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

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Abstract

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

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

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

1. Introduction

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

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

The global energy demand is estimated to increase by approximately 28% by 2040 in comparison with the current level (Osman et al., 2021). Today, fossil fuels based on coal, oil, and natural gas, as effective drivers of economic development (Ellabban et al., 2014), are the primary source of energy production and consumption in the global community. However, increasing concerns regarding fossil fuel consumption have attracted much interest in investing in biofuels production to substitute fossil fuels, towards a low-carbon and sustainable circular bioeconomy (CBE). Biofuels produced from biomass feedstock through eco-friendly and carbon-neutral approaches can potentially support future energy supply towards achieving energy security and sustainability (Ambaye et al., 2021). Biofuels are mainly preferred for their (i) carbon-neutral character, (ii) renewability, and (iii) production flexibility in decentralized systems from abundant and versatile resources (Gebremariam et al., 2019).

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

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

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

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

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

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

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

2. Scope and review methodology

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

2.1. Data source and search protocol

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

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

Second, a search string was constructed aiming to maximize the sufficiency of the extracted documents related to the topic of this research indexed in WoS. In this vein, the two main keywords "biofuel" and "supply chain" were considered as the core of attention for further investigation. To avoid neglecting critical and significant research within the BSC domain as much as possible, these two keywords were divided and carefully scanned to outline the crucial keywords referring to the BSC concept. In this regard, with a similar approach adopted by Pournader et al. (2021), we relied on the supply chain definition by Mentzer et al. (2001) as "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer". Consequently, we ended up with "supply chain", "supply network", "buyer-supplier", "supplier selection", and "supplier evaluation", as the major keywords covering the concept of the supply chain as a whole. Keywords that implicitly refer to the supply chain, such as "operation management", inventory management", and "logistics" were excluded from our search string to remain consistent with the main focus of this study. On the other hand, the keyword "biofuel" were searched within the most recent systematic reviews conducted on biofuels (for instance, see Padilla-Rivera et al. (2019), and Chaudhary et al. (2021)) to identify the main keywords and synonyms implicitly addressing the biofuel concept within the scientific production in the literature. To this end, "biofuel", "ethanol", "bioethanol", "biodiesel", "biogas", "biomass", "bio-oil", and "biorefinery" were outlined to be included in the search string. Moreover, due to the presence of "bio" in the keywords, different spelling styles, such as "bio-fuel", "bio fuel", "bio-diesel", and "bio diesel" were also taken into account. As a result, the identified keywords related to "biofuel" and "supply chain" were connected by using the Boolean operators "AND" and "OR" to formulate the following search string for capturing the most relevant documents related to the BSC background: "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*". The initial run of the search string on the topic field in WoS which searches title, abstract, author keywords, and keywords plus returned a total of 2,605 records.

Finally, a set of inclusion criteria were set up to limit the initial results to the most relevant and reliable research. In this regard, only peer-reviewed articles published in journals in the English language were included in the final sample and other forms of documents, such as conference proceedings, book chapters, and short communications were excluded from the study. The rationale behind adopting this approach was to enrich the quality and validity of the collected data and accordingly analyses and obtained results (Ranjbari et al., 2021c). Besides, due to the aim of this research to provide a comprehensive science map of the BSC field of research, no time-period restriction was considered. The continuous process of capturing data was stopped by adding the last update on December 19, 2021, to the dataset. As a result of this stage, 1,975 peer-reviewed journal articles met the inclusion criteria and were selected as the final sample for analysis in the present review. Table 1 summarizes the details of the adopted search protocol.

Table 1

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

2.2. Data analyses

To properly answer the RQs of this study, an inclusive approach to assess the research developments and outcomes in the BSC field was adopted. In this vein, an analytical method adopted from (Dutra et al., 2022; Ranjbari et al., 2021a, 2022b), combining descriptive analysis, keywords co-occurrence analysis, and qualitative content analysis was applied to render the state-of-the-art of BSC research. To do so, the analyses were performed in three steps as the following.

