	TLS	Most co-occurring keywords
Biofuel	169	2016.34	23.08	35	269	Supply chain (42); Optimization (35); Biomass (19); Bioenergy (17); Sustainability (17)
Biorefinery	71	2017.39	23.48	21	103	Supply chain (18); Optimization (14); Biofuel (11); Biomass (9); Geographic information system (6)
CE	33	2019.70	10.61	20	38	Sustainability (5); LCA (4); Supply chain (4); Biofuel (3); Bioeconomy (2)
Techno-economic analysis	31	2018.84	11.84	19	37	LCA (6); Biofuel (4); Biorefinery (4); Bioenergy (3); Bioethanol (2)
Ethanol	29	2015.55	22.69	17	47	Biofuel (10); Supply chain (9); Biomass (5); Optimization (4); LCA (3)
Bioeconomy	24	2018.08	12.75	8	20	Biorefinery (5); Biomass (4); LCA (3); Bioenergy (2); Biofuel (2)

369 * APY: Average publication year; AC: Average citation; TLS: Total link strength.

370

371 **3.2.1. Cluster 1: Biomass-to-biofuel supply chain design and planning**

372 As reported in Table 4, the most frequent keyword in cluster 1 is "optimization", which has
373 co-occurred several times with various other highly frequent keywords including "supply chain",
374 "biomass", "biofuel", "bioenergy", and "uncertainty". Optimization models have been extensively
375 used in the academic literature for "supply chain design" and also planning in the field of bioenergy
376 (Memari et al., 2021). These models are applied in various contexts such as economic optimization
377 of the cellulosic biofuel supply chain (Ge et al., 2021), optimization of food supply chains under
378 CE considerations (Baratsas et al., 2021), optimal design of a supply chain for jatropha-based
379 biofuel (Afkhami and Zarrinpoor, 2021), biomass feedstock delivery (Li et al., 2019), and lifecycle
380 optimization of bioenergy with carbon capture and storage (BECCS) supply chains (Negri et al.,
381 2021). BSCs have several "uncertainties" such as supply uncertainty (Fattahi et al., 2021), demand
382 uncertainty (Elaradi et al., 2021), and material quality (Saghaei et al., 2020).

383 To deal with the "uncertainties" linked with the BSC, different approaches have been adopted
384 by the researchers, such as "stochastic programming" (Elaradi et al., 2021; Fattahi et al., 2021),
385 robust optimization (Gilani and Sahebi, 2021), and fuzzy programming (Afkhami and Zarrinpoor,
386 2021). "Multi-objective optimization" models developed in this field mainly focus on
387 "sustainability" issues and try to optimize a combination of economic, environmental, and social
388 aspects of a considered BSC. For instance, Baghizadeh et al. (2021) used a mixed-integer non-
389 linear programming model to maximize profit, improve social impacts, and minimize the negative
390 environmental effects and the lost demands in a forest supply chain. Also, Díaz-Trujillo and
391 Nápoles-Rivera (2019) focused on the optimization of biogas supply chains based on satisfying
392 the biogas and biofertilizer demands, maximization of the profit, and minimization of the
393 environmental impact. In another research conducted by Santibañez-Aguilar et al. (2022), a multi-

394 objective optimization model was applied for the planning of a biomass supply chain, which
395 considered several objective functions to address the social impact as a function of the facilities
396 location, net profit, and net CO₂ emissions.

397

398 **3.2.2. Cluster 2: Environmental impacts of biofuel production**

399 Biofuel, as a type of "renewable energy", is considered a strong alternative for fossil fuels due
400 to its favorable "environmental impacts" and its support to lower climate change through emitting
401 less "greenhouse gasses". Bui et al. (2021) estimated that indigenous sources of biomass in the UK
402 can remove up to an annual amount of 56 Mt of CO₂ from the atmosphere. García-Freites et al.
403 (2021) also focused on the UK's net-zero emission target and found that their studied BECCS
404 supply chains can contribute to the GHG removal by CO₂e between -647 and -1,137 kg MWh⁻¹
405 net negative emissions. In another research with a CE approach, Mayson and Williams (2021)
406 studied the treatment and reuse of spent coffee grounds to fuel the roasting process in a coffee
407 company and found that using spent coffee grounds can result in carbon savings of 5.06 kg
408 CO₂e/kg⁻¹ fuel for each roasted batch of coffee in comparison with a conventional approach.

