

An inclusive trend study of techno-economic analysis of biofuel supply chains

*Original*

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1                   **An inclusive trend study of techno-economic analysis of biofuel supply chains**

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42 **Abstract**

43 Biofuels have gained much attention as a potentially sustainable alternative to fossil fuels to  
44 tackle climate change and energy scarcity. Hence, the increasing global interest in contributing to  
45 the biofuel supply chain (BSC), from biomass feedstock to biofuel production, has led to a huge  
46 amount of scientific production in recent years. In this vein, techno-economic analysis (TEA) of  
47 biofuel production to estimate total costs and revenues is highly important for transitioning towards  
48 a bioeconomy. This research aims to provide a comprehensive image of the body of knowledge in  
49 TEA evolution within the BSC domain. To this end, a systematic science mapping analysis,  
50 supported by a bibliometric analysis, is carried out on 1,104 articles from 1986 to 2021. As a result,  
51 performance indicators of the scientific production within the target literature are presented to  
52 explain how this literature has evolved. Besides, thematic trends and conceptual structures of TEA  
53 of biofuel production are discovered. The results showed that (i) biofuel production and  
54 consumption need promotion through tax measures and price subsidies, (ii) the development of  
55 cost-competitive algal biofuels has faced many challenges over recent years, and (iii) TEA of algal  
56 biofuels to identify commercial improvements and increase the economic feasibility is still lacking,  
57 which calls for more in-depth investigations. Consequently, current challenges and future  
58 perspectives of TEA in the BSC domain are rendered. The provided insights enable researchers  
59 and decision-makers involved in BSCs to (i) capture the most influential contributors to the field  
60 and (ii) identify major research hotspots and potential directions for further developments.

61

62 **Keywords:** Biofuels; Techno-economic assessment; Biorefinery; Biomass; Bibliometrix R-  
63 package; Biblioshiny

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65 **List of abbreviations**

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<b>Abbreviation</b>	<b>Full term</b>
TEA	Techno-economic analysis
BSC	Biofuel supply chain
LC	Local citations
GC	Global citations
APY	Average publication year

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## 81 **1. Introduction**

82       Due to existing economic and environmental issues for the global community, such as fossil  
83 fuel depletion, energy security, greenhouse gas emissions, and climate change (Coelho et al.,  
84 2014), biofuels as a potential alternative energy source (Nigam and Singh, 2011) have gained  
85 momentum worldwide. In this regard, biofuels derived from biomass, as a promising renewable  
86 alternative for fossil fuels, are evidenced by their potential to reduce (i) anthropogenic greenhouse  
87 gas emissions (Osman et al., 2021), (ii) air pollutants emissions (Carvalho et al., 2021), and (iii)  
88 global dependency on fossil fuels and energy scarcity (Pilecco et al., 2020). However, biofuel  
89 production has faced various economic and technical constraints, including feedstock availability  
90 and cost (Hajjari et al., 2017), commercialization (Venkata Subhash et al., 2022), lack of policy  
91 integration, and industry convergence at the macro level in transitioning towards a bioeconomy  
92 (Mossberg et al., 2021), and large-scale production to fulfill the current and future energy demand  
93 (Ambaye et al., 2021). As a result, techno-economic analysis (TEA) of biofuel production to  
94 estimate total costs and revenues has been widely carried out by biofuel research communities to  
95 support biofuel supply chain (BSC) stakeholders in decision-making and policy recommendations  
96 for further developments in the energy market.

97       Based on a comprehensive science mapping analysis conducted by Ranjbari et al. (2022a)  
98 on BSC management activities, TEA has appeared as one of the main research backgrounds of the  
99 BSC scientific production in the available literature. Over the last decade, a significant amount of  
100 research on TEA of biofuel production has been conducted, considering different stages of BSC  
101 from biomass feedstock to biofuel production. In this vein, the target research efforts have been  
102 mainly focused on the TEA of biomass gasification process (Lo et al., 2021), co-production of  
103 bioethanol and biogas from lignocellulosic biomass (Jarunglumlert and Prommuak, 2021),

104 biomass to methanol supply chains (Nugroho et al., 2022), thermochemical cellulosic biofuel  
105 pathways (Brown, 2015), waste-to-biofuel integrated system in wastewater treatment plants (Xin  
106 et al., 2018), biofuel production from macroalgae (Ribeiro and Silva, 2013; Soleymani and  
107 Rosentrater, 2017), algal biofuel production facilities design (Kern et al., 2017), wastewater-based  
108 algal biofuel production (Xin et al., 2016), biofuel production from biomass fast pyrolysis and bio-  
109 oil upgrading (Shemfe et al., 2015), bioenergy and biofuel production in integrated sugarcane  
110 biorefinery considering dilute acid pretreatment (Vasconcelos et al., 2020), transportation biofuels  
111 from hydrothermal liquefaction of forest residues (Nie and Bi, 2018), biofuels for maritime  
112 transportation (Carvalho et al., 2021), aviation biofuel production via aqueous phase processing  
113 (Olcay et al., 2018), aviation biofuel production from oilseeds (Diniz et al., 2018), production of  
114 solid biofuels and biochar from forest residues using portable systems (Sahoo et al., 2019), biofuel  
115 production via bio-oil zeolite upgrading (Shemfe et al., 2017), biofuel production using Fisher-  
116 Tropsh synthesis (Veipa et al., 2020), and hydrogen enhancement potential of synthetic biofuels  
117 manufacture (Hannula, 2016). Hence, the increasing growth of the scientific production in TEA of  
118 different practices and components of BSCs worldwide has led to mature and fragmented  
119 literature. Accordingly, the emerging interest of scientific communities has provided an  
120 opportunity to investigate techno-economic feasibility thematic trends and evolution within  
121 biofuel production and utilization in different domains.

122 To map the body of knowledge and unfold the thematic evolution of a specific domain, the  
123 potential benefits of employing bibliometric, scientometric, and science mapping analyses in  
124 conducting comprehensive reviews have been remarkably acknowledged by many scholars. This  
125 issue is mainly due to the capability of such analyses, as quantitative techniques and powerful  
126 statistical tools, in (i) capturing information from a huge amount of publications in the literature

127 in a reasonable manner, (ii) specifying the major connections among documents, sources, authors,  
128 contributing institutions, keywords, and citation-based networks, and (iii) identifying main  
129 research themes, hotspots, and conceptual structures of a body of knowledge over time (Ranjbari  
130 et al., 2022d, 2021a; Shams Esfandabadi et al., 2022a).

131 However, although few studies have conducted bibliometric and science mapping analyses  
132 on the BSC domain, such as biofuels and sustainable development goals (Nazari et al., 2021),  
133 macroalgal biomass as a source of biofuel feedstock (Coelho et al., 2014), and solid biofuel  
134 production (Knapczyk et al., 2019), a comprehensive science map of TEA research in BSCs is still  
135 lacking in the literature. In order to address the identified gap, this research aims to examine the  
136 themes and trends of the scientific productions in the field of TEA in BSCs through a  
137 comprehensive science mapping analysis. In this regard, a systematic science mapping analysis  
138 using the “biblioshiny” web-interface of the “bibliometrix” package in R programming language  
139 (Aria and Cuccurullo, 2017) and also VOSviewer (van Eck and Waltman, 2010) is performed to  
140 address the two main research questions (RQs) of the present study:

141 **RQ.1.** How has the scientific literature in the TEA of BSCs evolved over time?

142 **RQ.2.** What are the main thematic trends of TEA applications in BSCs, building the  
143 conceptual structure of the field?

144 To the best of the authors’ knowledge, this is the first research in the BSCs literature that  
145 conducts a systematic science mapping analysis on the TEA concepts to map the body of  
146 knowledge in this area. The provided insights through trend analysis of TEA of biofuel production  
147 contribute to the domain by enabling researchers to (i) identify the most influential articles,  
148 journals, countries, and institutions contributing to the field to date, (ii) discover the main themes  
149 and trends of the TEA within the BSC domain, and (iii) catch the main challenges and future

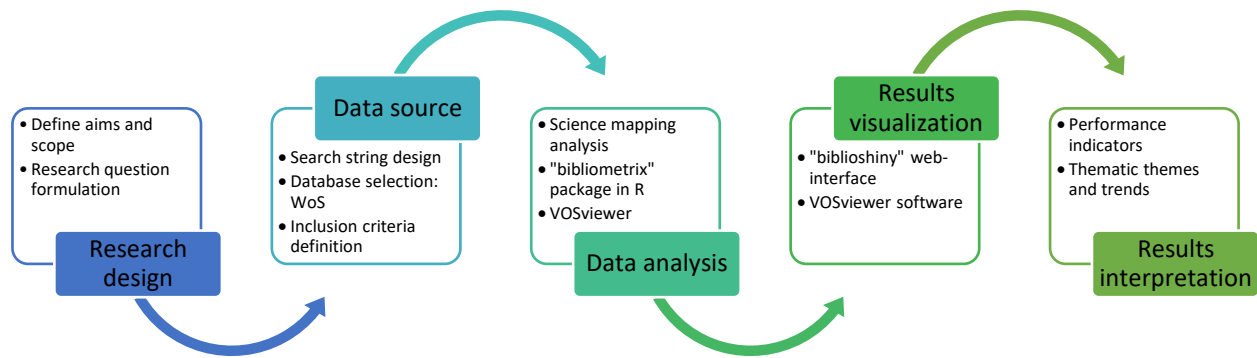
150 perspectives of TEA of biofuel production and consumption in order to find ways to reduce the  
151 level of conflicts and make a sustainable balance between the share of biofuels and petroleum fuels  
152 in the energy sector.

153 The rest of this study is organized as follows. Section 2 provides an overview of the data  
154 source and adopts a search protocol for conducting the systematic science mapping analysis in this  
155 research. The obtained results are presented and discussed in Section 3. In this regard, descriptive  
156 analysis results presenting performance indicators of the scientific production in the TEA of  
157 biofuel production are provided in Section 3.1 to answer RQ.1. Conceptual structures and thematic  
158 trends of the TEA of biofuel production are explained in Section 3.2 to address RQ.2. Current  
159 challenges and future perspectives of TEA in the BSC domain are rendered in Section 4, and the  
160 concluding remarks and limitations of the study are presented in section 5.

161

## 162 **2. Methodology**

163 In this study, a systematic science mapping analysis was adopted from Aria and Cuccurullo  
164 (2017) and Xie et al. (2020) to render an inclusive image of the thematic trends and evolution of  
165 TEA applications in the biofuel production literature. To this end, a standard workflow of science  
166 mapping analysis (Zupic and Čater, 2015) was followed, taking five steps, including research  
167 design, data collection, data analysis, data visualization, and interpretation. The overall research  
168 framework of the present study is illustrated in Figure 1.



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**Fig. 1.** The overall research framework.

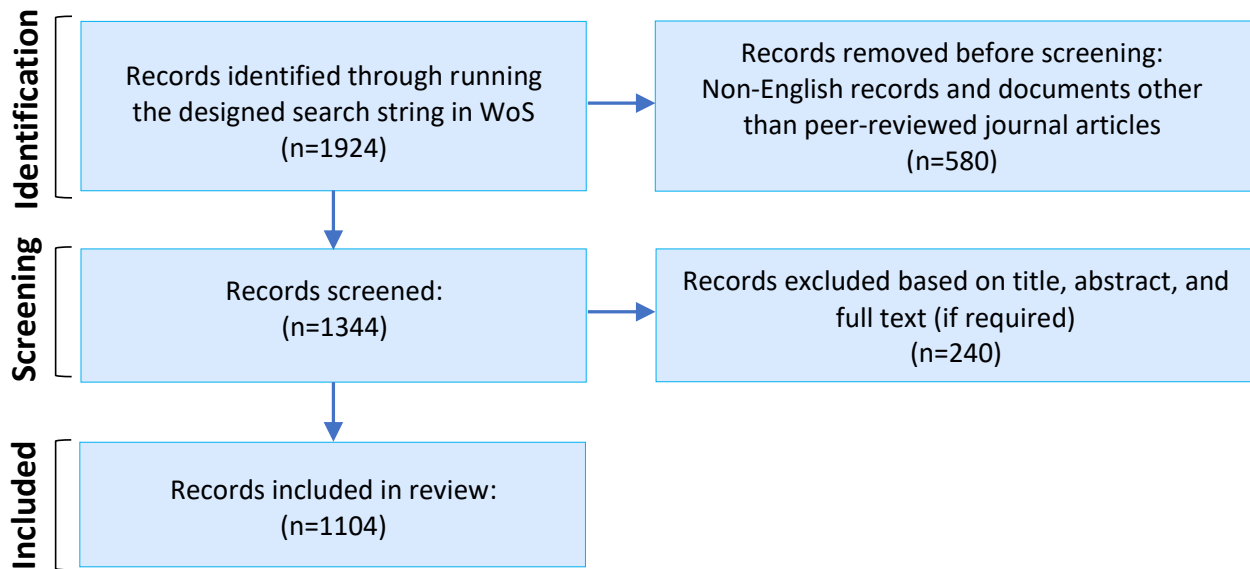
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172 Adopting a well-structured search protocol to sufficiently collect the most relevant data plays  
 173 a significant role in conducting reliable systematic reviews (Ranjbari et al., 2021b; Shevchenko et  
 174 al., 2022). On this basis, database selection, structured search string formulation, and inclusion and  
 175 exclusion criteria definition for investigating, screening, and selecting articles from the target  
 176 literature are crucial.

