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Article

Exploring the Synergy of Renewable Energy in the Circular Economy Framework: A Bibliometric Study

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Abstract: Over the past half-century, scientists from many different areas have been investigating how to switch to renewable energy, especially in the context of a circular economy. Numerous articles have discussed the scientific aspects of developing technology to support this process. This systematic literature review and bibliometric study aim to fill in research gaps by looking at trends, challenges, and possible future directions for the use of renewable energy in the context of a circular economy, especially in the fields of business, management, and economics. The study analyzed 294 peer-reviewed articles using the R Studio-Biblioshiny package version 4.1.2 software. The challenges of integrating renewable energy technologies within a circular economy include financial constraints, such as a high initial investment, the lack of an adequate regulatory framework and government support, the intermittent availability of renewable energy sources, the scarcity of resources and components for renewable energy generation technologies, relatively low energy conversion efficiency, the challenge of increasing consumer awareness, and the environmental impact of technological waste. The study suggests that future research should focus on financial models and policy incentives that can encourage businesses and investors to take advantage of renewable energy. The study also recommends exploring sustainable alternative fuel technologies, optimized waste-to-energy conversion, the increased efficiency of bioenergy conversion, more efficient solar panels, improved energy storage capacity, the life cycle management of solar panel devices, and the development of innovative business models to facilitate industrial symbiosis.

Keywords: circular economy; renewable energy; bibliometric analysis

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1. Introduction

The circular economy (CE) notion is gaining traction among many corporations. This economic paradigm shifts away from the traditional "take, make, and dispose" strategy in favor of the new "reduce, reuse, and recycle" method to maximize resource efficiency and reduce waste. Businesses that adopt a circular economy model are more resilient, save money, and have a smaller impact on the environment [1]. In the same way, today's business community has realized that the natural resources and energy sources used as operative materials are fixed and cannot be replenished, so companies must strive to use energy from renewable sources and avoid creating large carbon footprints in their use [1–6]. Before there was awareness of the scarcity of natural resources and the increasing demand, companies used a linear production approach, where companies took resources, produced, and did not think about whether the residue or waste from the product could be reused to maintain or improve the economic value [1–7]. The notion of a circular economy is not limited to recycling materials and energy used in production, but in this system, companies also promote the use of shared products (e.g., peer-to-peer, sharing, collaborative consumption), not just ownership, to minimize the raw materials and energy needed to make new products [4,8–10]. The application of closed-loop production should be adopted by businesses everywhere and applied in the form of their business models so that, at the same time, companies can still generate profits while preserving nature. Companies need to implement a circular economy system to achieve environmental sustainability goals, particularly by using renewable energy sources as their primary resources [7,10]. In a circular economy, producers must strive for optimal value creation by minimizing energy inputs, especially from non-renewable materials, so that materials remain in the production cycle for the maximum duration possible, reducing waste generation [7,11].

Circular economy actors can accomplish environmental sustainability through energy management by utilizing renewable and clean energy during production. It has been demonstrated that using renewable energy sources, such as solar panel technology, hydrogen, and wind power, significantly reduces greenhouse gas emissions, particularly carbon dioxide emissions and other hazardous gases from the production process, thereby gradually reducing environmental air pollution [7,12–16]. The use of environmentally friendly electric vehicles instead of conventional diesel or fossil fuel-powered vehicles for product distribution is another example of multiple companies' pervasive use of renewable energy [17–19]. Norway is the leading country for electric vehicle use, as company cars, private vehicles, and public transport, with more than four-fifths of new car sales in this country dominated by electric vehicles in 2022 [19,20]. Other countries that have successfully transitioned from conventional fossil fuel-powered vehicles to electric vehicles include the United States, China, India, Germany, and France [19].

Efforts to improve energy efficiency in the value chain also exemplify the circular economy principle during the transition to sustainable energy. Companies need to conduct integrated energy audits and assessments to review the amount of energy used at each point in the value chain, as well as the amount of energy and materials wasted or improperly used in the process [21]. Once the efficiency level of energy use is known, the company can optimize energy use by using waste heat recovery technology to convert heat previously wasted in the production process into usable heat and by prioritizing renewable energy sources using biodegradable materials [22]. Vertical and horizontal integration and symbiosis between companies, involving exchanging materials, energy, and by-products, can also be used to reduce waste and non-renewable energy consumption in the production process [5].

To incorporate renewable energy into the circular economy model, businesses should create systems for transforming leftover materials from production and consumption into energy sources. The key to the cradle-to-cradle system is reprocessing the material and energy residues wasted during production, as well as the mechanism for recycling and reusing waste from the consumer consumption process, also known as waste-to-energy conversion [23]. An example of this process is incineration, which is the process of burning organic and inorganic municipal waste to produce heat, electricity, or biofuels that possess economic value. Energy production from waste incineration has been used in several countries, such as Mexico [24], Brazil [25], and China [26], to meet a small part of each country's electricity needs. Other mechanisms in waste-to-energy conversion include anaerobic digestion, which is the process of decomposing inorganic waste by using microorganisms in situations with low or almost no oxygen to produce biogas [27–32]. Biogas can then power industries, households, and vehicles. It reduces waste and carbon emissions from agriculture and animal husbandry. In addition, a biogas plant can produce residual carbon in biochar, which can be used as a soil fertilizer and is anticipated to increase agricultural productivity [31]. The use and production of biofuel have been applied to the agro-industrial sector in Italy through agricultural residues [31,33], as well as in the use of livestock manure on farms in Poland [34] and in several other EU countries.

As evidenced by a growing body of literature on the subject, several authors have emerged as leaders in the field of renewable energy in the circular economy. Rosokhata 2021 found that the most influential authors in the field of renewable energy are from the United States, China, and India [35]. Cusa 2021 identified the University of Malaya as the institution with the highest number of publications regarding the optimization of hybrid renewable energy systems [36]. Portuguese researcher Azevedo in 2019 found that the most productive authors in the fields of supply chain performance and renewable energies are influential investigators [37]. Nunes 2023 analyzed public policies for renewable energy from the perspective of the circular economy and found that Germany was the country with the greatest contribution to the field [38]. Overall, these papers suggest that there are several influential authors in the field of renewable energy in the circular economy and that research in this area is being conducted by scientists from various countries.

Despite the increased research regarding the circular economy and renewable energy over the past few years, significant knowledge deficits still need to be addressed in the published literature. The existing research concentrates on the technical and environmental aspects of these transitions, while the business and management aspects are less thoroughly investigated. Currently, no specific literature review journal addresses the barriers and challenges of implementing renewable energy in a circular economy, nor a future research agenda. Arezoo Ghazanfari in her review article that analyzes the circular economy literature on a macro scale, with an emphasis on energy markets. The study highlights the advantages of energy recovery from waste for facilitating the energy transition and attaining zero-carbon decarbonization goals [9]. Different perspectives and concepts of the circular economy are presented in other articles. This article provides an overview of the circular economy concept, but does not address renewable energy specifically [39]. The literature demonstrates that the circular economy and renewable energy are complementary ideas that can contribute to a sustainable future. In addition, previous research has frequently viewed a circular economy and renewable energy as two different initiatives, as opposed to complementary and interdependent strategies. Therefore, there is a need for further research into how renewable energy can be implemented within the framework of a circular economy and how these synergies can impact business strategies and operations. This study presents bibliometric data on the development of discussions concerning a circular economy and renewable energy use in business and management research areas, challenges faced in the transition to renewable energy in a circular economy, and future research agendas that require additional study. In this study, the authors aim to answer two research questions: RQ1: What is the structure of the knowledge synthesis arising from the discussions on the application of renewable energy in the context of the circular economy in the management and economics disciplines? RQ2: What are the primary challenges and barriers to the implementation of renewable energy in accordance with the principles of a circular economy?

2. Materials and Methods

The use of a quantitative research approach is the aspect of this study that is of the utmost significance. The detailed approach adopted in this study is depicted in Figure 1, which also shows the sequential stages in assuring the process's robustness. To measure scientific output, quality, and influence, bibliometric analysis is an extremely valuable instrument. In addition to providing a comprehensive picture of a subject's intellectual, conceptual, and social framework, the method in this paper also enhances the relevance of the study. In addition, this research utilizes a systematic literature review framework with a combination of bibliometric methods to present quantitative data from numerous journal articles discussing renewable energy use in the context of a circular economy in a structured, sequential, and transparent manner [40–42]. A systematic literature review, especially with the bibliometric method, is used in this study with the aim that researchers identify significant findings, obstacles, and challenges from the transition to the use of renewable energy, primarily related to the principle of a circular economy, from various existing bodies of knowledge [43]. The bibliometric study, with the help of R Studio-Biblioshiny package version 4.1.2, allows the researcher to map and visualize subtopics related to the issue of renewable energy application in the circular economy framework, trends in research themes from one time period to another, the most cited references, cooperation patterns between authors, interrelationship patterns between documents, and other quantitative information more accurately and efficient compared to manually conducted literature review process [41,44,45]. The articles analyzed in this review were obtained from the Scopus and Web of Science databases, both of whose data formats are supported by the Bibliometrix or Biblioshiny package version 4.1.2, and processed with the R Studio application. Both databases enable authors to extract bibliographic metadata related to the authors, the keywords used by the authors, the list of references used in the article, as well as the affiliation and country of origin of the corresponding author, along with numerous other crucial pieces of data. The first stage of this systematic literature review includes identifying the research topic, followed by a search, using appropriate search terms, for documents that fit the topic and can answer the identified research questions.