409 A huge share of articles in the field of BSC deal with the environmental impacts of the
410 activities linked with the design and operation of BSC (e.g. Duarte et al. (2016) and Lu et al.
411 (2015)). Besides, "LCA" has been used in 170 articles in our dataset to assess the environmental
412 impacts of biofuel-related products, as a comprehensive evaluation approach for measuring
413 environmental impacts over the biofuels' entire production chain (Osman et al., 2021). For
414 instance, Lin et al. (2021) conducted an LCA on a biogas system for cassava processing in Brazil,
415 and Xu et al. (2021) studied the GHG emissions of the electricity generated from forest biomass
416 in the US from an LCA perspective. A cradle-to-grave industry-average assessment of the life-
417 cycle impacts of the wood pallet supply chain in the United States was done by Alanya-Rosenbaum

418 et al. (2021), highlighting the significant share of biomass from the total primary energy
419 consumption in the supply chain. Tsalidis and Korevaar (2022) pointed to the recent concentration
420 of LCAs on emerging technologies, which are not yet optimized with respect to energy and
421 materials, and conducted research to show the data scales effects on LCA results. They considered
422 a case study of the Dutch torrefaction industry and used its ex-ante experimental data, data derived
423 from simulations, and ex-post empirical data and modeled bench, lab, pilot, and commercial scales,
424 and simulations of torrefaction technology. Their investigations showed that simulations result in
425 better scores regarding all the considered environmental impacts including global warming, fine
426 particulate matter formation, terrestrial acidification and freshwater eutrophication potentials, in
427 comparison with the other scales modelled.

428 "Bioethanol", "biogas", and "anaerobic digestion" are other frequent author keywords
429 appearing in 49, 45, and 23 articles, respectively, that are labeled under cluster 2. Anaerobic
430 digestion is a biological process in which organic materials are converted to biogas through a series
431 of tandem biochemical reactions (Nie et al., 2021). This process is a waste-to-energy option to
432 recover energy from organic waste and produce value-added chemicals (Barati et al., 2017) and is
433 recognized as an environmental-friendly technology in this regard. As an example among the
434 papers investigated in our database, Nguyen et al. (2016) studied the energy conversion of rice
435 straw through anaerobic digestion and found that using rice straw for biogas production can
436 generate a positive net energy balance of 70% - 80%. In another research, Stougie et al. (2018)
437 studied the combustion of bioethanol from the fermentation of verge grass, combustion of
438 substitute natural gas from supercritical water gasification of animal manure, and combustion of
439 substitute natural gas from anaerobic digestion of animal manure, and found that the bioethanol
440 system has the best performance and is the most environmentally sustainable among the studied

441 systems. Bioethanol, as a type of biofuel, can be either blended with gasoline or used as a stand-
442 alone fuel (Haghighi Mood et al., 2013).

443

444 **3.2.3. Cluster 3: Biomass to bioenergy**

445 This cluster contains the keyword "supply chain", which is the most frequent keyword in our
446 database, as it constituted the main part of the search string in this research. As can be seen in
447 Table 4, the highest number of co-occurrences of "supply chain" is with "optimization" in cluster
448 1, which is the third frequent keyword with 174 occurrences. The strong co-occurrence link
449 between these two keywords highlights the interest in applying optimization models in different
450 supply-chain-related issues in the biofuel field of study, as also pointed to in cluster 1. Since the
451 conversion of "biomass to bioenergy" is the main objective of building a BSC, these two keywords,
452 representing the main input and output of the process, have significant link strengths with "supply
453 chain" (43 and 32, respectively).