177 The Web of Science (WoS) Core Collection database was selected as the main database in  
 178 this research since it is one of the most reliable academic citation databases. According to the main  
 179 scope and focus of the present study, “biofuel” and “TEA” were the two main keywords related to  
 180 the topic. Moreover, to ensure sufficient coverage and effective capturing of the articles, different  
 181 synonyms and also similar keywords referring to the BSC and TEA were added to the keywords  
 182 for data selection. Consequently, a search string using “OR” and “AND” Boolean operators was  
 183 constructed to search articles in WoS as the following: (“biofuel” OR “bio fuel” OR “bio-fuel” OR  
 184 “bio ethanol” OR “bio-ethanol” OR “bioethanol” OR “bio diesel” OR “bio-diesel” OR “biodiesel”  
 185 OR “biogas” OR “bio gas” OR “bio-gas” OR “syngas” OR “synthesis gas” OR “bio oil” OR “bio-  
 186 oil” OR “biobutanol” OR “bio-butanol” OR “bio butanol” OR “pellet” OR “briquette” OR

187 “biochar” OR “bio-char” OR “bio char”) AND (“techno econom\*” OR “techno-econom\*” OR  
188 “technoeconom\*” OR “economic analysis” OR “economic assessment” OR “economic  
189 evaluation” OR “economic feasibility” OR “economic study” OR “economic implication” OR  
190 “economic performance”).

191 Data was retrieved from WoS on January 12, 2022. To keep the research focused on the  
192 biofuel domain, the first part of the search string was run in the titles of the paper, while the second  
193 part was performed on the topic field (i.e., titles, abstracts, author keywords, and keywords plus).  
194 Accordingly, the initial search with the designed search string returned 1,924 results in WoS. In  
195 the next step, the results were refined by including only peer-reviewed journal articles in English  
196 and excluding other types of documents, such as book chapters, conference proceedings, editorials,  
197 and short communications. In addition, the records were limited to all scientific production  
198 published by the end of 2021. Consequently, 1,344 peer-reviewed journal articles published  
199 between the years 1986 and 2021 remained for further consideration. Finally, to remove irrelevant  
200 articles, a manual screening was carried out on the remaining articles. This screening was  
201 conducted mainly based on the title and abstracts of the articles and also the full text of the articles  
202 about which the decision about relevancy could not be made only based on the abstract. This  
203 process resulted in a total of 1,104 eligible articles as the final sample for the science mapping  
204 analysis. Figure 2 shows the details of the data collection process following the PRISMA statement  
205 framework (Liberati et al., 2009).



**Fig. 2.** Data collection process following the PRISMA framework.

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Although the source, authorship, citation, and publication information of the retrieved data did not require a data cleaning process, the keywords of the final sample of articles were cleaned to fulfill an essential step in keyword-based analysis (Ranjbari et al., 2022b, 2020). The cleaned data was then used in the analysis of conceptual structures and thematic trends presented in section 3.2. Science mapping and bibliometric analyses have been extensively applied as reliable tools to analyze thematic trends, research hotspots, scientific production impacts and networks, and the evolution of a research field (Sousa and Almeida, 2021). Compared to available software tools for conducting bibliometric analysis, such as VOSviewer and SciMAT, the “bibliometrix” package in R covers a more comprehensive set of techniques and is more suitable for practitioners through “biblioshiny” (Moral-Muñoz et al., 2020). In this study, the “biblioshiny” web-interface of the “bibliometrix” package in R (Aria and Cuccurullo, 2017) was used to obtain the descriptive bibliometric indicators and conceptual themes and trends in the evolution of the TEA application in the biofuel production literature. Biblioshiny is an open-source tool developed by Aria and

222 Cuccurullo (2017) that integrates bibliometric network analyses and visualization functions to map  
223 the body of knowledge in the target literature (Xie et al., 2020). In addition, in order to extract  
224 information such the average normalized citations, the software VOSviewer version 1.6.16 was  
225 employed. VOSviewer is a Java-based computer program widely used for bibliometric analysis and  
226 computing bibliometric indicators.

227

### 228 **3. Results and discussion**

229 In order to answer the RQs of the study more clearly, the obtained results are presented in  
230 two sections. While section 3.1 presents the results of the descriptive bibliometric analysis to  
231 answer RQ.1, the identified conceptual structures and thematic trends of the TEA within the BSCs  
232 are presented in Section 3.2 to answer RQ.2.

233

#### 234 **3.1. Descriptive bibliometric analysis results**

235 In this section, the main descriptive bibliometric analysis results, including summary  
236 bibliographic information, publication evolution over time, core journals, the geographical  
237 distribution of published articles, and most influential articles are presented to unfold how the  
238 scientific literature in the TEA of BSCs has evolved.

239

##### 240 **3.1.1. Summary bibliographic information**

241 In order to provide a comprehensive overview of the academic literature related to biofuels  
242 production and utilization, it is of critical importance to summarize basic statistics regarding the  
243 final literature dataset to be analyzed. Table 1 presents this study's dataset comprising selected  
244 papers from WoS through the defined search sting in the methodology section from 1986–2021.

245 The selected dataset consists of 1,104 peer-reviewed articles with an average distance of 5.3 years  
 246 from publication, which were published in 234 journals. The average number of citations per  
 247 article is 24.55, while the average citation per year per article equals 3.339. The total number of  
 248 author keywords and keywords plus in the present dataset are 2,631 and 2,067, respectively. The  
 249 number of authors involved is 3992, while 24 of whom wrote single-authored articles and 3968  
 250 were involved in multi-authored papers. The average number of articles per author is 0.277. The  
 251 number of authors and co-authors per document is 3.62 and 4.39, respectively.

252

253 **Table 1.** Main bibliographic information about the final dataset of the study.

<b>Description</b>	<b>Results</b>	<b>Description</b>	<b>Results</b>
Timespan	1986:2021	Number of author's keywords	2,631
Number of journals	234	Number of contributing authors	3,992
Number of articles	1,104	Authors of single-authored articles	24
Average citations per article	24.55	Authors of multi-authored articles	3,968
Average years from publication	5.3	Number of single-authored articles	26
Average annual citations per article	3.339	Articles per Author	0.277
Number of references	39,371	Authors per article	3.62
Number of keywords plus	2,067	Co-Authors per article	4.39

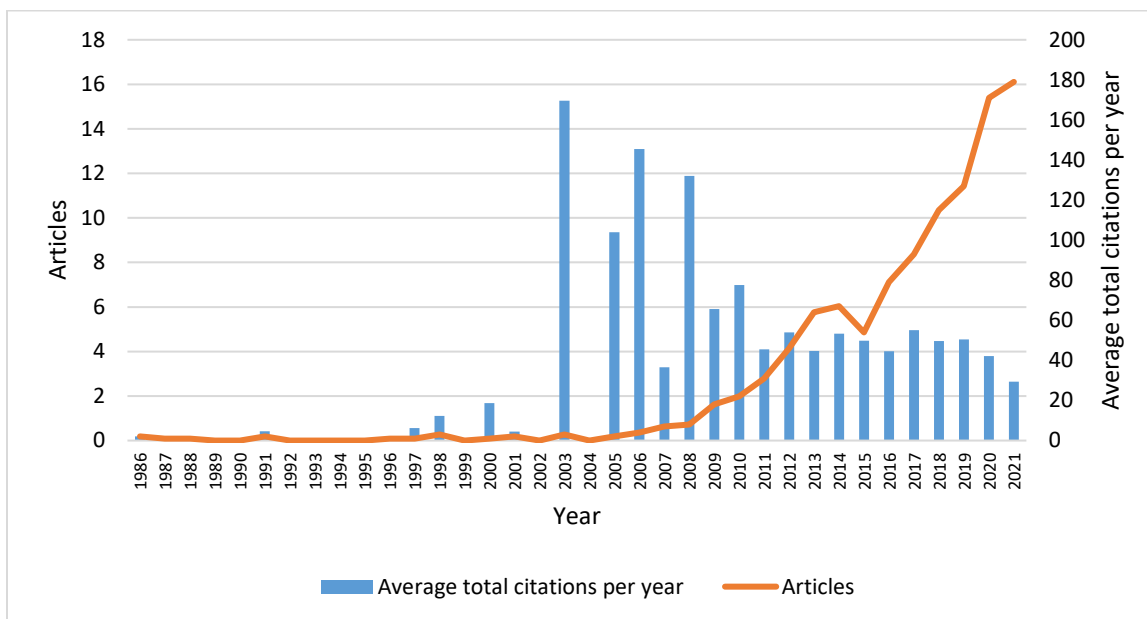
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### 255 **3.1.2. Publication evolution over time**

256 Figure 3 shows the scientific publication trend of research on TEA of BSCs covering the period  
 257 from 1986 to 2021. The publication evolution analysis can be undertaken year by year or in  
 258 different periods. Based on the selected literature, three main evolution periods can be highlighted  
 259 as the following: (i) the initial evolution period with 34 publications from 1986 to 2008, (ii) the  
 260 slow evolution period with 248 publications from 2009 to 2014, and (iii) the fast evolution period  
 261 with 922 publications from 2015 to 2021. From 2006, the total number of publications increased

262 continuously despite marginal fluctuations throughout the study timeline, particularly in 2014–  
 263 2015. The present statistics indicate a steady growth in annual scientific production in the period  
 264 2008–2014, with the fastest rate of increase in 2015–2021. Since the majority of articles were  
 265 published after 2008, the primary research period in terms of active academic involvement in the  
 266 research area can be regarded as the period between 2008 and 2021. During this period, the TEA  
 267 in the BSC domain acquired increasingly high significance for society and, therefore, attracted the  
 268 attention of scholars across various countries and continents.

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**Fig. 3.** Annual scientific production and average total citation per year in the domain of TEA in the BSC.

274 As shown in Figure 3, the average number of citations per year peaked in 2003, 2006, and  
 275 2008, while the lowest levels of citations can be seen before 1996. The research period with the  
 276 highest yield of highly cited papers was from 2002 to 2010, in which the highest average citation  
 277 per article reached 290 in 2003. As the majority of citations were recorded after 2002, the period

278 from 1986 to 2001 can be characterized as having weak academic communication among scholars.  
279 The main share of citations falls in the period 2002–2021, which can be considered as the core  
280 research period in terms of scholars' communication that is a positive step toward biofuels  
281 innovation and development. During this period, annual average citation had an abrupt trend from  
282 2002 to 2008 with a gradual stabilization and insignificant fluctuations from 2009 to 2021. A  
283 similar trend can be considered for the average citation per article, with three peaks occurring in  
284 2003 (290 times), 2006 (209.5 times), and 2008 (166.375 times).

285

### 286 **3.1.3. Core journals**

287 The sources of documents were processed and analyzed to identify the journals with the  
288 highest contribution to the research results published in the studied field. Within the study dataset,  
289 a total of 234 journals have published 1104 articles on the TEA of biofuels production and  
290 utilization in the period 1986–2021. The top 20 most productive journals are listed in Table 2 and  
291 their total citations, average normalized citations, average publication year (APY), and h-index are  
292 reported. Normalization of citations corrects for the fact that earlier published articles have had  
293 more time to receive citations than more recent articles (van Eck and Waltman, 2020).  
294 Accordingly, the average normalized citations reported in Table 2 refer to the average normalized  
295 number of citations received by the articles of a journal, taking into account that the normalized  
296 citations of an article is the number of its citations divided by the average number of citations of  
297 all articles included in our dataset that are published in the same year (van Eck and Waltman,  
298 2020). Also, the APY of a journal is the mean of the publication year of all its published articles  
299 within the studied field; and the h-index of a journal is h if h of its published articles within the  
300 studied field have at least h citation scores (Bihari et al., 2021).

301 The journals presented in Table 2 cover 623 out of 1,104 articles and account for 56.43% of  
302 the total publications of the dataset. The journal *Bioresource Technology* has the highest number  
303 of articles, accounting for approximately 7% of the publications. Therefore, this journal has a  
304 dominant role in the field of TEA of biofuels production research. At the same time, *Journal of*  
305 *Cleaner Production*, *Energy*, and *Energy Conversion and Management*, with 69, 62, and 58  
306 published articles, respectively, are not far behind *Bioresource Technology*.

307 While total citations and h-index of *Bioresource Technology* is far more than the other  
308 journals, comparison of the average normalized citations of the journals show that this journal is  
309 ranked fourth in terms of the average normalized citation score. Consequently, considering the  
310 citation score as a measure for the influence of the publications, it can be concluded that *Renewable*  
311 *& Sustainable Energy Reviews*, *Applied Energy*, and *Fuel* are ranked first, second, and third in  
312 terms of publishing influential articles in the field of TEA in the BSCs, respectively. Furthermore,  
313 the APY of the listed journals indicate that in contrast with *Renewable & Sustainable Energy*  
314 *Reviews* that has published the main share of its articles in the study area of TEA in the BSCs in  
315 recent years (APY: 2020.23), *Biomass & Bioenergy* has published the main share of its articles in  
316 this field in a much earlier time (APY: 2013.7) in comparison with the other listed journals. The  
317 APY of 2014.86 for *Bioresource Technology*, as the most productive journal in the field, justifies  
318 its large first-ranked total citation score and fourth-ranked average normalized citations.