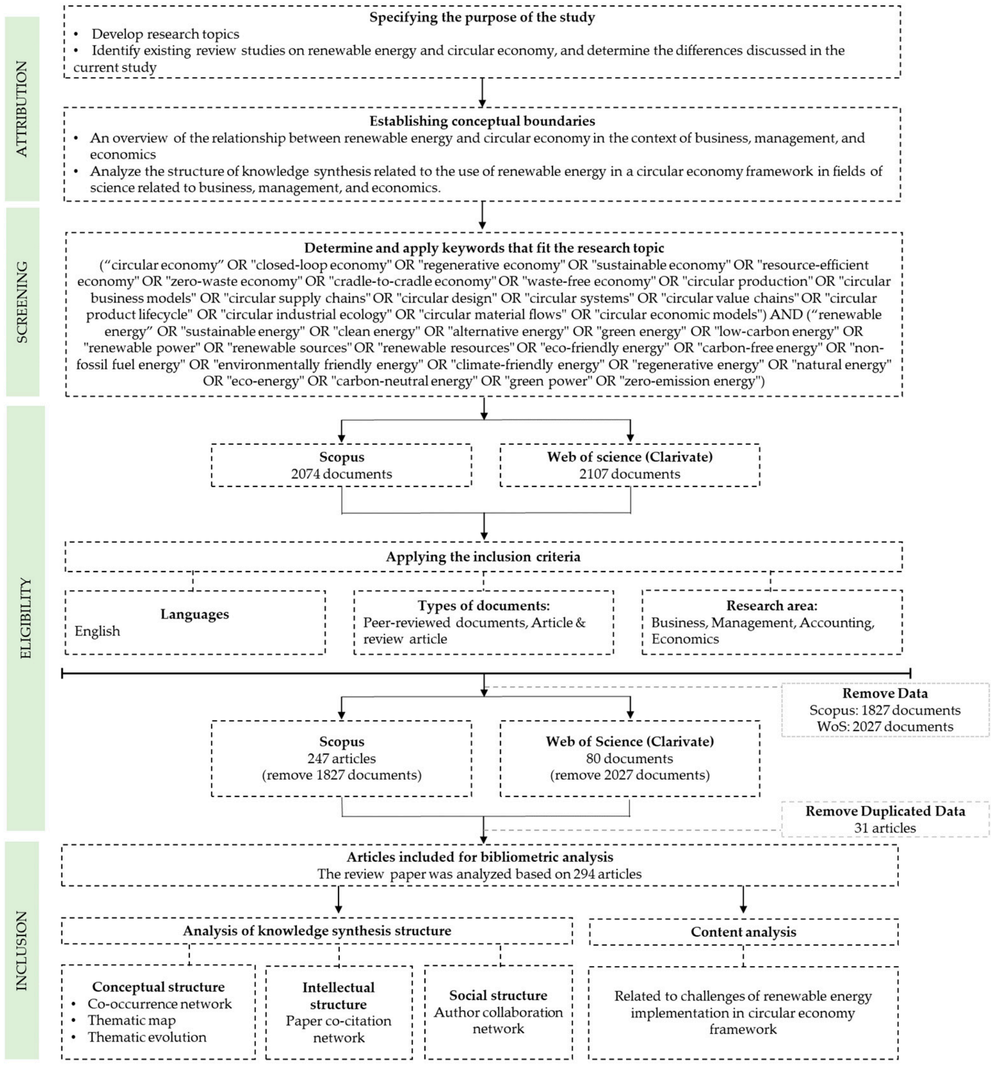

Figure 1. Steps taken for the bibliometric analysis. Source: authors' elaboration.

To retrieve articles from databases, a Boolean search uses "OR" for synonyms of the two terms and "AND" to combine the synonym sets of the two primary topics. The search yielded 2107 Web of Sciences documents and 2074 Scopus documents. Next, the author re-selected the documents using the following exclusion criteria, including (1) all non-English documents; (2) non-peer-reviewed documents, such as book chapters and all types of documents that are not final, do not show complete research results, and can still change, such as "proceedings", "editorial material", "early access", or articles whose publication stage is not yet final, such as "articles in press"; and (3) articles other than those from the research areas of business, management, economics, operations, and accounting, which were excluded from this study. These exclusions were imposed so that the discussion on circular economy and the use of renewable and sustainable energy can be focused on the business governance aspect, and the study's objectives can identify specific trends in the fields of economics and management. Using these exclusion criteria, 80 articles were acquired from the Web of Science and 247 from Scopus. The two data files were merged, and duplicate data was removed using the R Studio program version 2023.6.0.421. There were 31 duplicate articles removed, resulting in 294 articles subjected to bibliometric analysis regarding their knowledge synthesis, especially the conceptual structure, intellectual structure, and social structure in the discussion of the application of renewable energy within the framework of a circular economy from the perspective of management science and economics. To answer the second research question related to the challenges and implementation of renewable energy in a circular economy context, the author reads each of the previously collected documents manually and utilizes only articles discussing the challenges of implementing renewable energy within the circular economy context. Next, future research questions are answered by combining the results of discussions regarding emerging research topics in response to the first research questions and the insights gained regarding the challenges of renewable energy utilization in a circular economy, discussed after examining the second research question. Figure 1 provides a summary of the steps taken for the bibliometric and systematic literature review.

3. Results and Discussion

Based on the results of the bibliometric processing of 294 articles in Biblioshiny package-R Studio, discussions regarding a renewable and circular economy conducted in the disciplines of management and economics from 2003 to 2023 were identified. Throughout this time frame, the average annual growth of the bibliometric data was 21.36%. The articles utilized are relatively recent, with an average document age of 2.72 years and an average of 21.91 citations per document. The bibliometric article data contains a total of 4739 references.

According to the publication period of the examined articles, the number of articles published each year, and the average number of citations per year, the researcher divided the articles into four main phases, as shown in Figure 2, namely the nascent phase (2003–2016), the growth phase (2017–2018), the plateau phase (2019–2021), and the deceleration phase (2022-June 2023). The division of these four periods is based on the movement pattern regarding the number of articles produced each year, as seen in Figure 2. During the nascent phase, relatively few articles were related to a circular economy and renewable energy. The growth phase showed an increase in article production, while the plateau phase showed stable production, eventually leading to continued growth. However, during the deceleration phase, there was a decrease in the number of articles produced. When analyzing the article's production phase, the authors also consider significant global events, such as the financial crises, sustainability goal agreement, and pandemics. Discussions about energy scarcity such that various stakeholders need to make efforts to utilize renewable energy and participate in a circular economy have been initiated from around 1973, when the world oil crisis erupted [46]. Since 2008, the circular economy has been the subject of a growing number of publications from various research fields [47]; however, the management and economics research field did not exhibit a significant increase in publications in that same year. In the nascent phase, no more than five articles per year have ever been published. This phase began in 2003, one year after the initiation of the cradle-to-cradle's publication [48]. Some examples of industries that were raised as examples of the application of renewable energy with a circular economy framework include companies in Italy and Poland that produced milk by trying to utilize biogas and solar power as energy sources [49], the cement industry in Germany and Italy, which began to utilize thermal energy sourced from biomass [50], and the suggestion of more environmentally friendly electro-plastic production in Sweden by utilizing renewable electricity sources. However, at that time, the obstacle was the high cost of implementing the technology [51]. An article published in 2010 about Abu Dhabi's transition to a carbon-free city received the most citations during this period [52], with an average of 6.93 citations per year. During the development phase, the number of articles produced yearly increased dramatically, from 8 in 2017 to 24 in 2018. The average number of citations per year increased strongly in 2018, reaching 7.71 per year. The enthusiasm of researchers and investors who fund research into the use of renewable energy and the circular economy may be attributable to the ratification of the Paris Agreement [38], the approval of the plan to achieve sustainable purposes launched by the United Nations in 2015 [38], the effects of which were not immediately apparent in the same year, but only began to be noticed in 2017. The research enthusiasm continued in 2019, followed by a fairly stable annual article production in 2020, with 36 and 37 articles per year, respectively. The average total number of citations reached their highest point in 2019, with an increase of 10.09 points, while 2021 was the most productive year in terms of annual article production, with a total of 66 articles published in that year. COVID-19 events began occurring in 2019, but they did not diminish the enthusiasm of researchers interested in renewable energy and the circular economy, even though energy demand from the transport sector and global production decreased due to lockdowns [53]. Renewable energy use is considered one of the mechanisms for COVID-19-affected countries to increase their energy resilience and accelerate their economic recovery [54].