454 Biomass is not only a source of energy but also a feedstock to be used in biorefineries. The
455 biomass materials that can be used to produce biofuel range from wood and energy crops to
456 agricultural, municipal, and industrial waste (Rentizelas, 2013). "Forest residue" has been
457 identified as a highly frequent keyword in the dataset analyzed for this research several articles
458 have considered this type of biomass for the production of biofuel and have analyzed its relevant
459 supply chain. Through a System Dynamics model developed by Jin and Sutherland (2018), the
460 dynamic changes in the forest residue supply and demand were analyzed. Sahoo et al. (2019)
461 developed economic models to estimate the operational costs of different forest residue *logistics*.
462 Moreover, in the research conducted by Malladi et al. (2018), a decision support tool was
463 developed for optimizing the short-term "logistics" of forest-based biomass. Selection of a proper

464 location for the biofuel-related facilities (Santibañez-Aguilar et al., 2018; Woo et al., 2018) and
465 also the transportation and logistics (Fikry et al., 2021; Han et al., 2018) issues are some of the
466 other challenges addressed by researchers regarding the management of a BSC, whose relevant
467 keywords have appeared in this cluster.

468

469 **3.2.4. Cluster 4: Techno-economic analysis of biofuel production**

470 Considering the keywords in cluster 4 and their most co-occurring keywords, the main theme
471 of this cluster can be linked with the techno-economic and cost-based optimization and analysis of
472 biofuel production. The most frequent keyword in this cluster is "biofuel" with an APY of 2016.34
473 for 169 occurrences, followed by "biorefinery" with 71 occurrences and an APY of 2017.39. The
474 most co-occurring keywords with "biofuel" and "biorefinery" are "supply chain" and
475 "optimization", which point to a significant share of the articles reflecting research on the
476 optimization of biofuel production or optimization of biofuel supply chains, in line with the
477 discussions on cluster 1.

478 In many of the studies dealing with the optimization of the biofuel supply chain or a part of it,
479 costs and economic analysis have been considered crucial, since biofuel production is linked with
480 several economic constraints. For instance, Allman et al. (2021) proposed a biomass waste-to-
481 energy supply chain optimization model for the location and relocation of mobile and modular
482 production units and found that mobile production modules lead to the saving of 1-4% of supply
483 chain costs in Minnesota and North Carolina. An optimization framework for biorefineries design
484 was presented by Theozzo and Teles dos Santos (2021) to maximize the operational net present
485 value. Ankathi et al. (2021) proposed an optimization model for locating food waste and manure
486 anaerobic co-digestion facilities in Wisconsin to maximize the profit from the biopower supply

487 chain and carbon credits. In addition, "ethanol", which is the most produced biofuel at the industrial
488 scale level (Amândio et al., 2022), has been addressed in the optimization models of some research.
489 The optimization-based model by Punnathanam and Shastri (2021) for ethanol production from
490 the agricultural residue with an objective of minimizing the total annual cost, and the optimization
491 model by Soren and Shastri (2021) for commercial-scale ethanol production considering the cost
492 minimization are a few examples in this regard.

493 "Techno-economic analysis" of biofuel production and the processes involved are the focus of
494 some other studies. The research by Lan et al. (2021) on the techno-economic analysis of
495 decentralized preprocessing systems, the techno-economic evaluation by Abelha and Kiel (2020)
496 on biomass upgrading by washing, and the study conducted by Khounani et al. (2019) on the
497 techno-economic evaluation of safflower-based biorefinery can be named as a few examples in
498 this regard. As such, "techno-economic analysis" can be mentioned as the core keyword in this
499 cluster, which involves both technical and economic aspects of processes and activities in the
500 biofuels supply chain.

501 The "CE", as the most recent keyword in this cluster, has been pointed to in several articles,
502 for instance, to address biogas production in the anaerobic digestion process (Vondra et al., 2019),
503 using spent coffee grounds as fuel (Mayson and Williams, 2021), and wood-based biomass
504 (Marques et al., 2020). However, whether biofuel-related articles explicitly mention CE or not, CE
505 is linked with the nature of biofuel production in terms of particular focus on waste valorization
506 and resource efficiency. Furthermore, "bioeconomy", which addresses the utilization of renewable
507 biological resources for energy production and manufacturing domestic consumables (Guo and
508 Song, 2019), is the least frequent keyword in this cluster, addressed by a number of articles, such
509 as Egea et al. (2021) and Raimondo et al. (2018).