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321 **Table 2.** Top 20 most productive publication sources within the study area of TEA in the BSCs  
322 (ranking in the table is based on the number of published articles in the field).  
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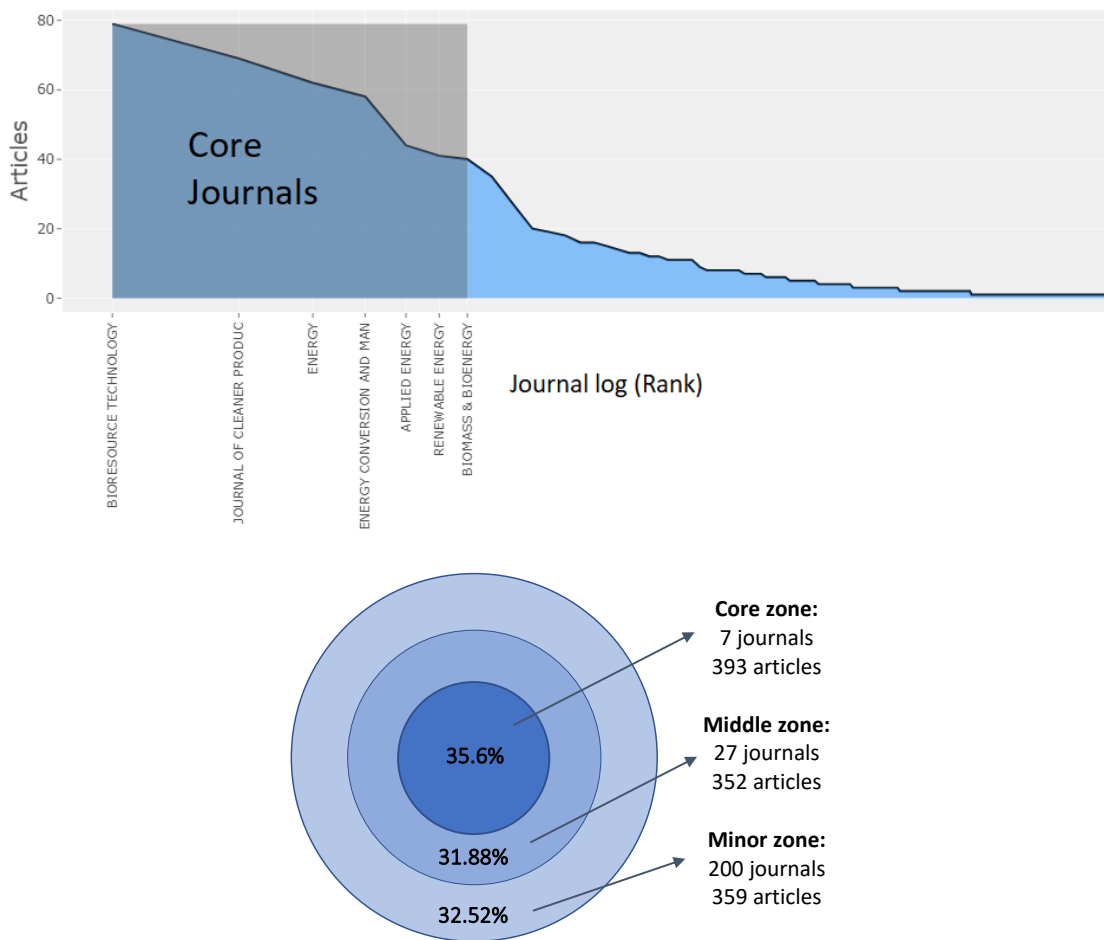
No.	Journal	Articles	Total citations	Average normalized citations	APY*	h-index
1	Bioresource Technology	79	5147	1.44	2014.86	36
2	Journal of Cleaner Production	69	1143	1.26	2018.93	20
3	Energy	62	1479	0.96	2016.05	23
4	Energy Conversion and Management	58	1143	1.13	2015.1	21
5	Applied Energy	44	1744	1.61	2016.32	25
6	Renewable Energy	41	807	1.23	2017.76	17
7	Biomass & Bioenergy	40	1879	1.07	2013.7	23
8	Energies	35	407	0.79	2019.29	11
9	Biofuels Bioproducts & Biorefining-Biofpr	27	361	0.63	2017.52	12
10	Fuel	20	834	1.46	2016.5	12
11	Industrial & Engineering Chemistry Research	19	322	0.53	2015.47	11
12	Chemical Engineering Research & Design	18	592	1.09	2016.17	13
13	Fuel Processing Technology	16	969	1.32	2014.81	14
14	International Journal of Hydrogen Energy	16	193	0.71	2015.81	8
15	ACS Sustainable Chemistry & Engineering	15	320	0.94	2016.93	10
16	Clean Technologies and Environmental Policy	14	345	0.74	2016.36	10
17	Waste and Biomass Valorization	13	146	0.81	2017.39	6
18	Renewable & Sustainable Energy Reviews	13	129	2.34	2020.23	6
19	Energy & Fuels	12	160	0.42	2014.17	8
20	Industrial Crops and Products	12	129	0.74	2018.33	7

324 \* Average publication year

325  
326 Figure 4 illustrates the core journals based on Bradford's law that outlines the scatter of  
327 articles. Bradford's law denotes that a high number of published articles within a specific subject  
328 area of research are concentrated in a small number of journals (Villalobos et al., 2022). The figure  
329 also shows core, middle, and minor zones allocating to journals depending on the number of  
330 articles and their cumulative frequency. The core zone includes only seven high-quality journals  
331 that published 393 articles, particularly *Bioresource Technology*, *Journal of Cleaner Production*,  
332 *Energy*, *Energy Conversion and Management*, *Applied Energy*, *Renewable Energy*, and *Biomass*

333 & *Bioenergy*. The middle and minor zones cover 27 and 200 journals with 352 and 359 papers,  
 334 respectively.

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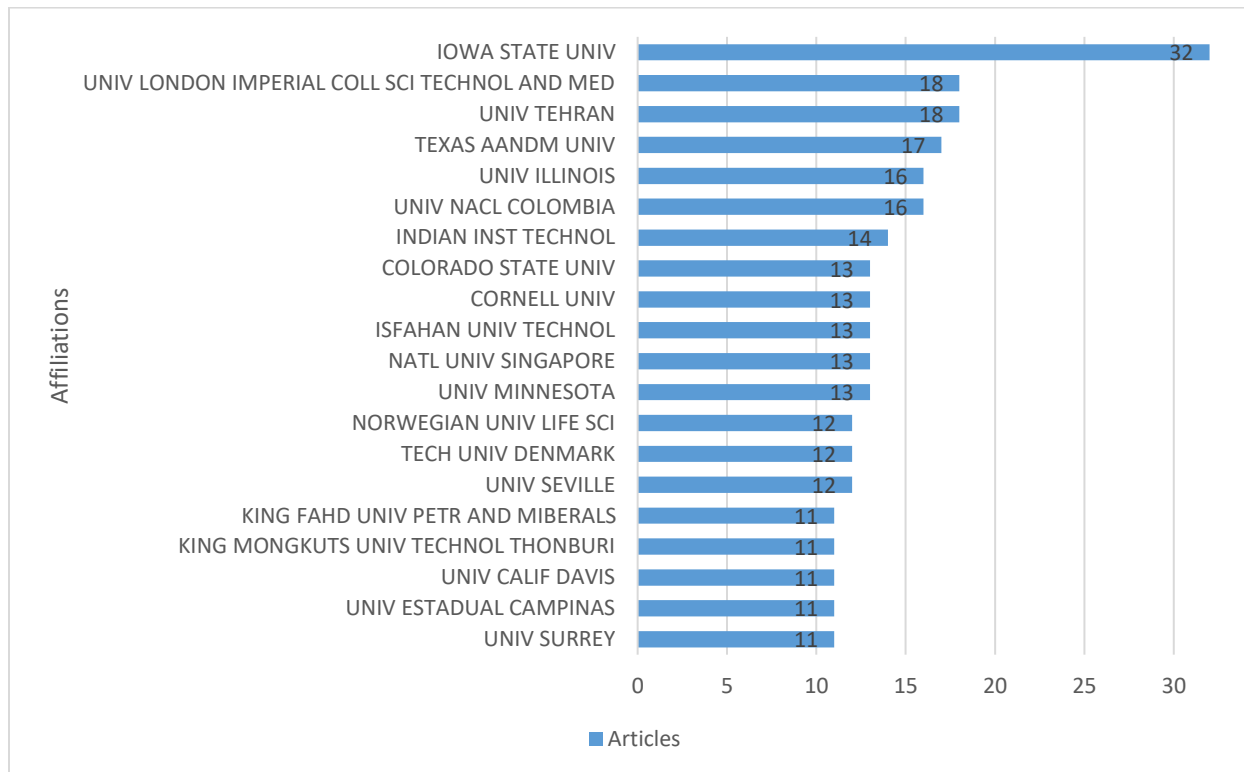
336 **Fig. 4.** Core journals contributing to the publication of articles in the study area of TEA in  
 337 the BSC based on Bradford's law.  
 338

339

### 340 3.1.4. Geographic distribution of published articles

341 In order to analyze the contribution and collaboration of countries and institutions in this  
 342 section, all the affiliations of the authors contributing to the publication of an article were  
 343 considered. Figure 5 shows the most contributing institutions to the subject of TEA of BSCs from

344 1986 to 2021. The top 20 listed institutions provided 287 publications or 21% of total documents  
345 during the specified period. Each of them has at least 11 articles published in the research field.  
346 As this figure illustrates, among the top 20 institutions, there are nine American countries  
347 institutions (Iowa State University, Texas A&M University, University of Illinois, Colorado State  
348 University, University Minnesota, Cornell University, University of California Davis, Universidad  
349 Nacional de Colombia, and Universidade Estadual de Campinas), six Asian countries' institutions  
350 (University of Tehran, Isfahan University Technologies, Indian Institutes of Technologies,  
351 National University of Singapore, King Mongkut's University of Technology Thonburi, and King  
352 Fahd University Petroleum and Minerals), and five European countries' institutions (Imperial  
353 College London, University of Surrey, Norwegian University of Life Sciences, Technical  
354 University of Denmark, and University of Seville). More specifically, Columbia, Brazil, India,  
355 Malaysia, Thailand, Saudi Arabia, Spain, Denmark, and Norway have been represented by only  
356 one institution, while the UK and Iran have two representations, and the USA has been represented  
357 by seven institutions. The most productive institution with 32 publications is the *Iowa State*  
358 *University* in the United States, which can be considered a leading contributor to the considered  
359 research area. This institution is followed by Imperial College London in the UK with 18 papers,  
360 University of Tehran in Iran with 18 papers, and Texas A&M University and University of Illinois  
361 in the USA with 17 and 16 papers, respectively. Although Denmark and Saudi Arabia are not  
362 among the top 10 contributing countries in the field, Technical University of Denmark from  
363 Denmark and King Fahd University Petroleum and Minerals from Saudi Arabia are equally the  
364 most active institutions, with 12 and 11 contributions, respectively. The above considerations make  
365 it clear that very few institutions and countries across the globe are actively contributing to the  
366 TEA of the bio-based fuels production research field.