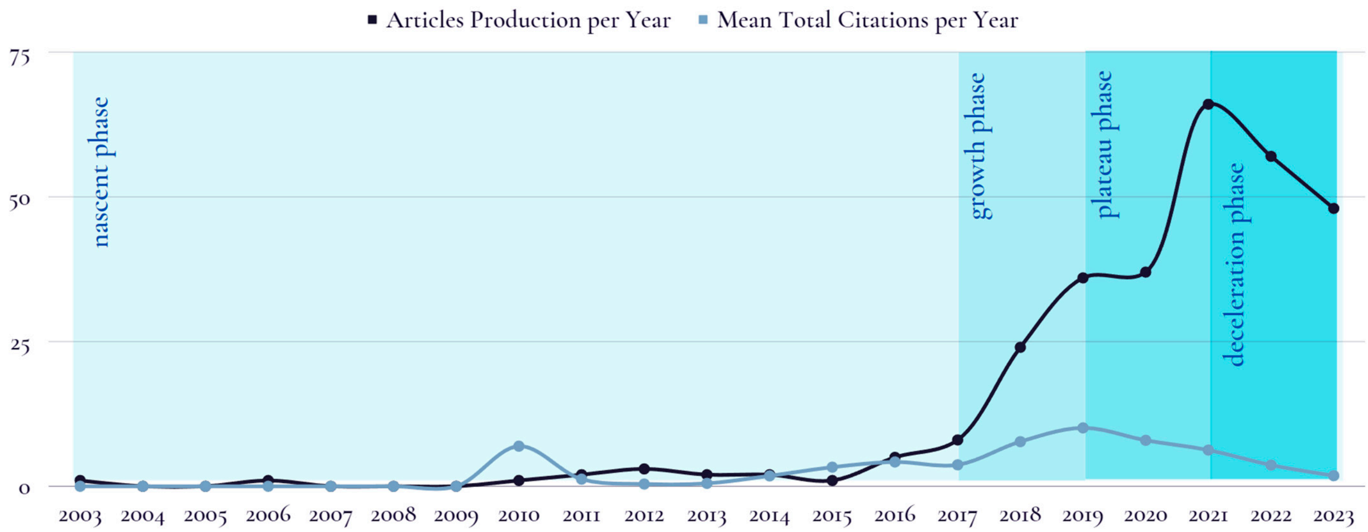

Figure 2. Production of articles and average citations. Source: authors' own compilation.

Regarding the article document type, 9 out of 294 articles were reviews that addressed various aspects of renewable energy, a circular economy, or the intersection between the two themes. The review articles examine the assessment method employed by companies in implementing circular economy practices [1]. Additionally, they explore the management of power generation devices at the end of their lifecycle, focusing on renewable energy sources [55,56]. The articles also delve into the Industry 4.0 technological advancements that facilitate circular economy processes and the intricacies of supply chains within this framework [57–59]. Furthermore, previous reviews analyze the various business models that align with circular economy principles and contribute to achieving sustainable objectives [60]. Table 1 displays the publication years of the review articles, ranging from 2019 to 2023. These studies employ a combination of systematic literature reviews, bibliometric analysis, and other methodologies. The papers using the systematic literature review approach examine a wide range of articles, with 42 as the minimum number of articles analyzed in the review focusing on the end-of-life management of wind turbines, mineral criticality, energy transition, and circular economy [56,61]. The maximum number of articles analyzed in the study regarding the end-of-life management of photovoltaic (PV) systems is 191 [55]. Studies employing bibliometric approaches commonly examined a relatively larger number of articles per document. For instance, the review on research trends in sustainable energy supply chains analyzed 69 articles [62], while the study on anaerobic digestion technology use for bioenergy production following CE examined a substantial 6854 articles [58]. Bibliometric methods are highly effective in rapidly assessing and visualizing bibliometric trends within extensive collections of article data [63]. This bibliometric study distinguishes itself from prior review articles by emphasizing research themes focused on the application of renewable energy within the circular economy framework. Specifically, it examines these topics from the vantage points of business, management, and economics.

Table 1. Previous review articles regarding the theme of RE and CE.

Article Review Code	Review Main Topic	Publication Year	Total Citation	Number of Analyzed Articles	Review Method	Important Findings
[1]	Method development for measuring corporate circular economy performance	2019	297	45	SLR	DfX and Guidelines enhance product design and development, while LCA, MFA, DEA/IeO, MCDM, and DES evaluate all system variables across their lifecycle.
[55]	End-of-life management of PV and BESS	2019	110	191	SLR	The paper categorized the factors affecting PV and BESS EoL management as drivers, barriers, and enablers. For drivers, the factors are economic, social, and environmental; for barriers, they are policy-related, economic, social, market-related, environmental, and recycling infrastructure-related; and for enablers, they are policy-related, economic, social, market-related, behavioral, and recycling technology and infrastructure-related.
[60]	Sharing economy business models in China to promote sustainable growth	2021	6	975	Bibliometric	The main subtopics of sustainable development in the sharing economy cover collaborative and sustainable consumption; climate change and bioeconomy; renewable resources and business models; the circular economy in China; and life cycle assessment.
[57]	Integration of Industry 4.0 and the circular economy for sustainable operations	2022	28	76	SLR	CE practices support SDGs, including clean water and sanitation, accessible and clean energy, industry innovation and infrastructure, ethical production and use, and climate action.
[62]	Research trends in sustainable energy supply chains	2022	2	69	Bibliometric	Circular economy and green supply chain management are significant topics for future research, suggesting that researchers and practitioners should develop more sustainable models.
[56]	End-of life management of wind turbines	2022	2	42	SLR	Studies focused on recycling composite materials, reusing wind turbine blades, exploring circular economy applications, analyzing recycled material properties, and decommissioning operations, but did not fully consider the entire life cycle assessment.
[61]	Mineral criticality, energy transition, and circular economy	2022	4	42	SLR	The availability of critical minerals needed to transition to a renewable energy system is insufficient to fulfill demand and is concentrated in only a few countries, which can disrupt the supply chain and cause geopolitical risk. The concepts of just transition and decarbonization need to be carefully considered.
[58]	Anaerobic digestion technology utilization for bioenergy production in accordance with CE	2022	46	6854	Bibliometric	Anaerobic digestion can be made more effective and sustainable for bioenergy recovery by combining feedstock characterization, pre-treatment, and process modeling.
[59]	Integration of Industry 4.0 technology, product-service systems, and CE	2023	1	126	SLR-Bibliometric	Applying I4.0 technologies in conjunction with PSS can support reverse logistics, save costs, and enable the development of circular products and waste management. I4.0 technologies aim to transform ordinary machines into intelligent, self-learning AI-based machines, enhancing performance and management maintenance.

Previous scholarly publications have examined the end-of-life considerations of wind turbines and solar technologies, which are extensively employed in the move towards renewable energy, to establish a self-sustaining production cycle [55,56]. Prior literature has also examined the evaluation of organizations that adopt a circular economy model, with particular emphasis on the management of renewable energy use as a means to enhance circularity [1]. The integration of technology within Industry 4.0 is widely acknowledged to have the potential to improve the effectiveness and sustainability of renewable energy systems and reduce waste within the circular economy framework [57,59]. Prior literature has examined the limited availability of specific metals essential for power production technologies in the context of renewable energy [61]. Additionally, scholarly works have explored establishing a sustainable supply chain for renewable energy and integrating renewable energy into business models within the circular economy framework [60].

3.1. Conceptual Structure

The conceptual structure summarizes the main topics associated with a specific field [64]. The conceptual structure can be analyzed in various ways, including by looking at co-occurrence networks, thematic maps, and thematic evolution. This conceptual structure aims to identify the proximity of numerous research topics, the research clusters that are in high demand or are underexplored, and the trend of research topics over time.

3.1.1. Co-Occurrence Network

Some topics that appear frequently in the title, abstract, or keywords of multiple studies are deemed to have close co-occurrence. Figure 3 depicts the co-occurrence network of the most frequently used author keywords in the articles analyzed for this study.