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

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

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

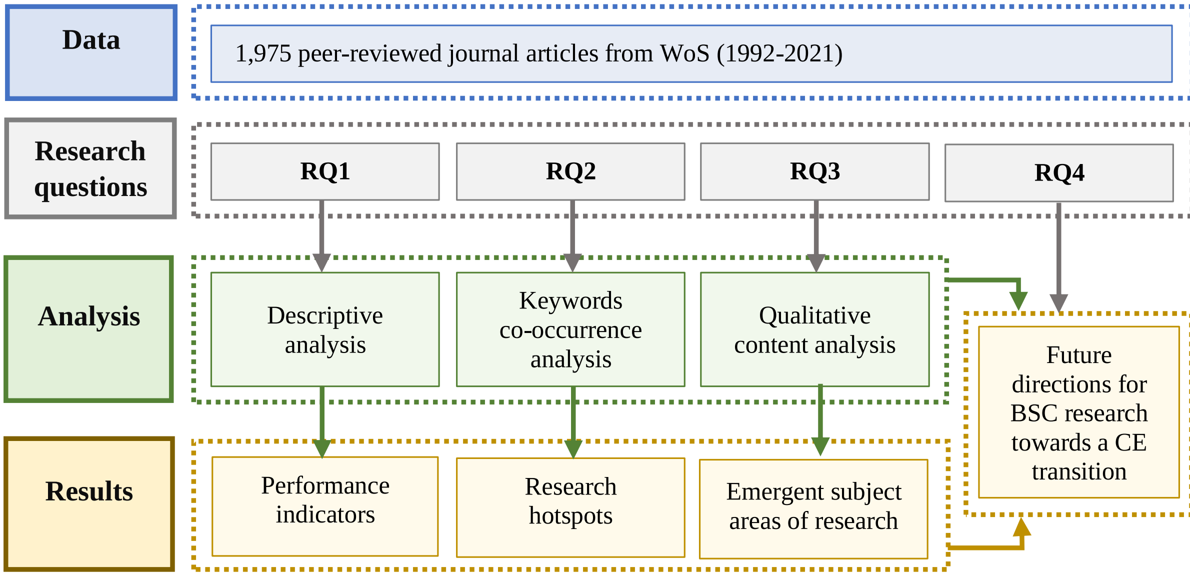


Fig. 1. The research framework adopted for mapping BSC research

3. Results and discussion

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

3.1. Descriptive analysis results: Performance indicators

3.1.1. Annual publication evolution over time

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

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

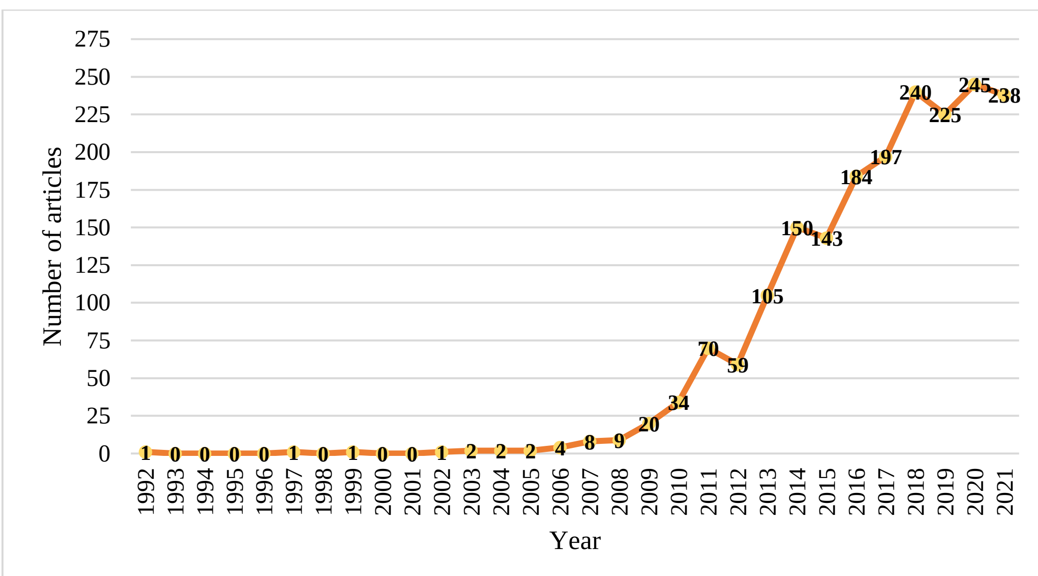


Fig. 2. The annual publication in the research field of BSC.