510

511 **3.3. Qualitative content analysis results: Emergent BSC research areas**

512 In this section, the most emerging topics considered by researchers in the field of BSC are
513 identified and discussed. To discover the emerging topics, the author keywords with a minimum
514 of two occurrences and the APY of at least 2019 are selected and analyzed. Considering a threshold
515 of two occurrences is meant to capture the keywords that are relevant to the studied research area
516 but are not yet widespread. This threshold resulted in capturing 947 keywords, which were then
517 reduced to 219 records due to the considered time constraint for focusing on the recent articles. As
518 a result, the following three main roadmaps, representing the most recent BSC-related subject areas
519 were identified: (i) global warming and climate change mitigation, (ii) development of the third-
520 generation biofuels, and (iii) government incentives, pricing, and subsidizing policies.

521

522 **3.3.1. Global warming and climate change mitigation**

523 The climate change and BSC activities trade-offs have appeared as one of the most recent
524 subject areas within the BSC literature. In this regard, "global warming", "GHG removal",
525 "decarbonization", "environmental analysis", "CO₂ removal", and "climate change mitigation" are
526 some of the authors' keywords in our sample data, which can be categorized under the climate
527 change subject area of research. The urgent need for mitigating climate change adverse effects
528 along with the potential threat of energy crisis have increased the interest to utilize biomass for
529 biofuel production (Liu et al., 2020a).

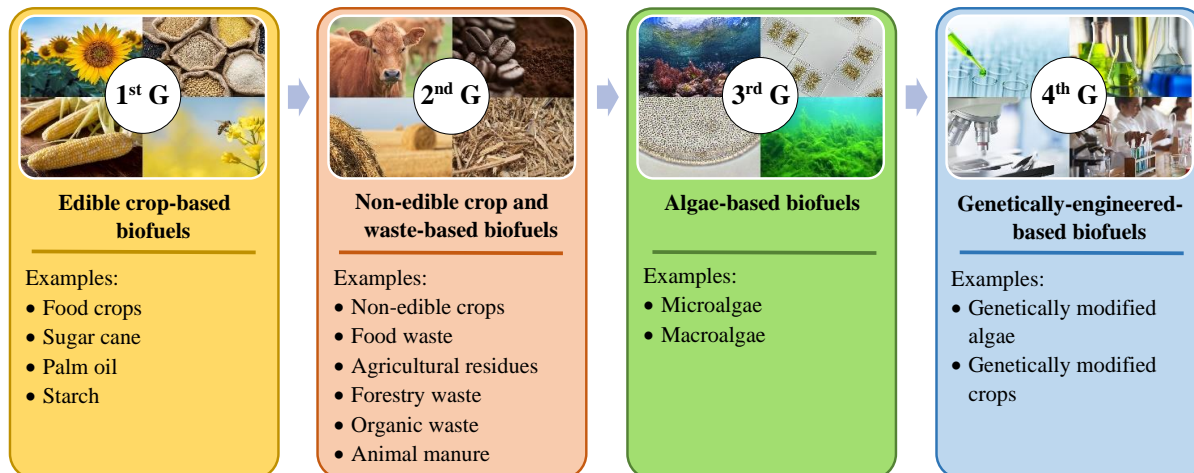
530 Yan et al. (2021) in a study in China showed that climate change has a significant impact on
531 the availability of land for producing liquid biofuels due to changing temperature and precipitation.
532 The main focus of research in this area has been on climate change impacts trade-offs with utilizing

533 logging residue for biofuel production (Liu et al., 2020b), economic and environmental effects of
534 biofuel production developments (Kung, 2019), policy formulation (Prasad et al., 2020), cellulosic
535 biofuel applications (Popovic et al., 2019), and biofuel cropping systems (Pilecco et al., 2020).
536 However, developing integrated frameworks to assess the climate change impacts of biomass
537 utilization for biofuel production needs more investigations in the future.