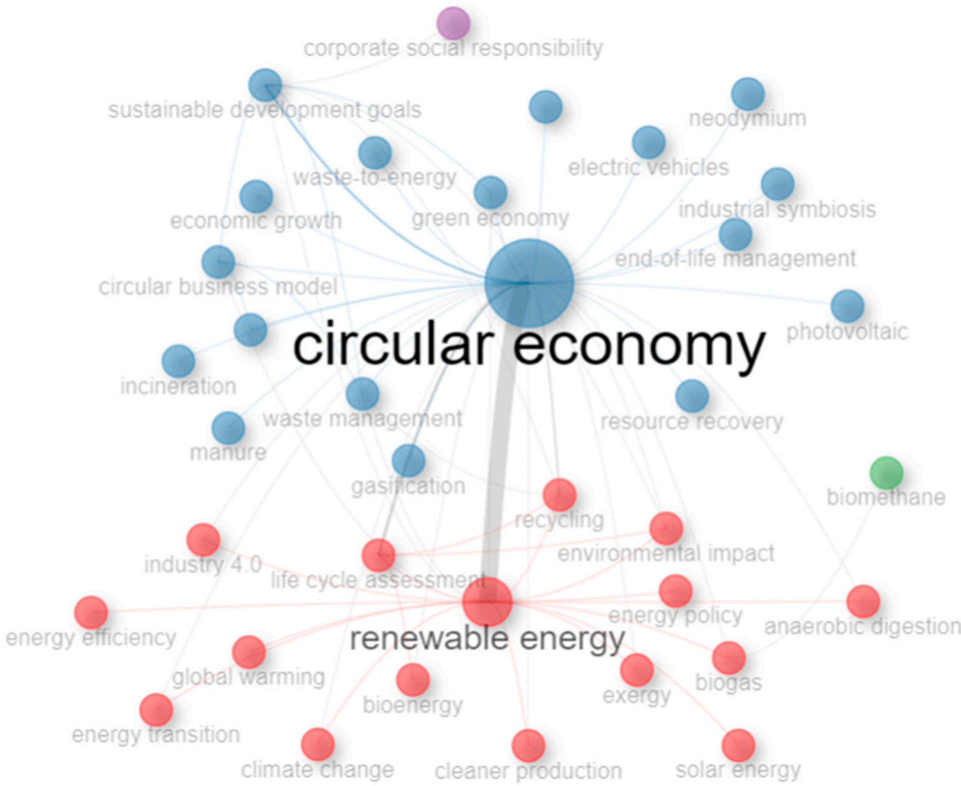

Figure 3. Co-Occurrence network of author's keywords. Source: authors' own compilation.

This co-occurrence network visualization employs an automatic network layout because this layout offers the most convenient graph display, association normalization, and the walktrap clustering algorithm. According to the results of this co-occurrence network visualization, it is determined that there are two main clusters regarding the topic of a circular economy, which are shown in blue clusters; renewable energy, shown with red nodes; and two topics outside the main cluster, namely corporate social responsibility and biomethane. The dense grey line connecting the circular economy and renewable energy topics demonstrates their close relationship. In the blue cluster, a circular economy is frequently juxtaposed with the concept of a green economy [65], concerning efforts to attain sustainable development objectives [57,66] and economic growth [67], circular business models [8,68], and industrial symbiosis [69,70]. Waste management efforts in the production cycle and optimization of waste conversion into energy sources are also discussed in the circular economy cluster, as evidenced by the emergence of topics such as waste management [71–73], end-of-life management [74,75], resource recovery [76,77], waste to energy [78–80], incineration [81], gasification [31,82], and manure [82–84]. In the red cluster, the renewable energy topic has the largest nodes with the highest page rank score in the cluster of 0.158, which indicates the highest prevalence in the articles. The betweenness node value is also the highest at 159.37, indicating that this topic is a link between topics. The topic of life cycle assessment [70,85] holds the second position in terms of page rank value, but its low betweenness centrality indicates that it does not serve as a link between other topics. This cluster also contains the following topics: cleaner production [86–88], exergy [67,89], recycling [90,91], climate change [92,93], global warming [94], environmental impact [95,96], energy efficiency [97,98], energy transition [99,100], industry 4.0 [101], anaerobic digestion [102,103], bioenergy [104,105], biogas [58,104,105], and solar energy [106,107]. Compared to solar energy, wind energy, and hydropower, bioenergy appears the most frequently in the author's keywords in the article database regarding the application of renewable energy in the circular economy framework. Related authors' keywords include biomass, biomethane, bioeconomy, biogas, manure, anaerobic digestion, gasification, and incineration. Utilizing bioenergy is consistent with the circular economy principle, which uses the production and consumption cycle of waste as an energy source for other processes, thereby closing the production loop [108,109]. In addition, the use of bioenergy, biomass, and biobased products adheres to the action plans of EU member states to promote the development of a circular economy [110].

3.1.2. Thematic Map

Thematic map analysis enables authors to visualize dominant topics, assess the proximity of topic relationships, and identify patterns and trends. The topics on the thematic map in this section are derived from the authors' keywords. As depicted in Figure 4, the thematic map consists of four quadrants, each displaying a distinct level of density and centrality of topics.

The basic theme quadrant, a location for research topics with a high centrality level but not significantly high density, displays well-established topics widely discussed in the article dataset. However, the development of topics in this cluster is still inferior to that of the motor themes. This quadrant consists of four major clusters: circular economy, biogas, biomass, and end-of-life management. In this quadrant, the circular economy theme has the largest bubble size, proportional to its high word frequency, along with renewable energy and life cycle assessment in the same cluster. The largest node size not only demonstrates the current concentration of publications on research topics related to circular economy, renewable energy, and life cycle assessment, but also predicts that these topics will continue to attract the attention of many researchers in the future. Life cycle assessment is a quantitative evaluation method that is widely used to assess environmental impacts, such as energy consumption, emissions, and pollution produced by businesses, which implement a circular economy [111,112]. Examples of LCA use in renewable energy business applications include evaluating biogas production, energy use, carbon dioxide generation, the amount of renewable fuel from a biogas facility [95], and the environmental impact of a hydroelectric installation in the United Kingdom [113]. In the biogas cluster, there are keywords associated with cleaner production, which is an effort to increase the efficiency of energy use while reducing harmful emissions [11,114,115], and gasification, which is associated with the process of converting organic matter into biogas [31]. The biomass cluster, as one of the renewable energy sources, is in the same cluster as biomethane, a gas that can be produced from the anaerobic processing of biomass [116,117], and neodymium, an element that is not too closely related to the concept of biomass, but which is the key component in wind power generation technology and electric vehicles [3,118,119]. The end-of-life management cluster reveals a discussion of the waste management of renewable energy processing technologies, such as electric car batteries, solar panels, and wind turbines [55,120]; it is grouped into the same cluster as material flow analysis [71,121] and offshore wind [100,122,123], although these three topics seldom appear in the same article.

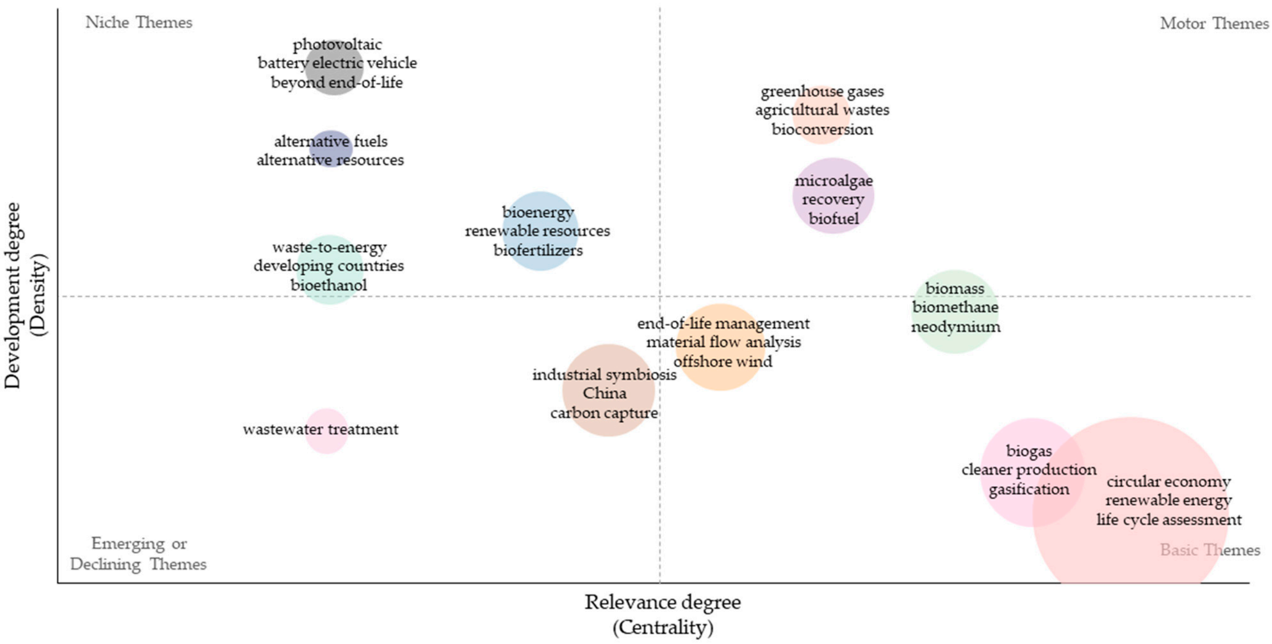

Figure 4. Thematic map. Source: authors' own compilation.