3.1.2. Core publishers and journals

In total, 120 publishers have contributed to the publication of the 1975 articles in our dataset. The six most contributing publishers (i.e. Elsevier, Springer Nature, Wiley, MDPI, American

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

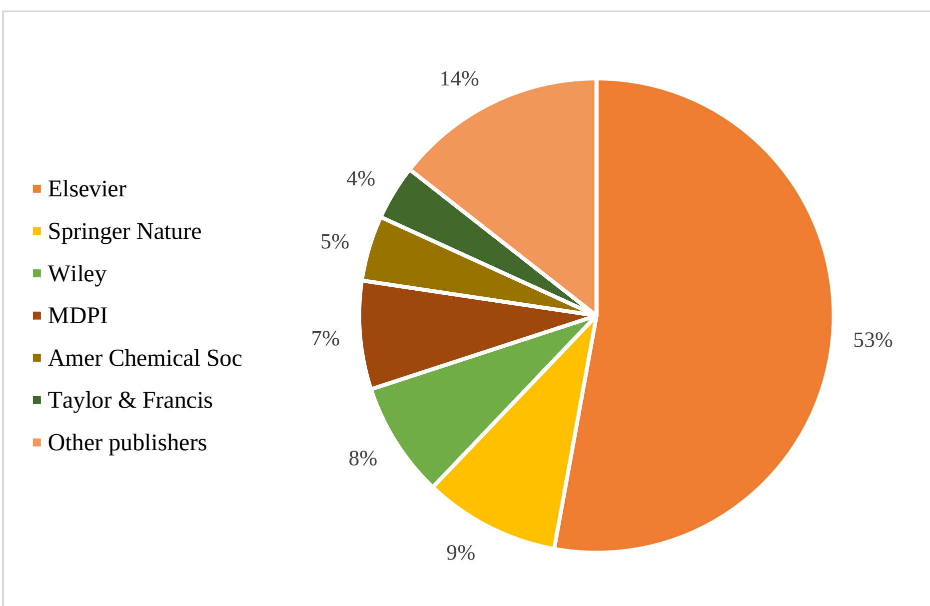


Fig. 3. The main contributing publishers in the publication of BSC-related articles.

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

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

3.1.3. Thematic research categories in WoS

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

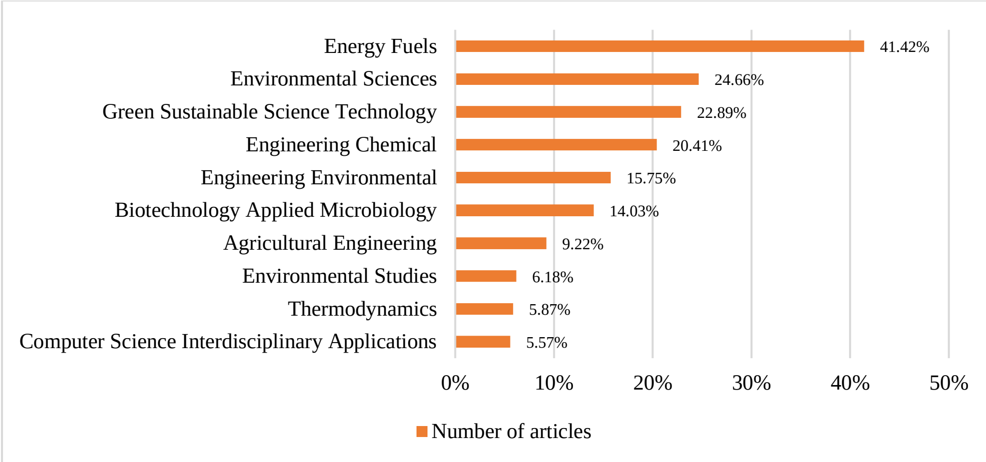


Fig. 4. The top 10 WoS thematic research categories containing BSC research.

3.1.4. Geographical distribution of contributions

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

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

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

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

Table 4 provides details about the keywords in the built clusters, including their (1) occurrence, (2) average publication year (i.e. mean of the publication year of the articles in which a specific keyword appears), (3) average citation (i.e. mean of the citations received by the article containing a specific keyword), (4) number of links (i.e. the number of keyword with which a specific keyword co-appear in a single article), (5) total link strength (i.e. the sum of all co-occurrences of a specific keyword), and (6) the five most co-occurring keywords with a specific keyword and their number of co-occurrences. Furthermore, for each cluster, the average publication year of the keywords is reported, which points to the recentness of the articles containing the keywords considered in each cluster. The built clusters, including "Biomass to biofuel supply chain design and planning", "Environmental impacts of biofuel production", "Biomass to bioenergy", and "Techno-economic analysis of biofuel production" are discussed in the following sub-sections.