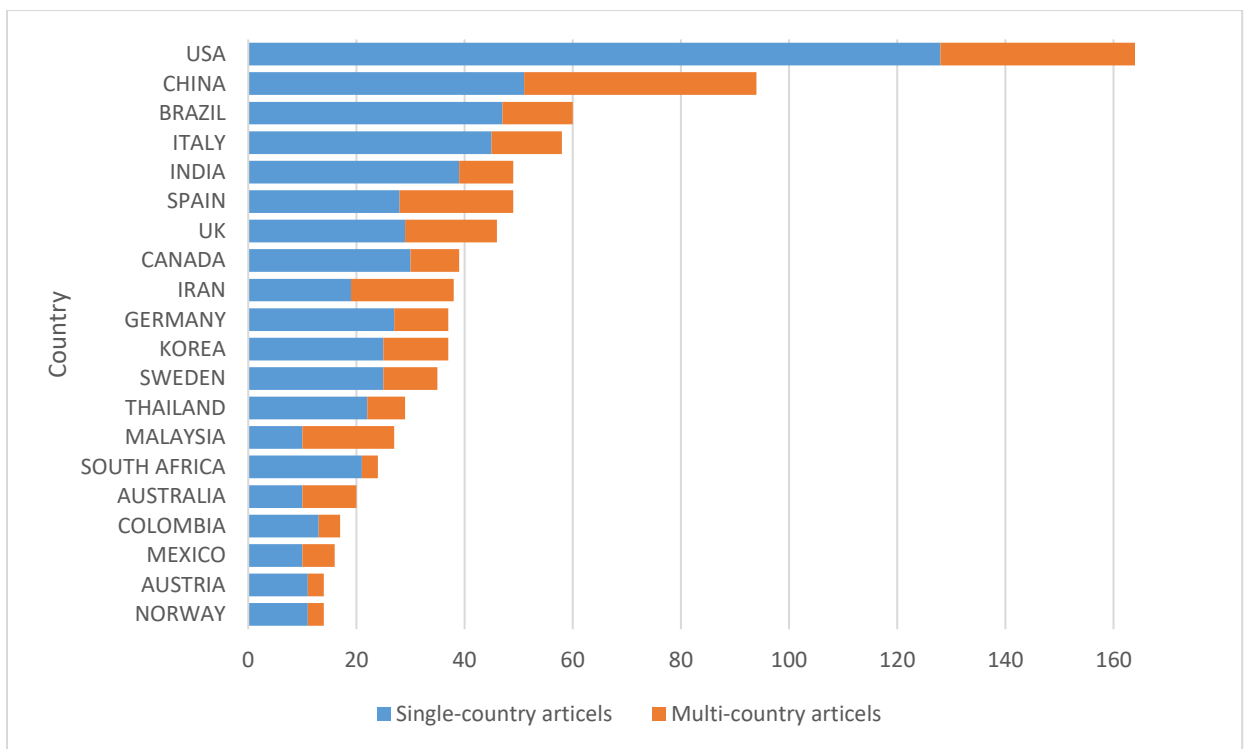


**Fig. 5.** The most contributing institutions to the literature on TEA of BSCs.

368  
369  
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371 The geographical distribution of authors' affiliations in the articles can show the contribution  
372 of various countries to the studied field in a specific period. The data collected reveals that 75  
373 countries contributed to the research domain of techno-economic studies in the BSC from 1986 to  
374 2021. Figure 6 presents the top 20 contributing countries based on the corresponding authors'  
375 affiliations specified in the published articles. As can be seen in this figure, 765 papers (69.36%)  
376 are single-country contributions, and 338 papers (30.64%) are multiple-countries contributions.  
377 Notably, the geographical distribution of publications in the studies indicates contributions from  
378 all continents, particularly Europe, the Americas, Australia, Oceania, Asia, and Africa. Most of  
379 these publications are produced by developed countries across continents, among which the USA,  
380 Canada, the UK, Australia, Norway, Italy, Spain, Austria, Germany, and Sweden can be mentioned

381 as examples. As shown in Figure 6, the USA and China, with the highest number of documents  
 382 (164 and 94 articles, respectively), are the two leading countries based on the scientific production  
 383 in the research domain for the studied period. From the perspective of countries' collaboration,  
 384 China, with 43 articles representing almost 46% of the total articles published by researchers in  
 385 China, recorded the highest production of multiple-countries publications. In addition, with 128  
 386 articles, the USA represented approximately 22% of the total USA's published articles and  
 387 recorded the most production of single-country publications. Brazil, Italy, and India, with 60, 58,  
 388 and 49 papers, respectively, follow the leading countries in terms of the number of papers.  
 389

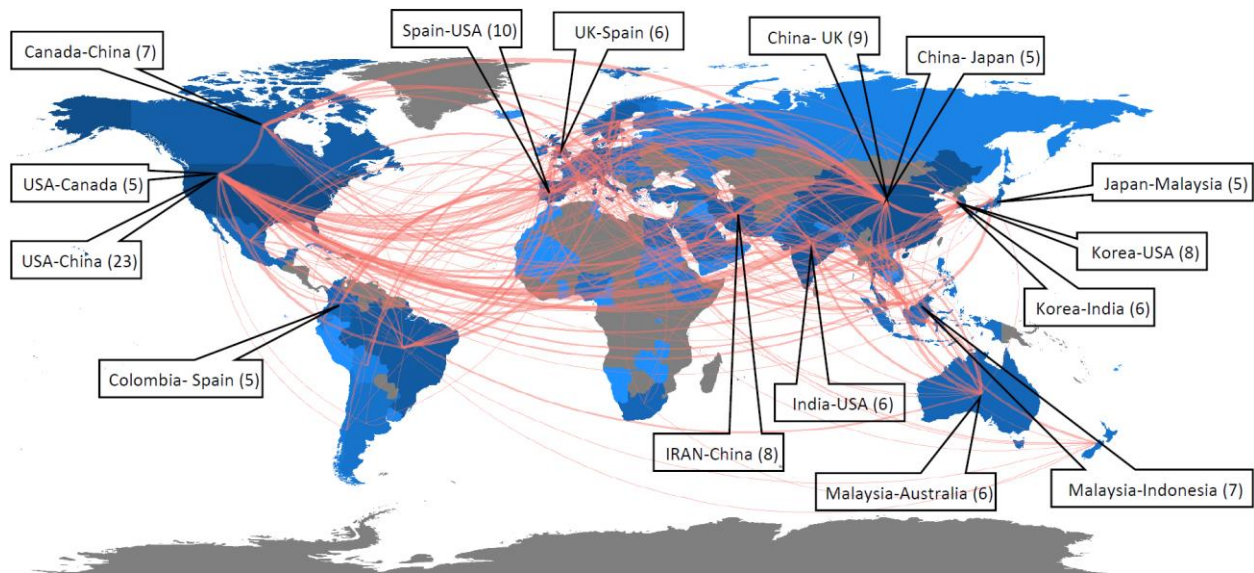


390  
 391 **Fig. 6.** Geographical distribution of the published articles based on the corresponding author's  
 392 country (top 20 contributing countries).

393

394 Figure 7 shows the co-authorship relationship among the contributing countries to the studied  
 395 literature and highlights the most frequent collaboration links (the frequency of at least 5). A total  
 396 of 341 unique collaboration links are identified among the countries, presented by orange lines in  
 397 Figure 7, and an overall 598 collaborations between the pair of countries, reflected through the  
 398 thickness of the relevant connecting lines in this figure. Among the identified links, the USA and  
 399 China have the strongest collaboration link with the publication of 23 co-authored papers. With a  
 400 huge gap, the collaboration between the USA and Spain with the frequency of 10 and the  
 401 collaboration between the UK and China with the frequency of 9 are the second and third strong  
 402 co-authorship links among the contributing countries.

403



404  
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 406  
 407

**Fig. 7.** The most frequent co-authorship collaborations among the contributing countries in the TEA of BSCs.

408 The top 10 countries in terms of the number of published articles and also the top 10 countries  
 409 in terms of the average normalized citations in the field of in the TEA of BSCs are listed in Table  
 410 3 to address the most productive and most influential countries in the field. Average normalized

411 citations in this table refers to the mean of normalized number of citations received by the articles  
 412 published by the authors affiliated with the institutions of a specific country. Notably there is no  
 413 country present in both of the lists, and therefore, the most productive countries are different from  
 414 the most influential countries in the field of the TEA of BSCs. In terms of the number of published  
 415 articles, the USA and China with 209 and 114 articles, respectively, are ranked first and second  
 416 among 75 countries, followed Italy, and Brazil, each with 70 articles. This is while in terms of the  
 417 influence of the published articles, Wales, Kuwait, and Russia with the average normalized  
 418 citations of 3.376, 3.021, and 2.338, respectively, are the top influential countries.

419

420 **Table 3.** The list of top 10 countries in terms of scientific production and average normalized  
 421 citations in the field of the TEA of BSCs.

Top 10 countries in terms of the number of articles			Top 10 countries in terms of average normalized citations		
Rank	Country	Articles	Rank	Country	Average normalized citations
1	USA	209	1	Wales	3.376
2	China	114	2	Kuwait	3.021
3	Italy/ Brazil	70	3	Russia	2.338
4	Spain	64	4	Cameroon	2.127
5	England	60	5	Sudan	2.077
6	India	57	6	Australia	1.871
7	Canada	53	7	Mauritania/ Senegal	1.842
8	South Korea	49	8	Saudi Arabia	1.690
9	Germany	48	9	Peru	1.689
10	Iran/ Malaysia/ Sweden	45	10	Singapore	1.616

422

### 423 3.1.5. Most influential articles

424 As derived from the study of Merigó et al. (2015), the number of citations to a paper can be  
425 considered a suitable metric for recognizing the most influential articles in a research area. The  
426 present study analyzed the collected articles using local citations (LC) score and global citations  
427 (GC) score and average normalized citation metrics. While LC shows the number of citations to  
428 an article by the articles within the studied dataset, GC refers to the total citations received by an  
429 article in the whole WoS database. The higher the LCS, the more important the paper is in the  
430 research area, as it is more cited by the articles within the studied dataset. This is while GCS refers  
431 to the total citation to a specific paper both by the documents within the studied dataset and by  
432 documents from other disciplines in the WoS database.

433 Tables 4, 5, and 6 provide the list of the top 10 articles in the studied dataset in the current  
434 research with respect to global citations, local citations, and average normalized citations,  
435 respectively. Out of the 10 articles listed in Table 4, four are published in the journal *Bioresource*  
436 *Technology* and two in *Fuel Processing Technology*. The remaining four papers are published in  
437 *Aiche Journal*, *Biomass and Bioenergy*, *Fuel*, and *Resources, Conservation and Recycling*. It can  
438 be seen that *Bioresource Technology* has made a considerable contribution to the research field in  
439 the studied period. Regarding the journal's contribution to LC, *Bioresource Technology* with three  
440 papers, *Chemical Engineering Research and Design*, and *Fuel Processing Technology*, each with  
441 two papers are the main significant contributors (see Table 5). Notably, the top 10 most cited  
442 papers based on the normalized citations score have been published in 10 different journals as can  
443 be seen in Table 6.

444 The article with the highest GC value and the second rank within LC is an original paper  
445 entitled *Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity*

446 *analysis* written by Zhang et al. (2003). Based on Table 5, the LC/GC ratio for this article is 8.22%,  
447 which indicates that this article is more cited by the documents from other disciplines than by the  
448 papers within the studied dataset on the TEA of biofuel production and utilization. In this paper,  
449 the Canadian researchers conducted an economic assessment of four continuous processes to  
450 produce biodiesel, including alkali-catalyzed and acid-catalyzed processes and the utilization of  
451 waste cooking oil and virgin vegetable oil as the raw materials. Their study revealed that the plant  
452 capacity and prices of feedstock oils and biodiesel are the leading factors affecting the economic  
453 efficiency of biodiesel production. Moreover, their study showed that among the economically  
454 evaluated processes, the acid-catalyzed process using waste cooking oil is more economically  
455 viable.

456 The second highly influential research paper, *A process model to estimate biodiesel*  
457 *production costs*, was authored by Haas et al. (2006). With 44.47 total citations per year, this article  
458 was cited 756 times globally until the end of 2021. Besides, it has 72 local citations and an LC/GC  
459 ratio equal to 9.52%, indicating the significant share of articles outside the studied dataset in the  
460 current research that has cited this article. The investigation conducted by Haas et al. (2006) at  
461 Eastern Regional Research Centre in the USA resulted in the proposal of a computer model to  
462 estimate the required capital and operating costs of an industrial biodiesel production facility. Their  
463 proposed model allows calculating the effects of changes in feedstock and its costs, the value of  
464 the glycerol co-product, and the process technology and chemistry on capital and production costs  
465 in a moderately-sized facility.

466 The research conducted by You et al. (2012) at the National Renewable Energy Lab of  
467 Northwestern University in the USA is ranked third among the most globally cited papers with a  
468 rather high citation per year of 41.18 times and 453 total citations. However, this paper is not

469 included in the top 10 most local cited articles. Therefore, a huge share of citations to this article  
470 is from other disciplines. You et al. (2012) focused on the optimal design and planning of cellulosic  
471 ethanol supply chains, considering the total annual cost as the economic consideration, life cycle  
472 greenhouse gas emissions as the environmental consideration, and the number of created jobs as  
473 the social consideration. They accordingly developed a multi-objective mixed-integer linear  
474 programming model and analyzed two case studies for the state of Illinois in the United States.

475         Among the top 10 globally cited articles, two papers have per year citations not less than 20,  
476 namely the research conducted by Sassner et al. (2008) and Koutinas et al. (2014), which are  
477 ranked fourth and ninth, respectively. The research by Sassner et al. (2008) was aimed at the  
478 comparison of utilizing the lignocellulosic materials spruce (softwood), Salix (hardwood), and  
479 corn stover (agricultural residue) as the input materials for bioethanol production in terms of  
480 production cost and energy demand. They highlighted the significance of a high ethanol yield and  
481 the need to utilize the pentose fraction for ethanol production to achieve more economic feasibility  
482 (Sassner et al., 2008). Koutinas et al. (2014) studied the design and TEA of the production of  
483 microbial oil from oleaginous yeast and subsequent biodiesel production. They highlighted that  
484 capital and electricity consumption for producing the microbial biomass and oil under fed-batch  
485 conditions are the main cost-generating sources and concluded that applying indirect  
486 transesterification of extracted microbial oil is a more cost-competitive process compared with the  
487 direct conversion of dried yeast cells (Koutinas et al., 2014).