The motor theme quadrant contains concentrations of research topics with high centrality and density, or the research in this quadrant may also focus on a vital and closely related topic. This quadrant contains two major clusters: greenhouse gases and microalgae. In the same cluster, the topic of bioconversion methods can be utilized to process waste from the agriculture industry to reduce greenhouse gas emissions [124]. The recovery or harvesting stages of microalgae, a photosynthetic organism that can produce biomass, also appear alongside the topic of biofuels, which is the conversion of one type of renewable energy source [125]. The utilization of microalgae has the potential to generate biofuel as renewable energy and absorb carbon emissions from many industries that pollute the environment.

The niche quadrant, which is a place for topics with low centrality and high density, or topics which are still relatively rarely researched, but which often appear together in the same article, consists of four main clusters, namely bioenergy, photovoltaics, waste-to-energy, and alternative fuels. In the bioenergy cluster, other emerging topics are renewable resources and biofertilizers. The connection between the three topics has been examined in a single study, namely the conversion of equine manure into fertilizer and energy in a Romanian riding arena [126]. The photovoltaic cluster appears alongside the topic of batteries from electric vehicles and the concept of beyond end-of-life, which is an effort to employ used batteries from electric cars to store solar energy for household or small industrial use, despite their insufficient storage capacity [74]. The waste-to-energy cluster, which is a mechanism for converting production and consumption waste into an energy source, is associated with the search terms "developing countries" and "bioethanol". No research in the dataset combines these three topics, but there is research on bioethanol as a form of renewable energy produced by Brazilian companies from the fermentation of sugarcane residue [127]. Another cluster in this niche quadrant is alternative fuels, which correspond to alternative resources, such as biogas and biomass, and which show lower greenhouse gas emissions than fossil fuels [50,127].

The emerging/declining quadrant is occupied by topics with low values of Callon's centrality and density or that are discussed infrequently in research, and the combination of these topics scarcely appears in the research. Concentrations of wastewater treatment and industrial symbiosis are included in this quadrant. Companies that implement a circular economy and prioritize energy efficiency, such as the garment sector in India and Turkey, coal sites in Poland, and silica manufacturers in Spain, which typically severely contaminate water [128–130], also implement wastewater treatment mechanisms. The industrial symbiosis cluster emerged with the keywords China and carbon capture. Carbon capture technology can reduce carbon emissions that pollute the environment, and the carbon captured from the emissions of various industries can be repurposed as an energy source [122]. China has initiated the application of carbon capture, which necessitates extensive cooperation between the country's industries for the process to become more efficient [69].

3.1.3. Thematic Evolution

In thematic evolution analysis, researchers can examine the dominant topics in each period and analyze how they are related and evolve, predicting potential future research topics [42]. As shown in Figure 5, three time-slices partition the period of development of topics related to the application of renewable energy within the context of the circular economy into four phases, following the previously described fluctuations in annual article production. Renewable energy and fossil fuel were the dominant research topics between 2003 and 2016. The United Arab Emirates, one of the world's largest exporters of fossil fuels, has undertaken initiatives to utilize renewable energy and implement circular economy principles [52]. The implementation of low financial transaction taxes for financing energy transition projects, a globally managed reserve system operating counter to economic cycles; the cessation of fossil fuel consumption subsidies; and the imposition of carbon taxes [131] are regarded as important catalysts for the transition of commercial enterprises from fossil fuels to alternative renewable energy. Other research conducted during this period has taken a pessimistic view of the transition from fossil fuels to cleaner energy, as there are still many companies that are highly dependent on fossil fuels. Therefore, to achieve sustainability, in addition to implementing technical efforts such as increasing energy efficiency and making efforts to capture carbon, it is also necessary to reform various social aspects, for example, by educating consumers about their preferences for consuming ozone-friendly products and implementing climate justice for the world's countries such that countries who are major contributors to greenhouse gas emissions are required to reduce their emissions, and developing countries who only produce a small amount of emissions are given some freedom to increase their productivity, even if the effect is an increase in energy consumption and carbon emissions [132]. During the period of growth from 2017 to 2018, the renewable energy theme substantially contributed to the formation of the circular economy theme, while fossil fuel also transitioned into the circular economy and sustainability topics. This indicates an increase in research focused on holistic economic governance strategies in renewable energy utilization, as well as the efficient utilization of the reprocessing of waste materials involved in the value chain. During this time, climate change also emerged as a new topic.

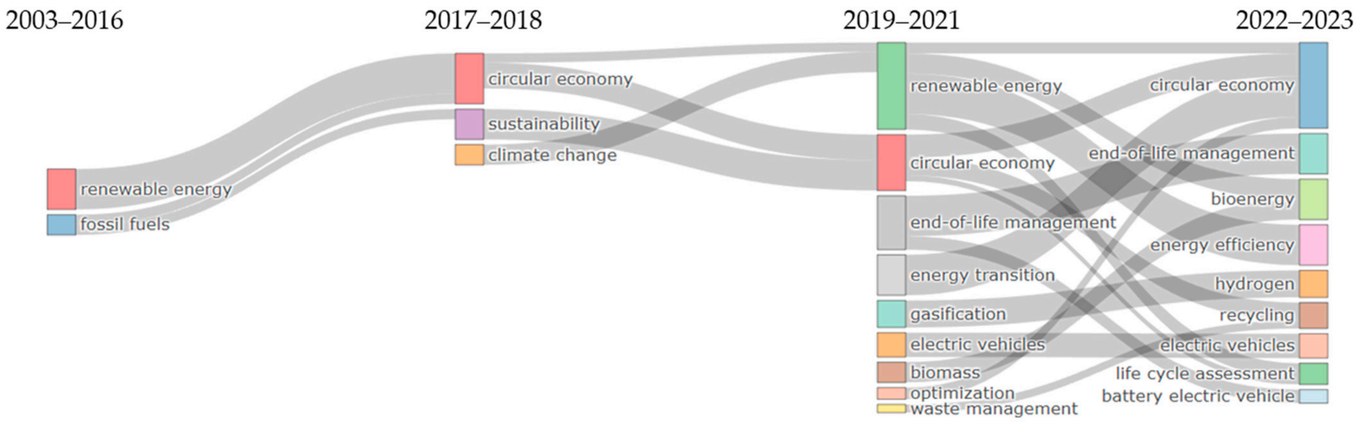

Figure 5. Thematic evolution of renewable energy and circular economy topics. Source: authors' own compilation.

Circular economy and renewable energy remained the primary research topics for 2019–2021. New research topics emerging in this plateau period included end-of-life management, energy transition, gasification, electric vehicles, biomass, optimization, and waste management. Discussions on end-of-life management revolved around the recycling of building materials so that they are not wasted at the end of their life cycle, which is estimated to be achieved with the concepts of material passport [105], wind turbine recycling [108], and photovoltaics [55]. Due to the ratification of the Paris Agreement and the European Green Deal [99,133], the energy transition in the context of a circular economy has become the focus of the world's nations, particularly those in Europe. In this period, the gasification process was used in a variety of contexts to support the use of renewable energy and to promote a circular economy approach, including the conversion of digested waste to produce electricity and nutrient-rich substances [31], biomass conversion in micro-trigeneration models [103], solar energy-based systems that produce a variety of useful products such as hydrogen and biogas [87], and the conversion of waste into energy by increasing the efficiency of electricity generation [78]. Electric vehicles are viewed were a more environmentally friendly alternative to conventional vehicles powered by fossil fuels. However, researchers during this period reported that the business models of electric vehicle manufacturers needed to be carefully considered [134], and the circularity must be increased in the production, use, and recycling of electric vehicle batteries [17,135]. Increased demand for electric vehicles could increase the demand for cobalt and potentially lead to irresponsible or unsustainable mining, especially for electric vehicle-producing countries such as China [136]. Therefore, increasing the reliance on electric vehicles must be balanced with solid resource management and recycling strategies. Research related to the topic of biomass throughout this period discussed wood waste as a biomass feedstock [105], the potential of biomass as a renewable energy source, and materials for carbon capture mechanisms [137], but the processing of biomass also needs to be considered for its impact on the environment, and water and waste from processing must be treated properly. Optimization plays a significant role in renewable energy and a circular economy by facilitating the assessment and improvement of the efficiency of urban agricultural systems, the determination of the optimal time to upgrade renewable energy system components, and the implementation of systematic approaches for the efficient transformation and reuse of waste [70,138,139]. Waste management is an important part of the circular economy framework, but waste management methods alone, such as those applied by the textile industry in Brazil, are considered to be short-term solutions to environmental problems. To support the circular economy, waste management must be combined with balanced resource utilization and renewable energy systems [71,94,98,140].