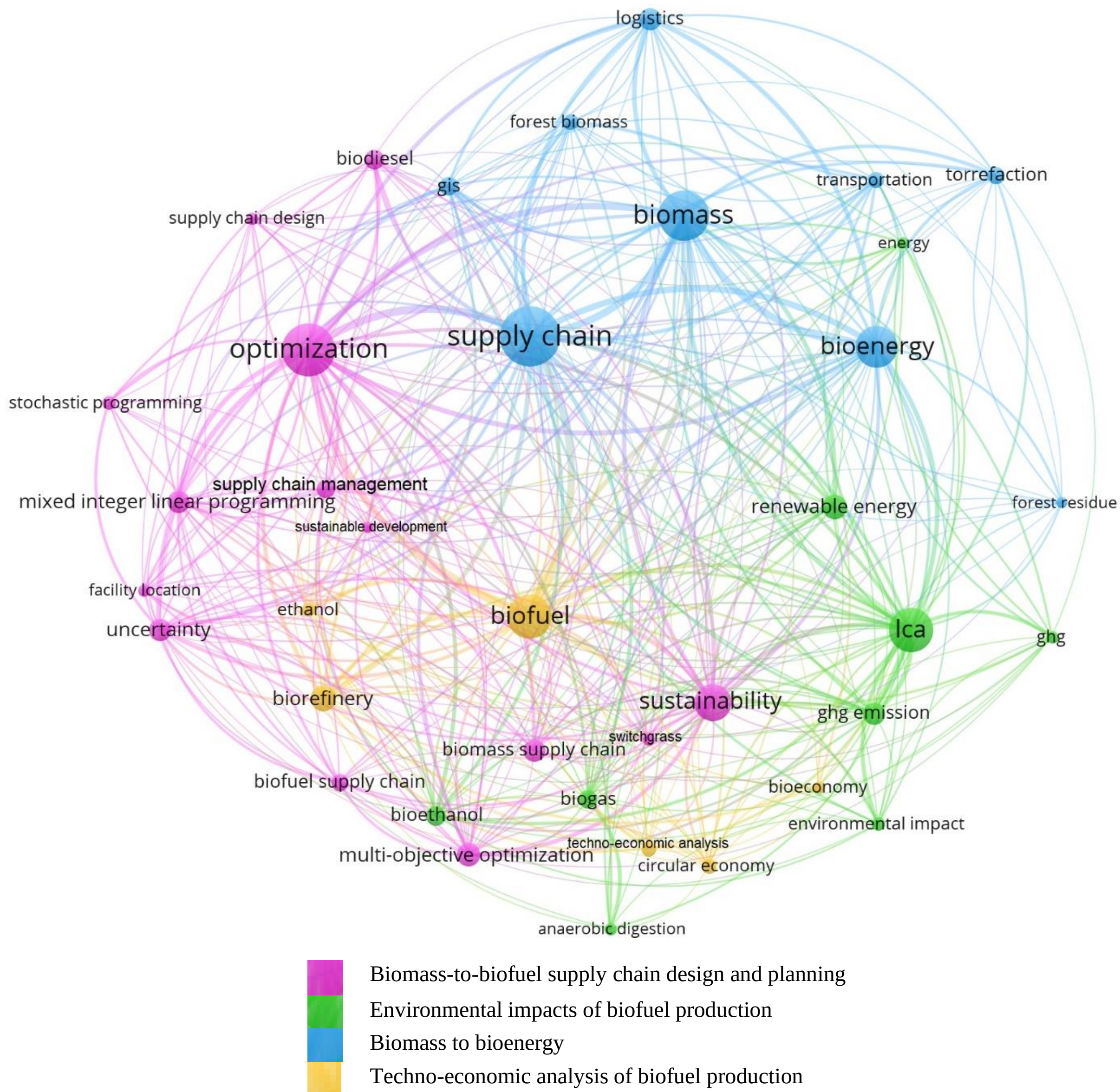


Fig. 5. Co-occurrence network of the keywords within the BSC research from the target literature.