488         Furthermore, three papers are available among the top 10 locally cited articles in Table 5,  
489 which have more than 20 citations per year but are not among the top 10 globally cited articles  
490 listed in Table 4. These articles present the studies of Apostolakou et al. (2009), Lee et al. (2011),  
491 and Santana et al. (2010), which are ranked fourth, fifth, and ninth in terms of LC, respectively.

492 These papers are devoted to the economic justification of certain biodiesel production processes.  
 493 Apostolakou et al. (2009) performed a TEA on biodiesel production plants that use classical alkali-  
 494 catalyzed transesterification and presented detailed calculations for the unit production cost and  
 495 fixed capital investment for a wide range of plant production capacities. Their findings showed  
 496 that only plants with capacities greater than 50–80 kt/year are economically feasible to be installed  
 497 to produce biodiesel from vegetable oils. Lee et al. (2011) assessed the economic performance of  
 498 Alkali-FVO, Alkali-WVO, and SC-WVO biodiesel production plants and found that SC-WVO is  
 499 the most economically sound process. Their results also showed that the leading factor affecting  
 500 the cost of biodiesel production is the oil feed cost, which accounts for approximately 64–84% of  
 501 the production costs. Finally, Santana et al. (2010) designed and simulated a biodiesel plant using  
 502 castor oil as feedstock and analyzed the technical process and production cost through a  
 503 transesterification reaction using ethanol. Taking into account material and energy flows and also  
 504 sized unit operations, they performed an economic evaluation of the considered process in Brazil.  
 505 Their obtained results indicated the feasibility of the process in terms of producing a high-quality  
 506 biodiesel product from the technical point of view and showed promising avenues for the  
 507 production of biodiesel from castor oil in Brazil from the economic viewpoint.

508

509 **Table 4.** The top 10 most globally cited articles within the domain of TEA in the BSC.

<b>Author</b>	<b>Title</b>	<b>Journal</b>	<b>GC*</b>	<b>GC/Year</b>
Zhang et al. (2003)	Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis	Bioresource Technology	827	41.35
Haas et al. (2006)	A process model to estimate biodiesel production costs	Bioresource Technology	756	44.47

You et al. (2012)	Optimal design of sustainable cellulosic biofuel supply chains: Multiobjective optimization coupled with life cycle assessment and input-output analysis	Aiche Journal	453	41.18
Sassner et al. (2008)	Techno-economic evaluation of bioethanol production from three different lignocellulosic materials	Biomass and Bioenergy	314	20.93
West et al. (2008)	Assessment of four biodiesel production processes using HYSYS.Plant	Bioresource Technology	272	18.13
Haas (2005)	Improving the economics of biodiesel production through the use of low value lipids as feedstocks: vegetable oil soapstock	Fuel Processing Technology	245	13.61
Kim and Parker (2008)	A technical and economic evaluation of the pyrolysis of sewage sludge for the production of bio-oil	Bioresource Technology	232	15.47
Marchetti et al. (2008)	Techno-economic study of different alternatives for biodiesel production	Fuel Processing Technology	215	14.33
Koutinas et al. (2014)	Design and techno-economic evaluation of microbial oil production as a renewable resource for biodiesel and oleochemical production	Fuel	210	23.33
van Kasteren and Nisworo (2007)	A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification	Resources, Conservation and Recycling	200	12.5

510 \* Global citation.

511

512 **Table 5.** The top 10 most locally cited articles in the studied dataset on TEA of the BSC.

Author	Title	Journal	LC*	GC**	LC/GC Ratio
Haas et al. (2006)	A process model to estimate biodiesel production costs	Bioresource Technology	72	756	9.52%
Zhang et al. (2003)	Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis	Bioresource Technology	68	827	8.22%

West et al. (2008)	Assessment of four biodiesel production processes using HYSYS. Plant	Bioresource technology	50	272	18.38%
Apostolakou et al. (2009)	Techno-economic analysis of a biodiesel production process from vegetable oils	Fuel Processing Technology	35	171	20.47%
Lee et al. (2011)	Process simulation and economic analysis of biodiesel production processes using fresh and waste vegetable oil and supercritical methanol	Chemical Engineering Research and Design	29	123	23.58%
van Kasteren and Nisworo (2007)	A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification	Resources, Conservation and Recycling	27	200	13.5%
Marchetti et al. (2008)	Techno-economic study of different alternatives for biodiesel production	Fuel Processing Technology	27	215	12.56%
Sassner et al. (2008)	Techno-economic evaluation of bioethanol production from three different lignocellulosic materials	Biomass and Bioenergy	22	314	7.01%
Santana et al. (2010)	Simulation and cost estimate for biodiesel production using castor oil	Chemical Engineering Research and Design	21	102	20.59%
Lantz (2012)	The economic performance of combined heat and power from biogas produced from manure in Sweden - A comparison of different CHP technologies	Applied Energy	21	121	17.36%

513 \* Local citations; \*\* Global citation.

514

515 **Table 6.** The top 10 most influential articles within the domain of TEA in the BSC based on the  
516 normalized citations.

Reference	Title	Journal	Normalized citations	GC*
Muhammad et al. (2021)	Modern developmental aspects in the field of economical harvesting and biodiesel production from microalgae biomass	Renewable and Sustainable Energy Reviews	14.73	39

You et al. (2012)	Optimal design of sustainable cellulosic biofuel supply chains: multiobjective optimization coupled with life cycle assessment and input-output analysis	AIChE Journal	9.33	453
Vendoti et al. (2021)	Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by homer software	Environment, Development and Sustainability	7.18	19
Collet et al. (2017)	Techno-economic and life cycle assessment of methane production via biogas upgrading and power to gas technology	Applied Energy	6.61	164
Thakur et al. (2021)	Performance analysis of a modified solar still using reduced graphene oxide coated absorber plate with activated carbon pellet	Sustainable Energy Technologies and Assessments	6.42	17
Gruber et al. (2021)	Fischer-tropsch products from biomass-derived syngas and renewable hydrogen	Biomass Conversion and Biorefinery	6.42	17
Aghbashlo et al. (2019)	Comprehensive exergoeconomic analysis of a municipal solid waste digestion plant equipped with a biogas genset	Waste Management	6.02	82
Alhashimi and Aktas (2017)	Life cycle environmental and economic performance of biochar compared with activated carbon: a meta-analysis	Resources, Conservation and Recycling	5.69	141
Koutinas et al. (2014)	Design and techno-economic evaluation of microbial oil production as a renewable resource for biodiesel and oleochemical production	Fuel	5.47	210
Yousef et al. (2021)	Microcrystalline paraffin wax, biogas, carbon particles and aluminum recovery from metallised food packaging plastics using pyrolysis, mechanical and chemical treatments	Journal of Cleaner Production	4.91	13

517 \* Global citation.

518

519                   Among the top 10 most cited papers based on the normalized citations score, two research

520 articles, including the second highest cited paper conducted by You et al. (2012), and the ninth

521 highly cited paper conducted by Koutinas et al. (2014) are also included in highly globally (Table  
522 4) and locally (Table 5) cited papers. On this basis, the highly cited research based on the  
523 normalized citation is a research conducted by Muhammad et al. (2021) in the field of economical  
524 harvesting and biodiesel production from microalgae biomass, outlining that (i) downstream  
525 techniques for biofuel and value-added materials production have yet to be fully developed to  
526 overcome techno-economic barriers, and (ii) new wet harvesting strategies extract major lipids in  
527 a cost-efficient way (30% less than conventional) since wet technologies can remove the cost of  
528 cell drying and associated instruments. In the third highly cited paper in this category, Vendoti et  
529 al. (2021) in an attempt to structure an electricity generation model at an identified off-grid village  
530 location in India, identified a combination of photo voltaic–wind–biomass–biogas–fuel cell along  
531 with battery as the cheapest and most dependable solution with a cost of energy of \$0.214/ kWh.  
532 In next highly cited paper, Collet et al. (2017) in a TEA of methane production via the combination  
533 of PtG technology and anaerobic digestion employed to valorize sewage sludge, showed that  
534 reducing the level of electricity consumption in the electrolysis step decreases the cost of  
535 production.

536 Aghbashlo et al. (2019) in an inclusive exergoeconomic analysis of a municipal solid  
537 waste digestion plant to reveal the cost structure of the plant, highlighted the significance of (i)  
538 genset efficiency to boost the overall performance of the system exergoeconomically, and (ii) the  
539 investment-related cost minimization of the digester in significantly improving the  
540 exergoeconomic performance of the plant. Alhashimi and Aktas (2017) in their study to evaluate  
541 the economic performance of biochar compared to activated carbon should that (i) the adsorption  
542 cost of biochar was lower than activated carbon to eliminate zinc and chromium with a 95%  
543 confidence, and (ii) biochar, if engineered properly, could be at least as effective as activated

544 carbon and at a lower cost. Yousef et al. (2021) showed that using pyrolysis, mechanical and  
545 chemical treatments as a combined approach to convert metallised food packaging plastics waste  
546 into energy products (including Microcrystalline paraffin wax and biogas) and raw materials  
547 (including carbon particles and aluminum) on an industrial scale can provide an economic return  
548 up to 610 \$/ton of metallised food packaging plastics waste.

549           Figure 8 illustrates the historical citation network in the field of TEA of biofuel production  
550 and utilization, which can be used for conducting the direct citation analysis as a tool to trace the  
551 historical development of advances in the considered scientific domain (Garfield et al., 1964). The  
552 nodes in this figure represent key articles within our dataset, and the links among the nodes reflect  
553 the direct citations between the pair of nodes. Based on the citation network in Figure 8, the  
554 citations of the key articles in the largest cluster (purple cluster) can be traced back to the research  
555 conducted by Zhang et al. (2003). Notably, this article was published in 2003 and is the earliest  
556 study in the presented citation network, has the highest GC (see Table 4), and is the second-highest  
557 LC among the studied papers in our dataset (see Table 5). Zhang et al. (2003) can be considered  
558 the most relevant and influential study in this research field. Furthermore, the second early key  
559 article in the network is the research by Haas et al. (2006). This article was published in 2006 and  
560 has the highest LC (see Table 5) and the second-highest GC among the studied papers (see Table  
561 4).

562



**Fig. 8.** Historiography of article citations in the field of TEA of the BSC.

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### 566 3.2. Conceptual structures and thematic trends

567 In this section, the identified conceptual structures and thematic trends, including  
568 keywords frequency and growth, trend topics and thematic evolution are provided to discover the  
569 main thematic trends of TEA applications in BSCs.

570

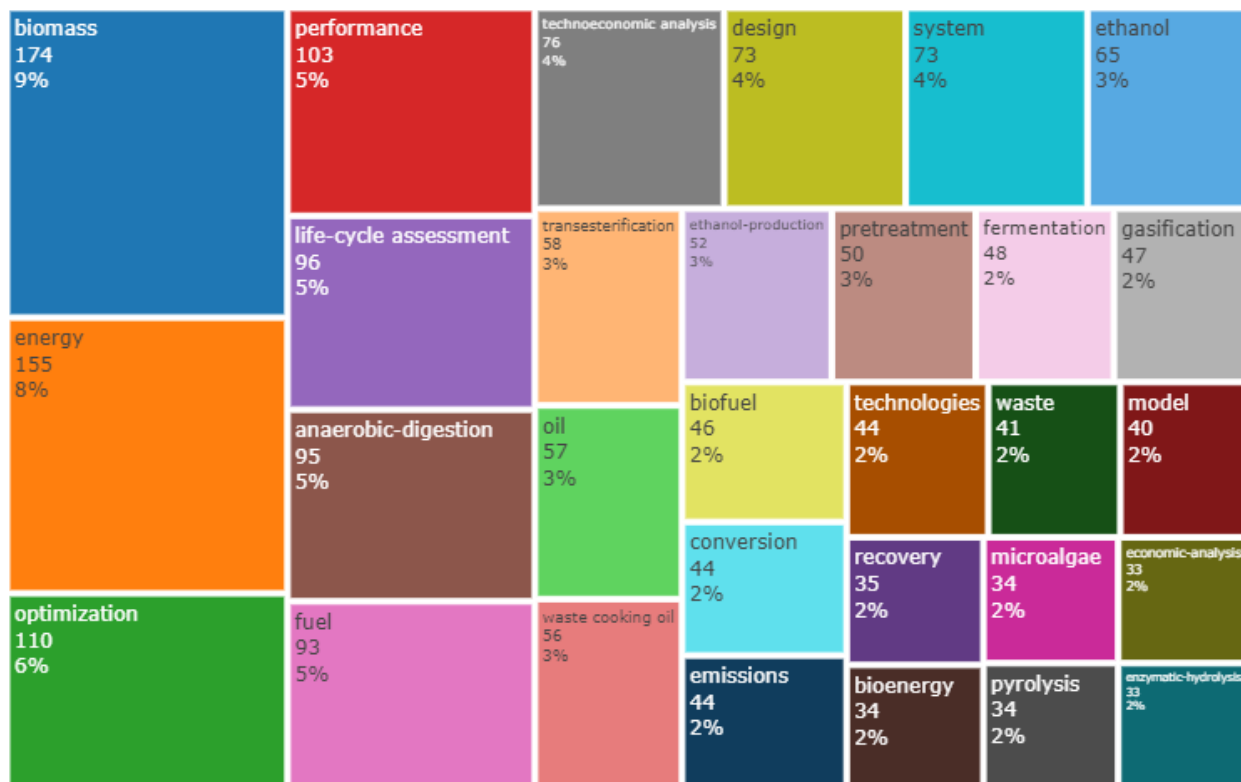
#### 571 3.2.1. Keywords frequency and growth

572 In order to identify the knowledge structure in the field of TEA of biofuels production, in  
573 this section, a comprehensive analysis is conducted on the keywords plus of the articles. Keywords  
574 plus can reflect the articles' contents (Garfield and Sher, 1993) and is found to be as effective as  
575 the authors' keywords in the articles for bibliometric analysis purposes (Zhang et al., 2016).