In 2022–2023, the topic of a circular economy was still the dominant research topic, which is the result of the development of the topic of renewable energy, energy transition, optimization, and the continuation of the circular economy itself. In this period, some discussions on the circular economy were integrated with Industry 4.0 technologies, such as the Internet of things, big data, or artificial intelligence, to optimize energy use and implement industrial integration [57,141,142]. The topic of end-of-life management continued to be discussed in this period, specifically the recycling of rare elements and lithium in electric vehicle components [143], the recycling and remanufacturing of wind turbines whose economic value has ended [56], and the processing of livestock waste to produce biogas [74]. The topic of biomass in the previous period shifted to bioenergy, which shows a shift in focus from identifying biomass sources to using biomass as an energy source. An interesting finding in the research regarding energy efficiency in this period is that there is an energy leakage phenomenon in the European Union countries, which are very concerned about the transition to renewable energy. High-income countries have managed to improve the energy efficiency of their domestic production; however, turns out that there was a practice in these countries of importing products from developing countries; thus, the global carbon footprint generated remains the same, or is even higher because there is a process that includes transporting products between countries [97]. In this period, the topic of hydrogen as an energy source became an extension of the topic of gasification. Hydrogen can be produced from biomass waste using photo-reforming processes [144,145]. The topic of recycling has also been discussed several times in the recent period, with the focus on various objects, including electronic and photovoltaic waste [146], wind turbines for power generation [56], and neodymium as an important component in power generation and electric vehicles [121]. Electronics manufacturers, especially those involved in renewable energy production, must be made aware of the need to manage e-waste in an integrated recycling manner to reduce the cumulative negative impact on the environment. Life cycle assessment research, which emerged in several studies during this period, discussed how the LCA methodology could help optimize emission reduction practices and sustainable resource use [147–150]. In these studies, sustainable technology innovation, efficient resource use, emphasis on recycling, and renewable energy alternatives became the main focus of LCA. The emerging topic of electric vehicle batteries involves a discussion regarding the reuse of vehicle batteries that have reached the end of their economic life to be used as an effective medium for storing renewable energy, improving the sustainability of energy systems and electric vehicles and optimizing the electricity grid [74].

3.2. Intellectual Structure

Intellectual structure analysis enables researchers to visualize the relationships and patterns between various elements in a field of knowledge, which are depicted in this section as co-citation networks (Figure 6) for influential papers focused on using renewable energy within a circular economy framework. A co-citation network is a form of graphical representation that illustrates the extent to which other documents cite scientific documents together. Nodes in the cluster consist of reference papers cited by other papers in the dataset, and connections in the network indicate that the papers have been cited in the same paper. Co-citation networks can identify citation patterns, uncover relationships between papers, and explain the evolution and structure of a field of knowledge.

The co-citation network is made up of two major clusters, one with blue nodes and the other with red nodes, which are smaller than the former cluster. The blue cluster is closely associated with the concept of a circular economy and critical sustainability parameters, such as challenges and opportunities, as well as its connection to business practices and policies. The dominant papers in the blue cluster include papers by Geissdoerfer, M., 2017 [151], Korhonen, J., 2018 [152], Ghisellini, P., 2016 [4], and Kirchherr, J., 2017 [153]. This cluster's papers exhibit greater betweenness and PageRank values than does the red cluster. The levels of closeness also vary, with Korhonen, J., 2018 having the closest relationship to the other authors in this cluster. The nodes of Geissdoerfer, M., 2017, Korhonen, J., 2018, and Ghisellini, P., 2016 exhibit the highest betweenness and PageRank, indicating that they significantly impact this network and are frequently cited alongside one another in other documents within the dataset. In general, the four primary papers are review articles that discuss different definitions of the circular economy as a potential framework for addressing production and consumption issues and achieving sustainability goals. They also acknowledge that using renewable energy is a key enabler for achieving circular economy goals [4,151–153].

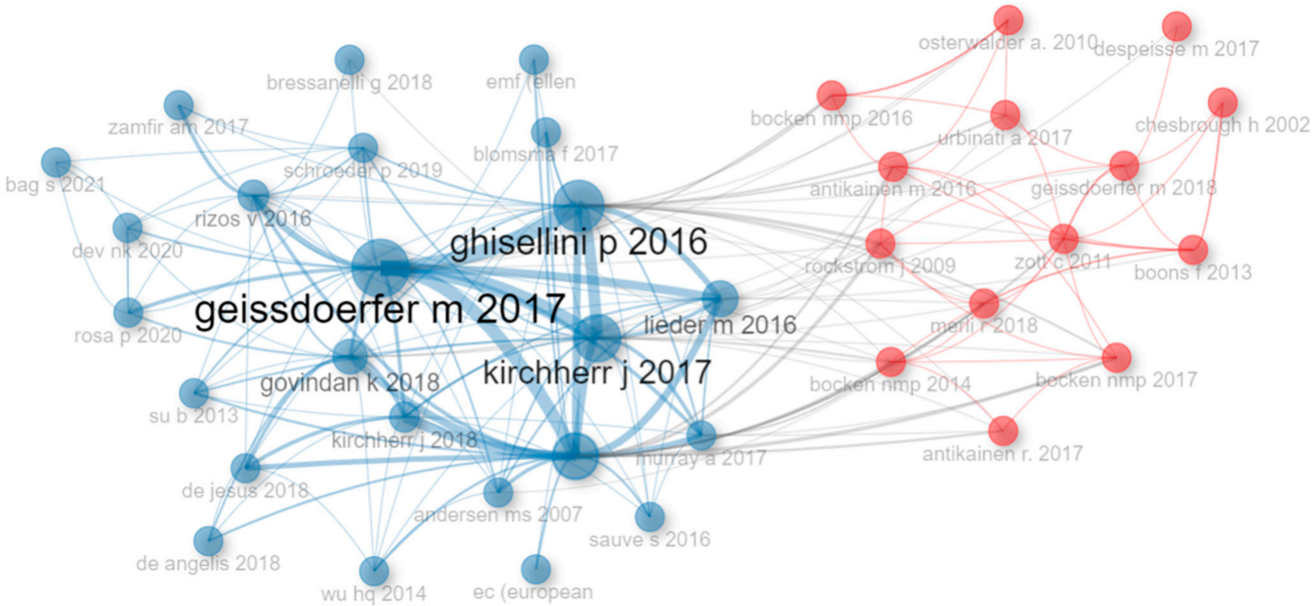

Figure 6. Papers co-citation network. Source: authors' own compilation.

The red cluster consists of several papers in the same cluster, with relatively equal node sizes, but this cluster is smaller than that comprising the dominant papers in the blue cluster. Some papers with the highest PageRank value in this cluster are those by Zott, C., 2011 [154], which discusses the conceptualization of business models to create value in the company; and by Geissdoerfer, M., 2018 [155], and Boons, F., 2013 [156], which are both literature review papers using the cross-reference snowball method to compare different business model innovations. Another popular paper is one by Rockstrom, J., 2009 [157], which discusses some of the earth's limits that must be considered by different stakeholders to maintain its sustainability. It can be concluded that none of the dominant papers in the red cluster explicitly discuss the circular economy or renewable energy as their main topics, but rather discuss business models, which means that papers in the dataset that discuss the application of renewable energy in the context of a circular economy also require business model innovation and natural constraints to support the arguments in their research and achieve a sustainable competitive advantage.