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)

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

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

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

To deal with the "uncertainties" linked with the BSC, different approaches have been adopted by the researchers, such as "stochastic programming" (Elaradi et al., 2021; Fattahi et al., 2021), robust optimization (Gilani and Sahebi, 2021), and fuzzy programming (Afkhami and Zarrinpoor, 2021). "Multi-objective optimization" models developed in this field mainly focus on "sustainability" issues and try to optimize a combination of economic, environmental, and social aspects of a considered BSC. For instance, Baghizadeh et al. (2021) used a mixed-integer non-linear programming model to maximize profit, improve social impacts, and minimize the negative environmental effects and the lost demands in a forest supply chain. Also, Díaz-Trujillo and Nápoles-Rivera (2019) focused on the optimization of biogas supply chains based on satisfying the biogas and biofertilizer demands, maximization of the profit, and minimization of the environmental impact. In another research conducted by Santibañez-Aguilar et al. (2022), a multi-objective optimization model was applied for the planning of a biomass supply chain, which considered several objective functions to address the social impact as a function of the facilities location, net profit, and net CO_2 emissions.

3.2.2. Cluster 2: Environmental impacts of biofuel production

Biofuel, as a type of "renewable energy", is considered a strong alternative for fossil fuels due to its favorable "environmental impacts" and its support to lower climate change through emitting less "greenhouse gasses". Bui et al. (2021) estimated that indigenous sources of biomass in the UK can remove up to an annual amount of 56 Mt of CO_2 from the atmosphere. García-Freites et al. (2021) also focused on the UK's net-zero emission target and found that their studied BECCS supply chains can contribute to the GHG removal by CO_2e between -647 and -1,137 kg MWh^{-1} net negative emissions. In another research with a CE approach, Mayson and Williams (2021) studied the treatment and reuse of spent coffee grounds to fuel the roasting process in a coffee company and found that using spent coffee grounds can result in carbon savings of 5.06 kg CO_2e/kg^{-1} fuel for each roasted batch of coffee in comparison with a conventional approach.

A huge share of articles in the field of BSC deal with the environmental impacts of the activities linked with the design and operation of BSC (e.g. Duarte et al. (2016) and Lu et al. (2015)). Besides, "LCA" has been used in 170 articles in our dataset to assess the environmental impacts of biofuel-related products, as a comprehensive evaluation approach for measuring environmental impacts over the biofuels' entire production chain (Osman et al., 2021). For instance, Lin et al. (2021) conducted an LCA on a biogas system for cassava processing in Brazil, and Xu et al. (2021) studied the GHG emissions of the electricity generated from forest biomass in the US from an LCA perspective. A cradle-to-grave industry-average assessment of the life-cycle impacts of the wood pallet supply chain in the United States was done by Alanya-Rosenbaum et al. (2021), highlighting the significant share of biomass from the total primary energy consumption in the supply chain. Tsalidis and Korevaar (2022) pointed to the recent concentration of LCAs on emerging technologies, which are not yet optimized with respect to energy and materials, and conducted research to show the data scales effects on LCA results. They considered a case study of the Dutch torrefaction industry and used its ex-ante experimental data, data derived from simulations, and ex-post empirical data and modeled bench, lab, pilot, and commercial scales, and simulations of torrefaction technology. Their investigations showed that simulations result in better scores regarding all the considered environmental impacts including global warming, fine particulate matter formation, terrestrial acidification and freshwater eutrophication potentials, in comparison with the other scales modelled.

"Bioethanol", "biogas", and "anaerobic digestion" are other frequent author keywords appearing in 49, 45, and 23 articles, respectively, that are labeled under cluster 2. Anaerobic digestion is a biological process in which organic materials are converted to biogas through a series of tandem biochemical reactions (Nie et al., 2021). This process is a waste-to-energy option to recover energy from organic waste and produce value-added chemicals (Barati et al., 2017) and is recognized as an environmental-friendly technology in this regard. As an example among the papers investigated in our database, Nguyen et al. (2016) studied the energy conversion of rice straw through anaerobic digestion and found that using rice straw for biogas production can generate a positive net energy balance of 70% - 80%. In another research, Stougie et al. (2018) studied the combustion of bioethanol from the fermentation of verge grass, combustion of substitute natural gas from supercritical water gasification of animal manure, and combustion of substitute natural gas from anaerobic digestion of animal manure, and found that the bioethanol system has the best performance and is the most environmentally sustainable among the studied systems. Bioethanol, as a type of biofuel, can be either blended with gasoline or used as a stand-alone fuel (Haghighi Mood et al., 2013).