576 The 30 most frequent keywords used in the TEA of biofuels production and utilization  
577 study area are presented in Figure 9. As can be seen, "biomass", "energy", and "optimization" with  
578 174, 155, and 110 occurrences, reflecting 9%, 8%, and 6% of the total keywords occurrences, are  
579 the first, second, and third leading keywords in the studied domain, respectively. Both "TEA" and

580 “economic analysis” can be observed among the top 30 presented keywords, with 76 and 33  
 581 occurrences representing 4% and 2% of the total keywords occurrences, respectively. The presence  
 582 of both of these keywords in this figure is due to the variety of terms being used to address the  
 583 economic evaluations of the technologies linked with the BSC, including “techno-economic  
 584 evaluation” (Li et al., 2021), “techno-economic assessment” (Mahabir et al., 2021), “TEA”  
 585 (Kleiman et al., 2021), economic analysis (Kashyap et al., 2021), and economic assessment  
 586 (Gianico et al., 2021), which are tried to be captured through the defined search string in section  
 587 2.1. Moreover, appearing “life-cycle assessment” and “emissions” with 96 and 44 occurrences and  
 588 the shares of 5% and 2%, respectively, indicates the huge attention towards the environmental  
 589 aspects of biofuels production and consumption, which also affects the technologies obtained in  
 590 this regard and the relevant costs incurred.

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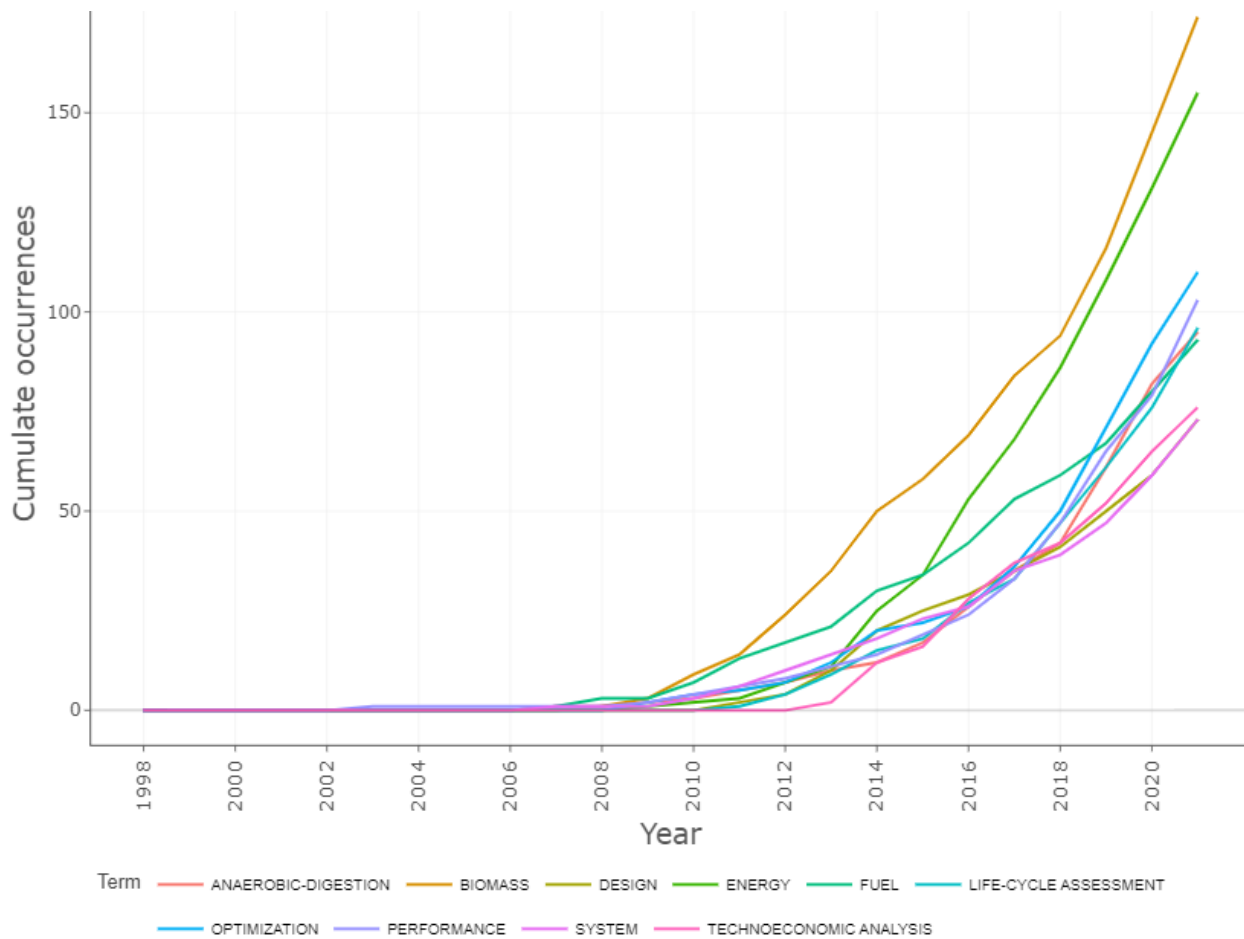
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**Fig. 9.** Tree map of the most frequent keywords plus in the studied domain.

594

595           Figure 10 shows the dynamics of the top 10 most frequent keywords. As can be seen in  
596 this figure, except for “performance” which was the first keyword to appear in the articles  
597 published in the domain in 2003, other keywords began to appear in the research field between  
598 2007 and 2013 and continued to grow afterwards. The terms “biomass” (being used from 2008)  
599 and “energy” (being used from 2009) followed the sharpest slopes and were the top two most  
600 frequent keywords by the end of 2021, with a cumulative frequency of 174 and 155, respectively.  
601 In line with the discussions provided in Figure 9, this may reflect the increasing attention toward  
602 biofuels as a cleaner source of energy to address the concerns on climate change (Mahabir et al.,  
603 2021; Niu et al., 2021) that have attracted increasing attention during the recent years and also the  
604 significant role of biomass and its required processing technologies (Griffiths et al., 2021; Pandey  
605 et al., 2021) in the economic viability of the biofuels production.

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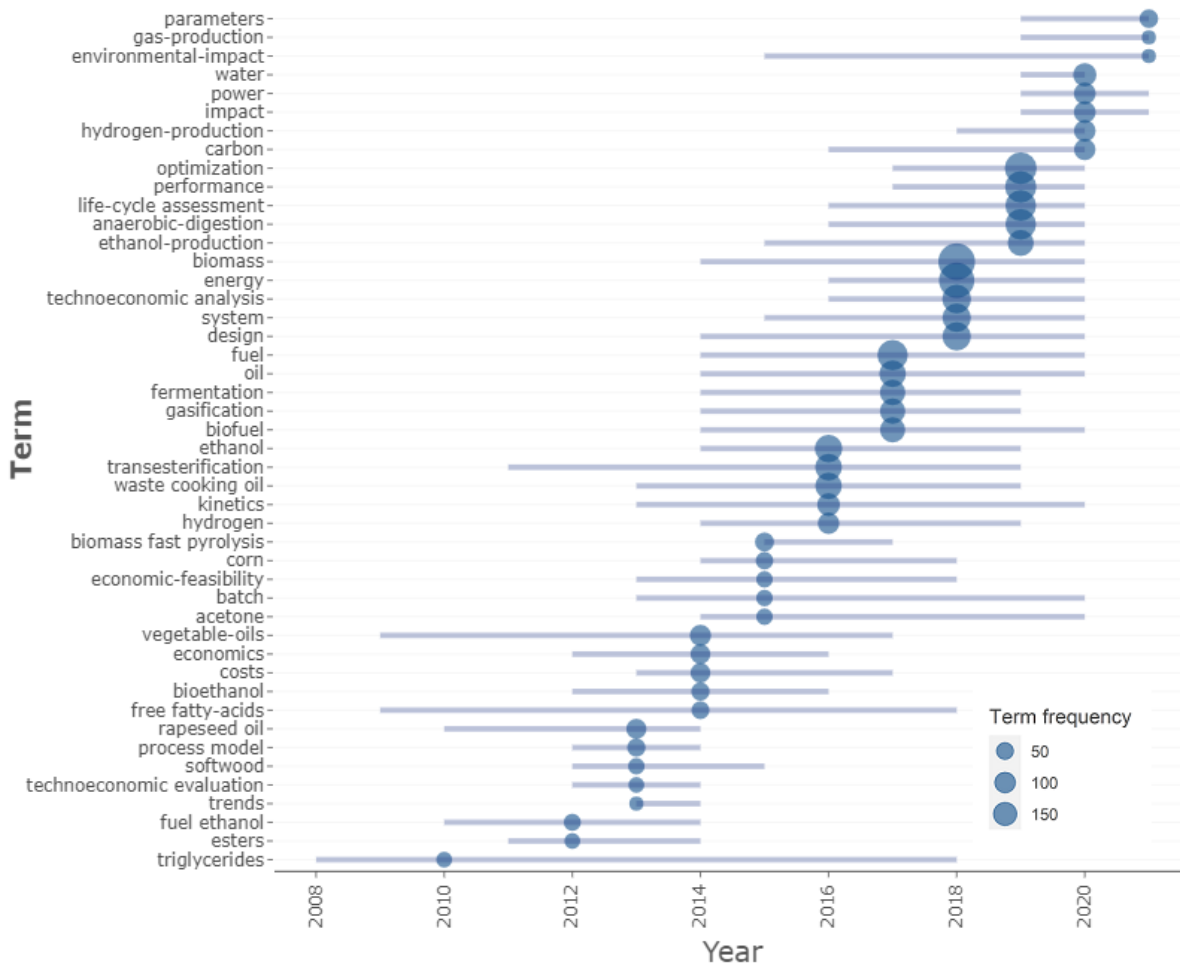


**Fig. 10.** Keywords growth over time in the study area of TEA in the BSC.

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609

610 To show the trend topics in the study domain of TEA of biofuel production and utilization,  
611 keywords with a minimum of 5 occurrences are considered, and for each year of the studied period  
612 (1986–2021), the top 5 most frequent keywords are shown in Figure 11. Since no keyword  
613 occurred at least 5 times during the period 1986–2008, the time horizon shown in this figure starts  
614 from 2008. The highlighted time range for each of the keywords in this figure indicates the period  
615 in which the keyword had appeared at least 5 times among the keywords plus of the articles  
616 published within a specific year. Besides, the blue circles reflect the overall frequency of the  
617 presented keywords from 1986 to 2021. These circles are located in line with the year in which the  
618 specified keywords appeared as one of the top 5 most frequent keywords. Therefore, following the

619 trend formed by the circles in this figure, the trend of the main topics within the study domain of  
 620 TEA in the BSC can be realized. In this vein, while the main trend topics in 2021 were  
 621 “parameters”, “gas production” and “environmental impact”, the trend topics in 2020 were  
 622 “water”, “power”, “impact”, “hydrogen production”, and “carbon”.  
 623