538

539 **3.3.2. Development of the third-generation biofuels**

540 Different categories and generations of development for biofuels have been presented in the
541 literature based on the type of feedstock that is used for their production (Abbasi et al., 2021;
542 Hajjari et al., 2017). However, according to Alalwan et al. (2019), biofuels are generally classified
543 into four generations, including (i) the first-generation biofuels that are produced from edible
544 biomass, such as corn or sugarcane, (ii) the second-generation biofuels which utilize non-edible
545 biomass, such as agriculture residues, (iii) the third-generation biofuels use microorganisms as
546 feedstock, such as algal biomass, and (iv) the fourth-generation biofuel which focuses on
547 genetically modifying microorganisms to minimize or eliminate carbon emissions. Fig. 6
548 illustrates the four generations of biofuels. Production of each biofuel generation has faced several
549 challenges. For instance, first-generation biofuel production deals with the price increase for
550 animal feeds and food, and the high rate of land use for cultivation (R. Chaudhary et al., 2021).
551 Moreover, while the second-generation biofuel production technologies have some difficulties in
552 the extraction of fuel, the third-generation biofuels are struggling with the financial competition
553 with petroleum-based fuels (Rodolfi et al., 2009). Although the first two generations of biofuels
554 have been immensely investigated by scholars, the third and fourth generations are still in their
555 infancy stage of research.



556

557 *G: generation.

558

Fig. 6. Biofuel generations.

559 Based on the average publication year of keywords within our data, the third generation of
 560 biofuels, which utilizes algal biomass, including microalgae and macroalgae has emerged as a
 561 recent subject area in the BSC literature. On this basis, "seaweed", "macroalgae", and "algae" have
 562 been used by researchers as keywords of their research with a minimum average publication year
 563 of 2019. Microalgae, as a potential feedstock for the third-generation biofuel production, has
 564 increasingly gained momentum among scholars and industrial practitioners due to its significant
 565 benefits, such as (i) sequestering huge amounts of CO₂ during their cultivation, (ii) high oil content
 566 and fast growth rate, (iii) flexibility in growing in inapplicable water resources, and (iv) using
 567 marginal lands which are not ideally used for agriculture purposes (Abbasi et al., 2021; Molino et
 568 al., 2020).

569 Bharathiraja et al. (2022) showed that in comparison with the biofuels made from crops and
 570 lignocelluloses, the third-generation biofuels produced from algae are more compatible with diesel
 571 engines due to their lower environmental footprint. The research in this area has been mainly
 572 focused on algae cultivation and production systems (Ou et al., 2021), the application of catalytic
 573 processes on the production of algae-based biofuels (Zuorro et al., 2020), modeling water-energy

574 tradeoffs (Mayer et al., 2020), acceptability of genetically engineered algae biofuels (Varela
575 Villarreal et al., 2020), and value-added products (Kumar et al., 2020). Nevertheless, although
576 much research has been conducted in this subject area, biofuel production from algae is still under
577 intense investigation to tackle main barriers, including commercialization (Shiru and Shiru, 2021),
578 and technological advancements for reducing production costs (Getachew et al., 2020).

579

580 **3.3.3. Government incentives, pricing, and subsidizing policies**

581 Governmental support plans, such as financial incentives, pricing strategies, and subsidy
582 programs in progressing towards using biofuels have appeared as a recent and ongoing subject
583 area of BSC research. Due to the increasing public awareness of global warming, many
584 governments are providing monetary incentives to replace biofuels with fossil fuels (Denizel et al.,
585 2020). In this regard, the role of governments to promote and encourage using biofuels through
586 developing various incentive programs is indispensable. Wu et al. (2021) highlighted the urgent
587 need for more investigations on effectively guiding the government incentive programs for the
588 biomass supply chain management and coordination and alliance of profit distribution issue. Haji
589 Esmaeili et al. (2020) in another research, recommended providing financial incentives to motivate
590 producers of first-generation bioethanol to switch to second-generation bioethanol production due
591 to serious food versus fuel debates resulting from the first-generation biofuel production.
592 Moreover, risk mitigation strategies and policies are required to tackle the evolving and fluctuating
593 effects of the COVID-19 pandemic on the sustainability of biomass supply chains (Sajid, 2021)
594 towards achieving sustainable development (Ameli et al., 2022; Ranjbari et al., 2021b). The
595 research in this domain has been mainly focused on waste-to-energy incentive policy design (Zhao
596 and You, 2019), and carbon-pricing strategies (Díaz-Trujillo et al., 2019).