3.3. Social Structure

Social structure analysis allows authors to examine the interactions and relationships between researchers as they collaborate to produce published articles and the way in which these collaborations contribute to knowledge production. This section discusses the social structure network between authors, as shown in Figure 7, consisting of eleven author network clusters. The brown cluster, consisting of Cucchiella, F., D'Adamo, Gastaldi, M., and Miliacca, M., is the most prominent network with the largest node size. Cucchiella, F., and D'Adamo lead this cluster in regards to the number of articles they have published and are often the first authors of collaborative papers. This cluster focuses on the study of renewable energy, in particular biomethane, and its impact on economic sustainability and carbon emission reduction [116,117,158,159]. The red cluster is another dominant cluster, including authors Ulgiati, S., Geng, Y., Chen, W., Ghisellini, P., and Chen, Y., Liu, G. Ulgiati, S., an author affiliated with institutions in Italy and China, seems to play a central role in linking the authors, while Ghisellini, P., is often listed as the first author of the resulting articles. This red cluster emphasizes circular economy, energy transition, and environmental impact mitigation strategies in their research [4,49,160–163]. More specifically, their research contexts are related to the impact of the conflict between Russia and Ukraine regarding the availability of natural gas and energy transition efforts in Europe [160], the environmental performance assessment of milk production in a Italian and Polish farms, with a focus on the implementation of renewable energy, such as biogas and solar power [49]; the analysis of the implementation of cleaner production in China's construction sector, particularly the management of construction and demolition waste [161]; and the energy analysis to improve environmental performance, water use efficiency, and renewable energy use in a river in China [163]. Subsequently, there is another prominent cluster of authors, including Dai, W., Goh, H., Goh, K., Kurniawan, T., Liang, X., and Liu, H., who have collaborated to publish articles on waste-to-energy conversion using innovative technologies, resource recovery, and contributions to China's sustainable development goals [77,86]. The blue cluster consists of Sutherland, J., Maani, T., Mathur, N., Singh, S., and Li, Z., with Sutherland, J., as the central author exhibiting the most connections, who functions as a mediator between the other authors. The primary themes of author collaboration in the blue cluster include the circular economy theme, which considers critical material fluxes and the steps required to implement recycling strategies in order to minimize supply chain risks and maximize the value of end-of-life products [112,121,143]. Other clusters include authors with relatively similar node sizes, such as Feiz, R., and Metson, G. [84,164]; Singh, R., and Obrecht, M. [74]; Martins, A., and Mata, T. [85,148]; Ponce, K., Ponce, P., and Khan, S. [73,141]; Dinu, V., Istudor, N., and Nitescu, D.; and Li, L., and Li, X. [138]. These data demonstrate how collaboration between authors and the distribution of their scientific expertise in the application of renewable energy within the context of the circular economy influences their relative position within the author collaboration network.

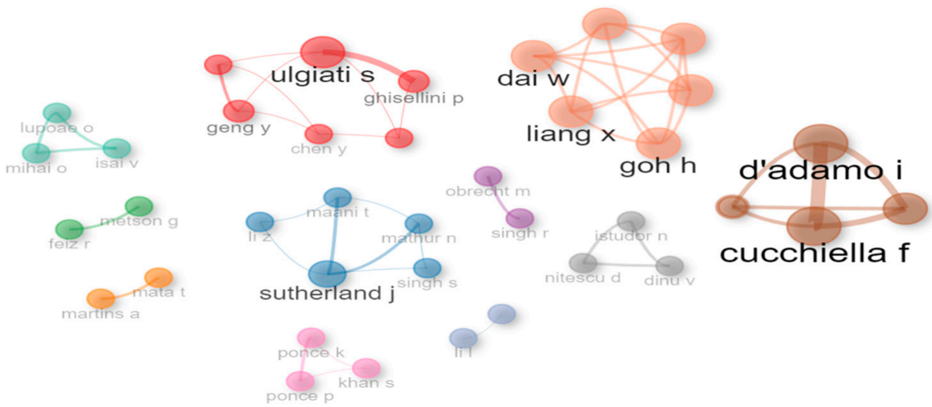

Figure 7. Author collaboration network. Source: authors' own compilation.

3.4. Challenges to Implementing a Circular Economy That Utilizes Renewable Energy

Many developed countries have adopted photovoltaic, wind, hydro, biomass, and ocean current energy as forms of renewable energy technology [98]. However, there are still many limitations and barriers to using renewable energy that are slowing down the transition from fossil fuel to cleaner energy and are difficult to apply globally. The following are the challenges that hinder the implementation of renewable energy in the context of a circular economy:

3.4.1. High Investment Costs for Renewable Energy Generation Technologies

The relatively high investment cost is a significant barrier to the widespread adoption of renewable energy technologies [38,141,165–168]. Initiators of renewable energy projects are also concerned about future thin project return margins and difficulties gaining access to funding [169]. Especially in the case of solar panels, the high initial investment can be a significant barrier to their implementation [98,161]. In other instances, converting cow manure into a biogas energy source has proven to be expensive, as it requires a large amount of pure sand, a large amount of space, and produces high ammonia emissions, so the process is not cost-effective [84,170]. The perception of high costs associated with the development and implementation of renewable energy technologies may deter decision makers, particularly those in the private sector, from investing in such initiatives [7,134,171]. On the other hand, profitability, which is still seen as the main motivation for companies to support the energy transition, can accelerate the implementation of the energy transition, but it also has many negative consequences. For example, in the case of electric vehicle sales in developed countries, it encourages over-consumption and ignores the larger sustainability goal of using vehicles with environmentally friendly fuels, which of course, only enriches a handful of elites. There is colonial injustice inherent in vehicle production in terms of exploiting non-renewable raw materials and certain metals from low-income countries possessing natural resources [20].

To address the financial obstacles pertinent stakeholders face in adopting renewable energy inside their enterprises, the author proposes that the government might offer subsidies, reduced tax rates for businesses, and provide financial support for green energy initiatives [172]. Funding for renewable energy initiatives can be derived from governmental sources and alternative means, such as crowdsourcing and collaborations with private enterprises that share a vested interest in addressing renewable energy concerns [173]. Furthermore, it is imperative for the government to allocate resources to research endeavors focused on power production technology that effectively harnesses renewable energy sources while being economically viable and capable of widespread implementation [174].

3.4.2. Inadequate Regulatory Framework, Policies, and Government Support

The deficiency of a defined regulatory framework and government policy support is also a barrier to applying renewable energy within the context of a circular economy, particularly in developing nations [7,55,134,141,165,166]. The implementation of the circular economy requires agreement, understanding, coordination, and joint cooperation between stakeholders such as producers, suppliers, consumers, and the government to achieve environmental sustainability [50,127,164,175–177]. It is not easy for the actors in this network to cooperate; thus, regulations need to be put in place, and the government needs to support the creation of this ecosystem. Some developed nations, including Germany, Spain, Taiwan, the United Kingdom, and Australia, have implemented financial incentives, such as feed-in tariffs, to increase the attractiveness of energy transition initiatives [101,178]. ASEAN member countries, which aim to generate a quarter of their energy needs from renewable sources by 2030, have initiated cooperation between countries to transfer knowledge, share technology research, and use renewable resources [179]. Integration of a country's various levels of government is necessary, particularly in authorizing the construction of power generation facilities that utilize renewable energy, as differing procedures at different levels of government will impede the realization of energy transition [99]. As was the case in India, flawed government regulations that support renewable energy projects while ignoring regulations regarding the disposal of all renewable energy-generating equipment, must also be considered [94,101]. To effectively tackle this problem, policymakers need to adopt a cohesive strategy at both the central and local government tiers, particularly concerning the bureaucratic processes involved in obtaining construction or project licenses for renewable energy facilities. This will ensure that business individuals or project initiators are not faced with unnecessary confusion. The legislation must also consider the complete life cycle of renewable energy applications inside firms operating under a circular economy framework, encompassing equipment management at the end of its useful life [55,71,123].

3.4.3. Discontinuity in the Availability of Renewable Energy Sources

Non-dispatchability, or the inability to assure the continuous availability of electrical power, is one of the obstacles to the implementation of renewable energy [99]. This is due to wind speed, which varies, and solar radiation, which changes according to the weather and season [98]. Therefore, to overcome this, energy storage technology that stores energy when the supply is abundant, as well as technology-based forecasting of energy supply and demand, are required [55,99,107,122,180]. Supply uncertainty also occurs in power plants that utilize hydropower, especially during the dry season when the water supply drops, as well as those that utilize ocean currents. The use of biofuels as renewable energy is also hampered by the input materials used, such as livestock waste, agricultural waste, or sludge, as a growing medium for microalgae, which, if polluted or of poor quality, will reduce the efficiency of energy generation or even increase toxic emissions [181]. Government support to address the challenge of non-dispatchability in renewable energy sources can be achieved by promoting investments in energy storage technologies, which can serve as a reliable backup during periods of low energy supply [182,183]. Using AI technology holds the potential for accurately forecasting energy supply and demand [184]. To harness this potential effectively, the government must establish a comprehensive program to facilitate data sharing and promote collaboration among energy suppliers, enterprises, and data scientists. Such a program should encompass both national and international levels of engagement.