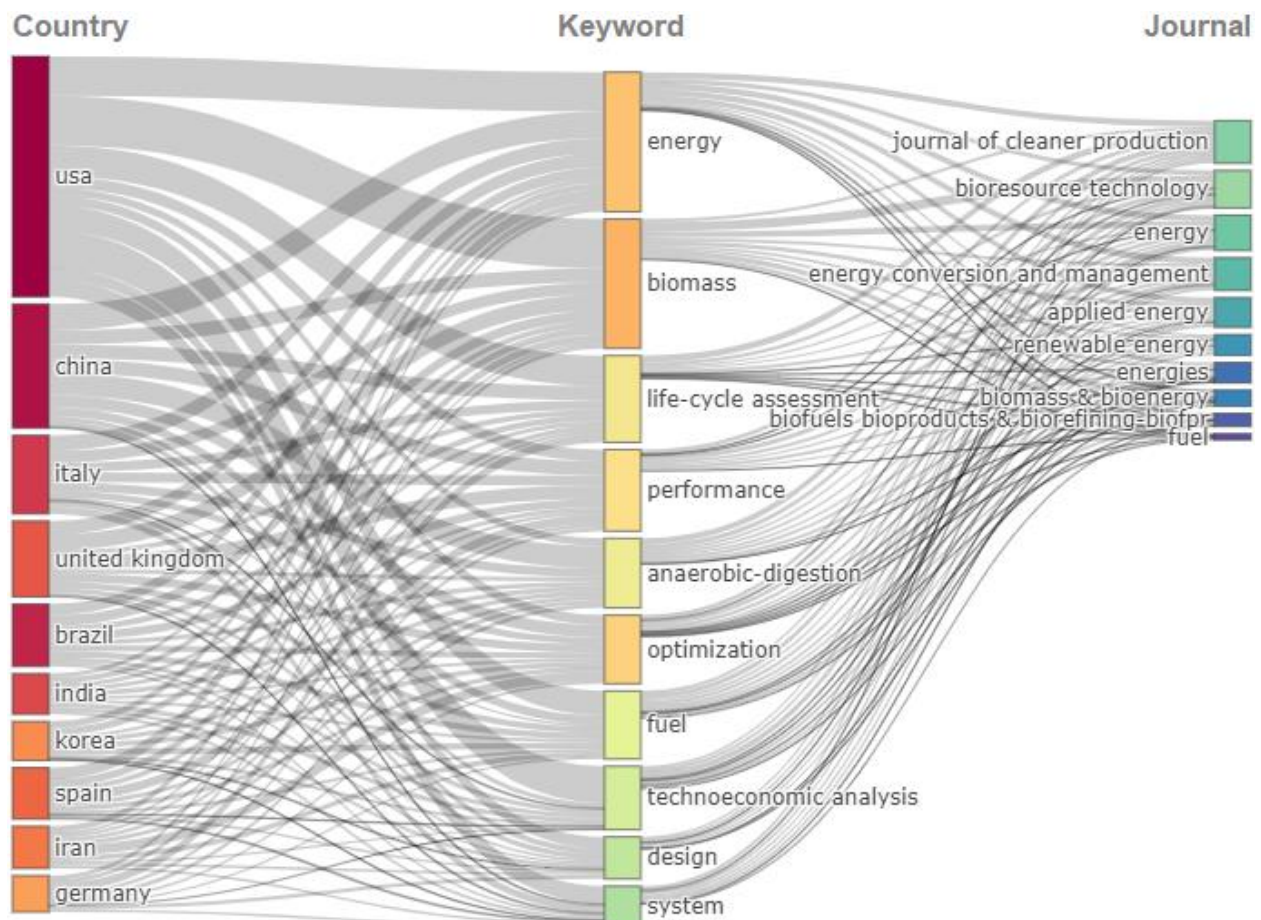


624 **Fig. 11.** Trend topics in the study domain of TEA of biofuel production and utilization.  
 625  
 626

627 The three-fields plot in Figure 12 is presented in this section to show the link between the  
 628 top 10 most frequent keywords, the countries whose scholars have focused their research on those  
 629 keywords, and the journal in which the relevant articles are published. As can be seen in this figure,  
 630 among the presented countries, the USA-affiliated scholars have focused their research more on

631 the top 10 most frequent keywords compared to the other countries. China and Italy are ranked  
632 second and third in this regard, according to their label size on the figure. On the right side of the  
633 figure, the keywords are linked with the journals in which the articles in the study domain of TEA  
634 of BSCs are published. The size of the journal labels shows that the *Journal of Cleaner Production*  
635 has the largest share of published articles linked with the presented keywords compared to the  
636 other journals. However, comparing the thickness of the links connecting the keywords “energy”  
637 and “biomass” to the *Journal of Cleaner Production* and *Bioresource Technology* indicates that  
638 *Bioresource Technology* has published more articles connected with the keyword “biomass” than  
639 the *Journal of Cleaner Production*, while *Journal of Cleaner Production* has published more  
640 articles connected with the keyword “energy” than *Bioresource Technology*.

641



642  
 643 **Fig. 12.** Three-fields plot linking keywords with the relevant contributing countries and journals  
 644 in the studied field.  
 645

646 **3.2.2. Thematic evolution of TEA applications in the BSC**

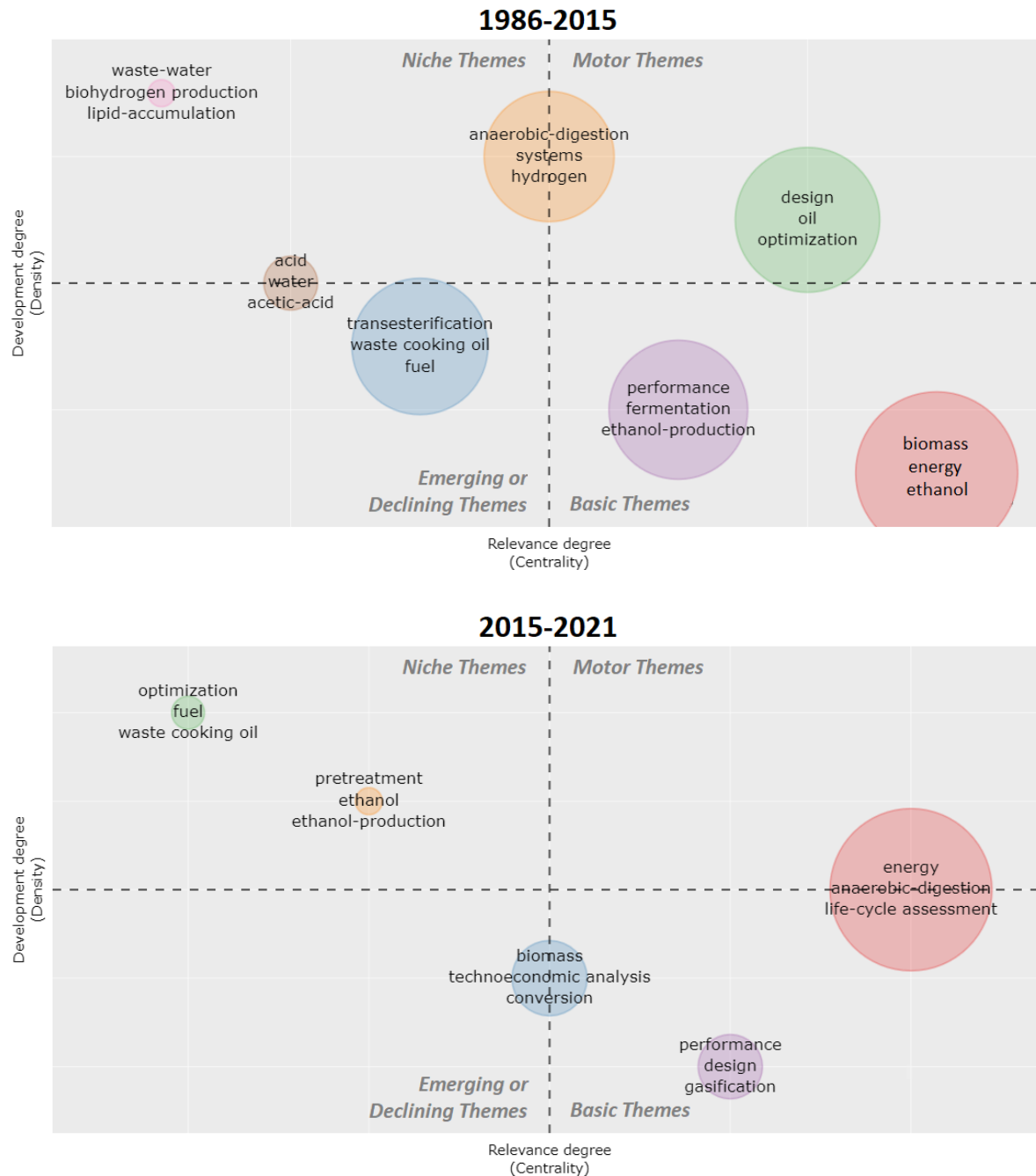
647 In order to study the evolution of topics along time, based on the fluctuations in  
 648 publication trend in Figure 3, two time slices were considered for our data, dividing the studied  
 649 sample into two parts addressing the periods 1986–2015 and 2015–2021. The top 250 most  
 650 frequent keywords were considered for the clustering process, and the inclusion index weighted  
 651 by word occurrences was applied to build the clusters. For each time slice, a thematic map was  
 652 built, as in Figure 13. These thematic plots serve as a strategic map based on the clusters of  
 653 keywords. The colorful circles on the plots represent keywords clusters, which are named based  
 654 on their most frequent keywords, and their size is proportional to the number of keywords they

655 contain. To provide a more developed picture of the themes clusters, the top 3 most frequent  
656 keywords in each cluster are presented.

657 Two properties, namely density, characterize the identified themes on the maps, and  
658 centrality, reflecting cohesiveness among the nodes within the cluster and the degree of correlation  
659 among different topics (Agbo et al., 2021), respectively. The higher the density, the higher the  
660 development degree, and the higher the centrality, the higher the relevance degree. As shown in  
661 Figure 13, the thematic map is divided into 4 quadrants. As the themes located in the lower-left  
662 quadrant are less developed and have a low relevance degree, these themes are either emerging or  
663 declining themes. On the contrary, the upper-right quadrant contains highly developed themes,  
664 which are also highly relevant. The theme located in this quadrant is called driving or motor  
665 themes. While the upper-left quadrant introduces the specialized themes with a low relevance but  
666 a high development degree (niche themes), the lower-right quadrant provides an overview of the  
667 basic themes with high relevance but low development degree that constitute the underlying  
668 themes within the study domain. Accordingly, the density and centrality of the clusters define in  
669 which quadrant the theme is located.

670 TEA, as a tool to assess the viability or economic feasibility of a product or process during  
671 its development phase (Sharma et al., 2019), has been widely used in BSC management. TEA  
672 plays a significant role in commercializing biofuels (Preethi et al., 2021) and prioritizing research  
673 and development activities through adopting empirical data from a pilot-scale to design the  
674 scaling-up process toward a commercial-scale biorefinery (Scown et al., 2021). According to  
675 Figure 13, in the period 1986–2015, the conceptual structure of the research in the field of TEA of  
676 the BSC represented 7 major themes, while this number has reduced to 5 with smaller clusters in  
677 the period 2015–2021. Moreover, while all the quartiles in the strategic map of the period 1986–

678 2015 contain at least one thematic cluster, the clusters in the map for the period 2015–2021 are  
679 more focused on limited quartiles. A comparison between the maps of the two time slices shows  
680 that the red cluster focusing on “energy” has been more developed during the time and is gradually  
681 moving from a basic theme towards becoming a motor theme. This is in line with the keywords  
682 growth trend illustrated in Figure 10 that highlights the sharp increasing slope of the keyword  
683 “energy”. Besides, the blue cluster addressing the “biomass” theme, which was an emerging theme  
684 during 1986–2015, is gradually moving towards being considered as an underlying theme within  
685 the study area of TEA in the BSC. This is while “performance” (purple cluster) has kept its location  
686 on the strategic map, “optimization” (green cluster) has lost its relevance over time and changed  
687 from a motor theme to a niche theme, and “ethanol production” lost its relevance degree to be  
688 recognized as a niche theme in 2015–2021 instead of a niche-motor theme in 1986–2015. The  
689 latter three themes have been more concentrated over time, and their cluster sizes have diminished.  
690  
691



692 **Fig. 13.** Thematic evolution in the field of TEA of the BSC domain in the periods 1986–2015  
 693 and 2015–2021.  
 694

695 **3.2.2.1. Economic perspectives of biodiesel production**

696           Lopes et al. (2013), in an economic feasibility study of biodiesel production in Brazil,  
 697 highlighted the necessity of additional revenues for successful biodiesel production beyond that

698 derived from the produced biodiesel itself, including income from the feedstock co-products.  
699 Souza and Seabra (2014) showed that the integrated production of sugarcane bioethanol and  
700 soybean biodiesel is economically feasible but highly uncertain, which highly requires fiscal  
701 incentives for biodiesel producers, founded on improvements in logistics and the reduction of  
702 fossil energy use. Evaluating bioethanol production from lignocellulosic resources, such as wood  
703 and straw, Kravanja et al. (2012) outlined that the type and amount of by-products highly affect  
704 the economic, environmental, and technical performance of lignocellulosic ethanol production. Ali  
705 et al. (2021), through conducting a TEA of bio-oil co-processing in a petroleum refinery, indicated  
706 that co-processing is significantly sensitive to changes in the price of crude oil and petroleum  
707 products. Farid et al. (2020), by investigating net energy and macroeconomic characteristics in  
708 Malaysia, showed that biodiesel production from waste cooking oil is capable of withstanding the  
709 variations in plant capacity and raw material price, which offers strong business growth.