3.2.3. Cluster 3: Biomass to bioenergy

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

Biomass is not only a source of energy but also a feedstock to be used in biorefineries. The biomass materials that can be used to produce biofuel range from wood and energy crops to agricultural, municipal, and industrial waste (Rentizelas, 2013). "Forest residue" has been identified as a highly frequent keyword in the dataset analyzed for this research several articles have considered this type of biomass for the production of biofuel and have analyzed its relevant supply chain. Through a System Dynamics model developed by Jin and Sutherland (2018), the dynamic changes in the forest residue supply and demand were analyzed. Sahoo et al. (2019) developed economic models to estimate the operational costs of different forest residue *logistics*. Moreover, in the research conducted by Malladi et al. (2018), a decision support tool was developed for optimizing the short-term "logistics" of forest-based biomass. Selection of a proper location for the biofuel-related facilities (Santibañez-Aguilar et al., 2018; Woo et al., 2018) and also the transportation and logistics (Fikry et al., 2021; Han et al., 2018) issues are some of the other challenges addressed by researchers regarding the management of a BSC, whose relevant keywords have appeared in this cluster.

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

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

In many of the studies dealing with the optimization of the biofuel supply chain or a part of it, costs and economic analysis have been considered crucial, since biofuel production is linked with several economic constraints. For instance, Allman et al. (2021) proposed a biomass waste-to-energy supply chain optimization model for the location and relocation of mobile and modular production units and found that mobile production modules lead to the saving of 1-4% of supply chain costs in Minnesota and North Carolina. An optimization framework for biorefineries design was presented by Theozzo and Teles dos Santos (2021) to maximize the operational net present value. Ankathi et al. (2021) proposed an optimization model for locating food waste and manure anaerobic co-digestion facilities in Wisconsin to maximize the profit from the biopower supply chain and carbon credits. In addition, "ethanol", which is the most produced biofuel at the industrial scale level (Amândio et al., 2022), has been addressed in the optimization models of some research. The optimization-based model by Punnathanam and Shastri (2021) for ethanol production from the agricultural residue with an objective of minimizing the total annual cost, and the optimization model by Soren and Shastri (2021) for commercial-scale ethanol production considering the cost minimization are a few examples in this regard.

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

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

3.3. Qualitative content analysis results: Emergent BSC research areas

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

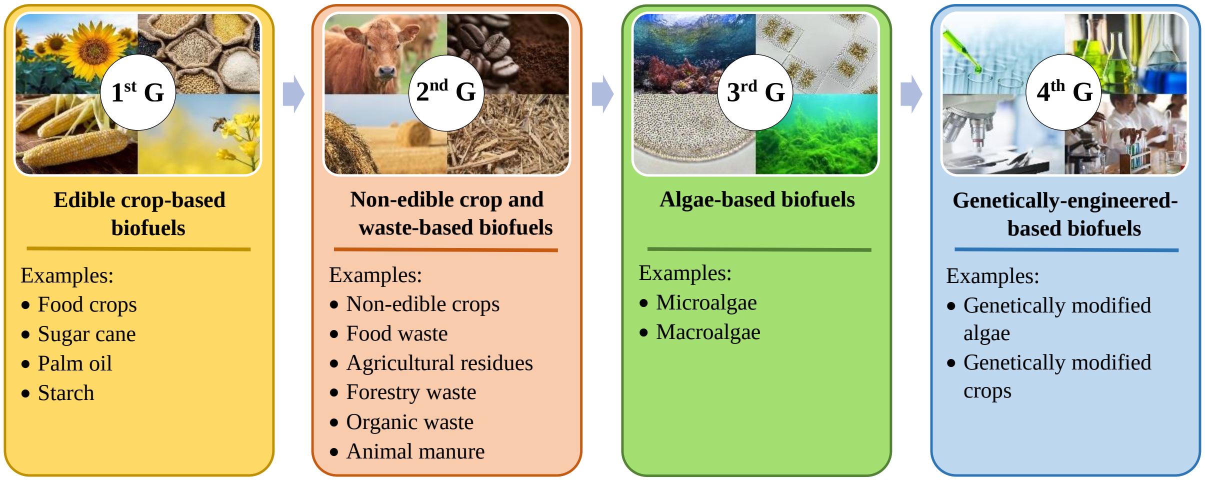
3.3.1. Global warming and climate change mitigation

The climate change and BSC activities trade-offs have appeared as one of the most recent subject areas within the BSC literature. In this regard, "global warming", "GHG removal", "decarbonization", "environmental analysis", "CO_2 removal", and "climate change mitigation" are some of the authors' keywords in our sample data, which can be categorized under the climate change subject area of research. The urgent need for mitigating climate change adverse effects along with the potential threat of energy crisis have increased the interest to utilize biomass for biofuel production (Liu et al., 2020a).