3.4.4. Scarcity of Resources and Components of Renewable Energy Generation Technologies

Resources such as raw materials for solar panel manufacturing, especially silicon and cobalt, may face availability issues and significant environmental impacts in the long run [98,167]. PV technology, which has been touted as a solution for companies to reduce their carbon emissions, also exhibits production problems, as this solar panel technology depends on silicon, cadmium, or copper materials, whose prices are currently rising due to low supply but high demand, causing difficulties for the largest solar panel producers, such as those located in China [185]. As a crucial device related to the energy transition, lithium-ion batteries require contested components such as lithium, cobalt, and nickel from competing manufacturers around the globe [134]. If magnet-forming materials are difficult to procure, the production of wind energy turbines could also be hampered [3]. Innovation and careful planning are required to address this issue, beginning with the search for alternative materials; proper end-of-life management, reuse, and recycling; and extending the optimization of the mining process for these materials to make them more environmentally friendly [71,74,121,123]. To reduce its reliance on the availability of nonrenewable resources, the government may fund research to develop more sustainable alternatives to unrenewable materials. There is a pressing need to establish policies regarding the recycling and reusing of critical metals essential for renewable energy power plants. Additionally, regulators should consider implementing incentives to encourage those parties capable of engaging in such practices.

3.4.5. Relatively Low Energy Conversion Efficiency

In terms of energy conversion efficacy, current renewable energy technologies have limitations, particularly solar panel technology and wind power generation [98]. Solar technology has a relatively low energy conversion efficiency, which reaches an average of one-quarter at best, due to the process's sensitivity to weather, dust levels, atmospheric humidity, and temperature [186,187]. Wind turbines have only a slightly higher energy efficiency than solar panels, and improvements to the turbine control system and converters are required to increase their energy efficiency [188–190]. To fully utilize renewable energy, it is essential to manage storage, transmission, energy consumption, and energy efficiency in a comprehensive manner. It is necessary to establish policies that incentivize academics affiliated with private research institutes, universities, and enterprises to actively pursue technological advancements to enhance energy conversion efficiency. Furthermore, the government can offer tax incentives to corporations or establishments that adopt energy-efficient measures [191,192].

3.4.6. Consumer Awareness and Behavioral Change

Aside from the production side, another challenge comes in the form of changing the behavior of people, consumers, and organizations to adopt circular economy principles [193]. This involves adopting sustainable consumption patterns, reducing waste, and understanding the significance of utilizing renewable energy [7]. Changes in consumer preferences are anticipated to motivate producers to engage in sustainable production, including using renewable energy [161]. A considerable number of developing nations rely heavily on fossil fuels because most consumers' devices are incompatible with renewable energy sources [94,168]. Manufacturers can play an active role in shaping consumer behavior by designing business models that support circularity in their value chain, such as converting ownership of electronic products with renewable energy sources to a rental system in order to make the price more affordable for consumers and encourage them to convert to renewable energy [55,59,134,177,193]. There is a need for education, effective communication, and dialogue with the general public in order to increase their awareness and understanding of energy transition issues [57,175]. The government must establish regulations requiring producers to use renewable energy up to a particular point and regulate how their residual goods are handled at the end of their useful lives. To encourage consumers to buy environmentally friendly items, the government can offer incentives in the form of tax cuts or subsidies [194].

3.4.7. End of Life Cycle of Renewable Energy Power Generation Technologies

At the end of the life cycle, the use of solar panels also causes serious environmental problems because the batteries used to store energy in photovoltaic technology contain materials and chemicals, such as lead, lithium, tin, and cadmium, that are harmful to human health and the environment [55,106]. PV waste is expected to be less of a global problem for the next few years due to its small-scale use. However, it is expected to become a significant problem by 2050, when approximately 200,000 kilo tonnes of PV waste will be produced [55]. Governments and companies need to anticipate this waste, for example, by leasing solar panels so that at the end of their lives, the waste can be taken back by the manufacturer and recycled, or by implementing a solar panel waste buy-back program. The success of the e-waste treatment strategy is highly dependent on the consumers' initiative and cooperation to return their refuse at the end of its useful life or pay a deposit at the beginning of the usage cycle, following the company's established mechanism [55]. To incentivize corporate entities to manage their product waste effectively, it is imperative to enact policies regarding extended producer responsibility [185]. These policies necessitate that firms assume complete accountability for the entire lifecycle of their products, particularly encompassing the end-of-life management phase.

3.4.8. Future Research Direction

From the analysis of the structure of knowledge synthesis, especially in thematic map analysis, the topics of renewable energy, circular economy, and life cycle assessment will continue to receive attention from researchers. The discussion regarding the transitioning to renewable energy in the circular economy is shown to be stable through the analysis of thematic map evolution from the growth phase to the end of the analysis period. Subtopics in the niche and emerging quadrants have the potential to be further developed and researched in the future, especially those regarding the development and improvement of solar panel efficiency, photovoltaic panel life cycle assessment, the end-of-life management of solar panel devices, and the integration of photovoltaic systems in building architecture, as well as electricity grid systems. Future research in the field of renewable energy is recommended to concentrate on the development of sustainable alternative fuels, the optimization of waste-to-energy conversion through waste-to-energy schemes, and the improvement of bioenergy conversion efficiency from organic waste, all while considering environmental and social impacts and integration in the current energy system. To accelerate the energy transition process and achieve sustainability goals, businesses need to engage in industrial symbiosis, and more research is needed regarding business model innovation and the most optimal business integration framework. The evolution of thematic maps reveals a specific focus among researchers on electric vehicles, particularly regarding the management of batteries that have reached the end of their economic life. As the global community increasingly adopts electric cars, poor management of battery waste could lead to various new environmental issues.

Related to the challenges of implementing renewable energy in the context of a circular economy, as noted in the articles in the dataset, the researchers suggest future research to formulate financial models, business models, and financial incentive policies that can encourage investors and businesses to conduct business in a manner that utilizes renewable energy. More research on the roles and strategies of various stakeholders in implementing the circular economy concept, including government, industry, consumers, and civil society, is required, especially in the context of developing countries, southern countries, or low-income countries that still do not significantly utilize renewable energy. As certain resources and components for renewable energy production are scarce and environmentally damaging, future research should focus on alternative materials and sustainable mining practices. Research should also focus on managing, recovering, and recycling these resources at the end-of-life as part of a circular economy approach. To improve energy conversion efficiency, there is a need for extensive technical and specific research. Additionally, promoting the use of renewable energy and circularity requires effective education and communication strategies to raise awareness about the shift towards sustainable energy and to encourage changes in consumer behavior and attitudes. In regards to future research, it is important to focus on end-of-life management to anticipate the environmental impact of the energy transition process.

4. Conclusions

This bibliometric study provides a holistic view of the synergy between renewable energy and the circular economy within the disciplines of management and economics. It highlights key phases in the accumulation of knowledge. There are two main findings from this systematic literature review:

1. Our first findings relate to the structure of knowledge synthesis in studies associated with applying renewable energy in the circular economy context. As environmental consciousness developed, the emphasis turned from renewable energy to effective waste and resource management and green technology in a circular economy. Co-occurrence network analysis showed the circular economy and renewable energy as recurring themes, with authors like Geissdoerfer, M., Korhonen, J., Ghisellini, P., and Kirchherr, J. discussing sustainability, and Zott, C., Boons, F., and Rockstrom, J. discussing business model innovation and the earth's sustainability constraints. A co-citation network emphasizes sustainability and business model innovation.
2. Our second finding relates to the barriers and challenges of integrating the renewable energy process into the circular economy, which includes financial constraints, such as a high initial investment, the lack of an adequate regulatory framework and government support, and the inconsistent availability of renewable energy sources. Other obstacles include the scarcity of resources and components for renewable energy generation technologies, relatively low energy conversion efficiency, and a variety of other issues.

Future Research opportunities include financial models for renewable energy, circular economy approaches, and developing efficient solar panels and energy storage, along with exploring alternative fuel technologies and improving waste-to-energy conversion. Our recommendations for policymakers, based on the main barriers, are as follows:

1. Offer financial incentives (tax breaks, subsidies) to energy suppliers, producers, and consumers to increase the use of renewable energy.
2. Create a comprehensive regulatory framework to support regional, national, and international renewable energy initiatives.

3. Invest in research focusing on renewable energy storage technologies and environmentally friendly alternative components for electric power and encourage collaboration between researchers and commercial companies.

This study possesses certain limitations, as it only focuses on business, management, and economics. While this concentration significantly contributes to research knowledge in these fields, it may limit its relevance outside of these areas. To gain a more comprehensive understanding of renewable energy implementation within a circular economy framework, future multidisciplinary studies involving various other fields will be necessary. Additionally, the results of this bibliometric analysis are limited to data from two reputable databases. While these databases exhibit extensive and high-quality literature coverage, excluding other databases, as well as gray literature, may limit the analytical perspective. Therefore, future research should explore this topic using additional databases and gray literature to expand and deepen its scope.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151713165/s1, Supplementary Bibliometric Data.

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