597

598 **4. Future directions for BSC research in transitioning towards a CE**

599 As shown in Table 4, a comparison between the occurrence and APY of the "CE" keyword
600 with the "biofuel" keyword in our data shows that although the CE concept inherently exists in the
601 BSC, this concept as a keyword has been more recently attracted attention to be used in the
602 scientific productions. Besides, the "CE" keyword has appeared as the most frequent keyword with
603 an APY of more than 2019 in our dataset, highlighting the recentness of serious efforts and focus
604 on the CE transition in the biofuel production and utilization practices.

605 Transitioning from a linear economy to a CE with a waste-to-wealth approach plays a
606 significant role in supporting sustainable development in the local and global contexts
607 (Shevchenko et al., 2021). Although the nature of waste conversion in biorefineries to produce
608 biofuels can potentially address CE principles, the research in putting the CE framework in place
609 as a whole within the BSCs in industrial and commercial scales is still in its infancy stage.
610 Therefore, implementing CE strategies in the context of BSCs, as a promising solution towards
611 sustainable development, need more investigations and further development. In this vein, two
612 mainstreams of research are identified as potential avenues for further research in the future to
613 facilitate the CE transition in the BSCs:

614 **(i) Integrative policy convergence at macro, meso, and micro levels**

615 Investments in the nexus of the CE and bioeconomy considering the potentials of the bio-
616 based sector have gained momentum to create a sustainable future. On this basis, the CBE, as a
617 bio-based CE, highly relies on the sustainable and resource-efficient valorization of biomass and
618 organic waste through integrated biorefineries (Stegmann et al., 2020) to close supply chain loops.
619 However, existing guidelines and standards developed for businesses lack a clear definition and

620 framework, outlining which cycles between the CE and bioeconomy contribute most to a
621 sustainable future economy (Leipold and Petit-Boix, 2018). In this regard, Leipold and Petit-Boix
622 (2018) showed that the bio-based businesses in the European context predominantly stick to
623 already established practices and, so far, do not employ the business model innovation potentials
624 to implement a CE.

625 Potential conflicts and frictions among different components of biofuel supply chains and CE
626 strategies and policies hinder the CE transition in the bio-based economy. Hence, an integrative
627 policy convergence from macro to micro levels for biofuel production in BSC management still
628 seems lacking. The extant research in this area is mainly limited to technical aspects at meso and
629 micro levels. Developing an integrated framework to converge CE and BSC management policies
630 at macro, meso, and micro levels to align biofuel production and utilization with CE principles is
631 highly recommended for further research. In particular, investigations need to address convergence
632 opportunities between CE and BSC stakeholders through (i) supporting initiatives in enabling
633 innovative business models, (ii) drafting national plans for maximizing the local capacity in waste-
634 based biofuel production pathways, and (iii) adopting systems thinking approach to effectively
635 evaluate the dynamics of the BSC as a whole in the CE transition.

636 **(ii) Industrializing algae-based biofuel production towards the CE transition**

637 Algae are used as promising feedstocks for different applications, such as bioenergy and
638 biofuel production, and the manufacturing of high-value bioproducts (Ahmad et al., 2022). Algal
639 biofuels, as a clean and renewable energy source, are of high interest to the energy sector due to
640 their energy-efficient and environmentally-friendly potential in tackling GHG emissions and
641 widespread pollution (Ferreira Mota et al., 2022). In this regard, biofuel production from algal
642 biomass towards a CBE has been under intense debate, leading to development in different aspects,

643 such as microalgae cultivation (Devadas et al., 2021), techno-economic feasibility assessments
644 (Venkata Subhash et al., 2022), anaerobic digestate valorization (Stiles et al., 2018), and
645 production and harvesting of microalgae (Khan et al., 2022), to name a few. However, algae-based
646 biofuel production has faced critical challenges and barriers, mainly economic and technological
647 barriers that prevent the commercial and industrial use of algae (Ahmad et al., 2022).