Yan et al. (2021) in a study in China showed that climate change has a significant impact on the availability of land for producing liquid biofuels due to changing temperature and precipitation. The main focus of research in this area has been on climate change impacts trade-offs with utilizing logging residue for biofuel production (Liu et al., 2020b), economic and environmental effects of biofuel production developments (Kung, 2019), policy formulation (Prasad et al., 2020), cellulosic biofuel applications (Popovic et al., 2019), and biofuel cropping systems (Pilecco et al., 2020). However, developing integrated frameworks to assess the climate change impacts of biomass utilization for biofuel production needs more investigations in the future.

3.3.2. Development of the third-generation biofuels

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



*G: generation.

Fig. 6. Biofuel generations.

Based on the average publication year of keywords within our data, the third generation of biofuels, which utilizes algal biomass, including microalgae and macroalgae has emerged as a recent subject area in the BSC literature. On this basis, "seaweed", "macroalgae", and "algae" have been used by researchers as keywords of their research with a minimum average publication year of 2019. Microalgae, as a potential feedstock for the third-generation biofuel production, has increasingly gained momentum among scholars and industrial practitioners due to its significant benefits, such as (i) sequestering huge amounts of CO_2 during their cultivation, (ii) high oil content and fast growth rate, (iii) flexibility in growing in inapplicable water resources, and (iv) using marginal lands which are not ideally used for agriculture purposes (Abbasi et al., 2021; Molino et al., 2020).

Bharathiraja et al. (2022) showed that in comparison with the biofuels made from crops and lignocelluloses, the third-generation biofuels produced from algae are more compatible with diesel engines due to their lower environmental footprint. The research in this area has been mainly focused on algae cultivation and production systems (Ou et al., 2021), the application of catalytic processes on the production of algae-based biofuels (Zuorro et al., 2020), modeling water-energy tradeoffs (Mayer et al., 2020), acceptability of genetically engineered algae biofuels (Varela Villarreal et al., 2020), and value-added products (Kumar et al., 2020). Nevertheless, although much research has been conducted in this subject area, biofuel production from algae is still under intense investigation to tackle main barriers, including commercialization (Shiru and Shiru, 2021), and technological advancements for reducing production costs (Getachew et al., 2020).

3.3.3. Government incentives, pricing, and subsidizing policies

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

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

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

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

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

Investments in the nexus of the CE and bioeconomy considering the potentials of the bio-based sector have gained momentum to create a sustainable future. On this basis, the CBE, as a bio-based CE, highly relies on the sustainable and resource-efficient valorization of biomass and organic waste through integrated biorefineries (Stegmann et al., 2020) to close supply chain loops. However, existing guidelines and standards developed for businesses lack a clear definition and framework, outlining which cycles between the CE and bioeconomy contribute most to a sustainable future economy (Leipold and Petit-Boix, 2018). In this regard, Leipold and Petit-Boix (2018) showed that the bio-based businesses in the European context predominantly stick to already established practices and, so far, do not employ the business model innovation potentials to implement a CE.

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

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

Algae are used as promising feedstocks for different applications, such as bioenergy and biofuel production, and the manufacturing of high-value bioproducts (Ahmad et al., 2022). Algal biofuels, as a clean and renewable energy source, are of high interest to the energy sector due to their energy-efficient and environmentally-friendly potential in tackling GHG emissions and widespread pollution (Ferreira Mota et al., 2022). In this regard, biofuel production from algal biomass towards a CBE has been under intense debate, leading to development in different aspects, such as microalgae cultivation (Devadas et al., 2021), techno-economic feasibility assessments (Venkata Subhash et al., 2022), anaerobic digestate valorization (Stiles et al., 2018), and production and harvesting of microalgae (Khan et al., 2022), to name a few. However, algae-based biofuel production has faced critical challenges and barriers, mainly economic and technological barriers that prevent the commercial and industrial use of algae (Ahmad et al., 2022).

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

5. Conclusions

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

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

5.1. Limitations of the study

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

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