710 Vasconcelos et al. (2020), in a TEA of the first- and second-generation integrated  
711 sugarcane biorefinery to produce ethanol, indicated that (i) profitability of the process is mainly  
712 influenced by sugarcane cost, capital costs associated with the investment, and input chemicals  
713 costs, (ii) using the lowest solids content in the pretreatment reactor and the pentose stream using  
714 to produce additional ethanol lead to a better economic return, and (iii) the obtained economic  
715 benefits do not only depend on final product yields but also industrial facilities, highlighting the  
716 importance of suitability of process simulation to identify industrial bottlenecks, calling for more  
717 research in the future. Peng et al. (2021), through a TEA of the biorefining process via deep eutectic  
718 solvent pretreatment considering rice straw as feedstock to produce bioethanol, showed that the  
719 minimum ethanol selling price was 3049.9 USD/ton, while the choline chloride/lactic acid  
720 pretreatment was 2128.1 USD/ton. According to their study, high solid loading pretreatment can

721 positively affect cost reduction. In an economic analysis of ethanol and biodiesel co-production  
722 from industrial hemp, Viswanathan et al. (2021) indicated that the breakeven unit production cost  
723 of biodiesel with 2, 5, and 10% lipid-containing industrial hemp was 18.49, 7.87, and 4.13  
724 USD/gallon, respectively. Besides, they showed that a 10% reduction in hemp feedstock cost leads  
725 to a 7.80% reduction in biodiesel unit production cost. In a lifecycle environmental and economic  
726 analysis of regional-scale food-waste biogas production with digestate nutrient, Koido et al. (2018)  
727 denoted that (i) electricity sales and food waste disposal income are the main hotspots in the  
728 revenue, (ii) maintenance cost has significant impact on expenditure, and (iii) biomethane yield is  
729 the most sensitive parameter for sustainable and profitable operation of the biogas plant.

730

#### 731 **3.2.2.2. Optimization models for TEA of biofuel production**

732 Optimization models have been extensively applied for economic analysis of various  
733 biofuels production within the BSCs. In addition to static optimization models, in which variables  
734 are given a single value (at a point in time), dynamic optimization models that have a specified  
735 range of values depending on conditions have been mainly employed to maximize net returns from  
736 biofuel production (Tran et al., 2011). As shown in Figure 13, using optimization models in TEA  
737 of biofuel production in the literature shows a change from a motor theme to a niche theme over  
738 time due to the density (development) and centrality (relevance) degrees. This means that from  
739 1986 to 2015, optimization models have been used in TEA of BSCs as a highly developed and  
740 also relevant theme, while from 2015 onwards, this cluster has gradually lost its relevance.

741 In this regard, the optimization models have been used in TEA of BSCs for various  
742 purposes, such as lifecycle costs for the optimized biogas production from microalgae (Meyer and  
743 Weiss, 2014), optimizing biofuel feedstock production (Tran et al., 2011), process design and

744 supply chain optimization of biodiesel synthesis from waste cooking oils (Kelloway et al., 2013),  
745 forest-based biorefinery supply chains for bioenergy and biofuel production (Cambero et al.,  
746 2016), biodiesel production catalyzed by liquid and immobilized enzymes (Andrade et al., 2019),  
747 optimization of bioethanol production (Silva Ortiz et al., 2020), and advanced biofuel production  
748 and emission utilization from macroalgal biorefinery (Dickson and Liu, 2021).

749

### 750 **3.2.2.3. Economic analysis of anaerobic digestion**

751 Anaerobic digestion, a robust technology to transform organic waste and biomass into  
752 bioenergy and biofertilizer, provides significant potential benefits across the water, energy, and  
753 food domains (Tolessa et al., 2022). Using anaerobic digestion as a sustainable method for treating  
754 organic materials and bioenergy production has gained momentum due to its high versatility, low  
755 investment costs, and greenhouse gas emissions reduction (Sganzerla et al., 2021; Tena et al.,  
756 2022). Moreover, among different waste-to-energy conversion technologies, anaerobic digestion  
757 plays a significant role in transitioning from a linear economy to a circular economy (Ranjbari et  
758 al., 2022c).

759 According to the thematic evolution of TEA in BSCs (see Figure 13), while the centrality  
760 (relevance) degree of TEA in anaerobic digestion applications in biofuel production has increased,  
761 the density (development) degree has decreased over time, which positions this topic between  
762 motor and basic themes. In this vein, anaerobic digestion application and capabilities in producing  
763 biofuels have been economically evaluated for different cases, namely economic analysis of  
764 anaerobic digestion in biogas plants (Gebrezgabher et al., 2010), potentials of anaerobic digestion  
765 of microalgae in producing renewable energy (Zamalloa et al., 2011), economic feasibility of  
766 macro-algae utilization from European temperate zones (Dave et al., 2013), the role of pricing in

767 carbon markets in facilitating the implementation of anaerobic digestion and biochar production  
768 (Galgani et al., 2014), biomethane production for the road transport sector (Larsson et al., 2015),  
769 profitability of anaerobic digestion for processing sugarcane vinasse in diversified biogas  
770 applications (Fuess and Zaiat, 2018), economics of farm-scale anaerobic digestion plants (Aui et  
771 al., 2019), economics of anaerobic digestion of different agricultural wastes (Li et al., 2020),  
772 integrating anaerobic digestion in the conversion of dairy waste into energy (Kassem et al., 2020),  
773 anaerobic digestion of swine manure (Lymperatou et al., 2021), and energy recovery from  
774 municipal solid waste (Mabalane et al., 2021). Although using anaerobic digestion for biogas  
775 production is well-established and promising, from an economic perspective, in many  
776 circumstances, this process cannot be cost-competitive with natural gas (Bhatt and Tao, 2020).  
777 Accordingly, further research and developments in terms of technological advancements,  
778 appropriate waste management strategies, and government incentives are required to increase  
779 potential cost savings of anaerobic digestion for waste-to-energy conversion pathways.

780

#### 781 **3.2.2.4. Feedstocks TEA: a special focus on waste cooking oil**

782 Waste cooking oil is used as an alternative feedstock for biofuel production to avoid using  
783 virgin oil, creating competition between food and energy sources. However, due to the high  
784 concentration of free fatty acids in waste cooking oil, its application in conventional conversion  
785 processes using alkali catalysts has been limited (Budiman Abdurakhman et al., 2018). As  
786 illustrated in Figure 13, economic studies on waste cooking oil applications in biofuel production  
787 have emerged as an emerging theme within the period 1986–2015, with both centrality and density  
788 degrees at a low level. However, from 2015 to 2021, this subject has gained much development  
789 degree (density) with less relevance degree (centrality), leading to appear as a niche theme.

790 Producing biofuels from waste cooking oil has attracted much attention as a promising  
791 multiple-advantage solution to (i) minimize waste and environmental pollution, (ii) support energy  
792 security and food safety, and (iii) facilitate the circular economy transition (Zhao et al., 2021). In  
793 this vein, inclusive economic evaluations are crucial for providing production infrastructures and  
794 appropriate BSC strategies to promote biofuels and keep businesses on the right track in the long  
795 run (Farid et al., 2020). Zhang et al. (2003), in an economic feasibility study of biodiesel  
796 production using waste cooking oil, highlighted that (i) acid-catalyzed process using waste cooking  
797 oil was more economically feasible by providing lower biodiesel break-even price and total  
798 manufacturing costs, and (ii) plant capacity and prices of feedstock oils and biodiesel are the most  
799 important factors influencing the economic viability of biodiesel manufacture. In another study,  
800 van Kasteren and Nisworo (2007) showed that the significant keys to the economic feasibility of  
801 the plant are plant capacity, raw material and glycerol price, and capital cost. In this regard, many  
802 TEAs have been conducted mainly on waste cooking oil potentials for biodiesel production based  
803 on different circumstances worldwide. For instance, in a TEA of biodiesel production from waste  
804 cooking oil in Hong Kong, Karmee et al. (2015) showed that lipase and acid are the most expensive  
805 and cost-effective catalysts for biodiesel production, respectively. In a similar study in Yemen, Al-  
806 attab et al. (2017) denoted that medium-scale biodiesel production from waste cooking oil provides  
807 a promising option with a reasonable biodiesel selling price of 0.62 USD/L, a payback period of  
808 4.3 years, and an annual net revenue income of 19,200 USD.

809

#### 810 **4. Challenges and future perspectives**

811 Although biofuels have many advantages in comparison with fossil fuels, such as lower  
812 carbon emissions and Sulphur content, their higher production costs compared to fossil fuels are

813 challenging (Kargbo et al., 2021). This higher cost mainly comes from the BSC components,  
814 including biomass feedstock, biomass logistics, densification and storage, and pretreatment  
815 processes, highlighting the significance of TEA in developing biofuels. From the economic point  
816 of view, TEA of biofuel production within the BSC domain is crucial to (i) provide inclusive  
817 insights and understanding of costs and revenues, and (ii) ensure the long-term sustainability of  
818 biofuel production and consumption and facilitate commercial developments to balance fossil fuel  
819 and biofuel markets.

820           The increasing interest in investments in biofuels in the energy market has placed  
821 biorefineries in competition with existing conventional petroleum-based refineries and products  
822 (Shahid et al., 2021), resulting in various challenges and opportunities. Moreover, raw material  
823 price, capital cost, and plant capacity have been recognized by many scholars as the main variables  
824 affecting the economic feasibility of biofuel production, which need to be optimized as much as  
825 possible (Gutiérrez Ortiz, 2020). Therefore, it is crucial to find ways to reduce the level of conflicts  
826 and make a sustainable balance between the share of biofuels and petroleum fuels in the energy  
827 sector. On this basis, promoting biofuel production and consumption through government  
828 incentives, tax measures, price subsidies, and risk mitigation policies to enhance the economic  
829 feasibility of biofuel production deserves more research in the future. Besides, the Ukraine-Russia  
830 war has significantly impacted energy and food markets due to the considerable share of these  
831 countries in exporting oilseeds and grains to the global markets. In this regard, while this war has  
832 led to a shortage of crops and grains, lowering biofuel mandates could potentially result in rising  
833 petroleum supply and demand challenges. Shams Esfandabadi et al. (2022b) highlighted the  
834 critical importance of switching from first-generation biofuels to higher generations to prevent  
835 food insecurity and keep biofuel mandates in the post-war era.

836           Although the dominant biofuels in the market are sugarcane/corn-based biodiesel or  
837 bioethanol derived from various oil resources (Chia et al., 2018), microalgae biorefinery produces  
838 algal biofuels, which are known as the third-generation biofuels, should be further developed. The  
839 reason is mainly due to the significant benefits of the algae-based biofuels, such as sequestering  
840 huge amounts of CO<sub>2</sub> during their cultivation, flexibility in growing in inapplicable water  
841 resources, and using marginal lands that are not ideally used for agriculture purposes (Abbasi et  
842 al., 2021; Molino et al., 2020). Nevertheless, while the first two generations of biofuels have been  
843 significantly investigated by scholars, the research and development of the third-generation  
844 biofuels that use microorganisms as feedstock, such as algal biomass, are still in their infancy  
845 (Ranjbari et al., 2022a). In this regard, the development of cost-competitive production algae-  
846 based bioenergy products, such as gaseous and liquid biofuels, has faced many challenges, namely  
847 low prices of natural gas, petroleum price reduction, and lack of consistent policies on carbon  
848 pricing (Zewdie and Ali, 2022). Accordingly, more in-depth techno-economic and market analyses  
849 considering capital cost, operating cost, and plant capacity are needed to determine total revenue  
850 and net profit and identify potential commercial improvements in producing algal biofuels.

851

## 852 **5. Conclusions**

853           Because of the increasing interest of scholars and practitioners involved in BSCs, a huge  
854 amount of research has been performed to examine different aspects of BSC management. In this  
855 regard, TEA has gained momentum to evaluate the total costs and economic feasibility of various  
856 biofuel generations. As the first research in the literature, this study aimed to provide an inclusive  
857 image of the body of knowledge in the TEA evolution within the BSC domain by conducting a  
858 comprehensive science mapping analysis. The results shed light on the TEA of biofuel production

859 through (i) introducing the most influential articles, journals, countries, and institutions  
860 contributing to the field to date, (ii) discovering the main themes and trends of the TEA within the  
861 BSC arena, and (iii) proposing the main challenges and future perspectives of TEA of biofuel  
862 production and consumption in order to find ways to reduce the level of conflicts and make a  
863 sustainable balance between the share of biofuels and petroleum fuels in the energy sector. The  
864 provided insights support BSC stakeholders in decision-making and policy recommendations for  
865 further developments in the energy market. The trend analysis results highlighted that (i) biofuel  
866 production and consumption need promotion through tax measures and price subsidies, (ii) the  
867 development of cost-competitive algal biofuels has faced many challenges over recent years, and  
868 (iii) TEA of algal biofuels to identify commercial improvements and increase the economic  
869 feasibility is still lacking, which calls for more in-depth research and developments. The provided  
870 insights support BSC stakeholders in decision-making and policy recommendations for further  
871 developments in the energy market.

872         The systematic science mapping conducted in the present research has some limitations.  
873 These limitations are mainly oriented to the database and science mapping analysis methods  
874 employed. In this regard, we based our research on the WoS Core Collection database.  
875 Incorporating research articles from other databases such as Scopus can serve as a basis for further  
876 investigations. Besides, we used the “biblioshiny” web-interface of the “bibliometrix” package in  
877 R for conducting bibliometric analysis in this research. Performing similar bibliometric analyses  
878 using other software packages, such as VOSviewer and SciMAT, are encouraged to help increase  
879 the reliability of the findings.

880  
881

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894

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896

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