648 Increasing the share of the third-generation biofuels compared to the first and second
649 generations that create food and landmass competition, can potentially strengthen the link between
650 bioeconomy and the CE towards an algae-based CBE. In this regard, algae-based biofuels, as the
651 third generation of biofuels, are not produced on industrial and commercial scales. Hence, further
652 efforts and research are needed to switch algal biofuel production from a laboratory scale to an
653 industrial and commercial scale under a new biorefinery paradigm. On this basis, future research
654 efforts should be mainly focused on (i) developing technological initiatives to foster algae
655 cultivation, production, and harvesting for biofuel production, and (ii) defining an inclusive agenda
656 at the national level as a shared blueprint for providing economic incentives and government
657 support to help commercialize the third-generation biofuels in the energy market.

658

659 **5. Conclusions**

660 This research was the first attempt in the literature employing a systematic review, supported
661 by a keywords co-occurrence analysis and qualitative content analysis to present an inclusive
662 knowledge map of the BSC research so far. Adopting a structured search protocol, a total of 1,975
663 peer-reviewed journal articles from the WoS database was scrutinized based on the co-occurrence
664 algorithm using VOSviewer version 1.6.16 (van Eck and Waltman, 2010).

665 On one hand, four seminal research hotspots of the BSC literature were identified. In this
666 regard, the BSC research has been mainly focused on (i) designing and planning for biomass-to-
667 biofuel supply chains, (ii) investigating the GHG footprint and environmental impacts of biofuel
668 production and biorefineries, (iii) biomass to bioenergy conversion processes, and (iv) techno-
669 economic analysis of biofuel production. On the other hand, based on the analysis conducted on
670 the average publication year of authors keywords in our data, (1) global warming and climate
671 change mitigation, (2) development of the third-generation biofuels produced from algal biomass,
672 which has recently gained momentum in the CE debate, and (3) government incentives, pricing
673 and subsidizing policies appeared as the main recent BSC-related subject areas of research.
674 Moreover, potential research avenues to implement the CE framework in BSCs, including (i)
675 integrative policy convergence at macro, meso, and micro levels, and (ii) industrializing algae-
676 based biofuel production towards the CE transition were proposed. Compared to the existing
677 reviews in the BSC literature, the provided insights in this study through a science mapping
678 analysis contribute to the domain by (i) providing performance indicators of scientific production
679 in the BSC research, (ii) discovering major research hotspots, themes, and trends in BSCs, (iii)
680 discovering BSC subject areas of research which have recently attracted more attention, and (iv)
681 proposing future directions for BSC research to support the CE transition. Accordingly, BSC
682 research communities, practitioners, policy-makers, and stakeholders are potentially benefited
683 from the delivered inclusive image of the BSC academic production through the enhancement of
684 their perception of the field and recent developments.

685

686 **5.1. Limitations of the study**

687 As is often the case, there are some limitations regarding the scope and review process adopted
688 in our research, which can serve as promising directions for future studies. First, we relied on the
689 keywords co-occurrence analysis for clustering the articles in our sample data. Using other
690 clustering techniques in bibliometric analysis, such as co-citation analysis (Ertz and Leblanc-
691 Proulx, 2018), bibliographic coupling analysis (Belussi et al., 2019), and text mining analysis
692 (Ranjbari et al., 2022a) are recommended for further studies. The obtained results can be compared
693 with the present study to evaluate the advantages and disadvantages. Second, our data was
694 extracted from Wos, which is one of the most well-known academic citation databases. However,
695 incorporating other databases, such as Scopus may help increase the reliability of the findings.
696 And finally, the main focus of our review was on providing a general overview of the BSC
697 research, as a knowledge map. Therefore, more in-depth analyses on each identified hotspot and
698 the recent subject area within the BSC domain, in particular (i) the third and fourth generations of
699 biofuels, and (ii) technological advancement to support the transition from a linear economy to a
700 CBE with a special focus on waste-based biomass are highly encouraged for future research.

701

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714

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