

Article

Bioeconomy and Livestock Production Nexus: A Bibliometric Network Analysis

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Abstract: Over the last couple of decades, the livestock production systems of the agri-food sector increase meat production in order to meet the demand and adapt to satisfy the food preferences of the continuously increasing world population. This fact, along with the promotion of sustainable production, has brought to light the topic of bioeconomy. The rapid increase in publications on the research area of bioeconomy has become the motivation for this study in order to analyze its relation with livestock production. This study provides a thorough review of the scientific literature on the bioeconomy of livestock production. The bibliometric network analysis (i.e., software VOSviewer) were performed over the time frame of 2004–2021. The results identified 624 documents bioeconomy of livestock production by 160 research organizations from 83 countries. This paper visualizes the strongest links about livestock production bioeconomy, main research topics, most influential countries, authors, and organizations, as well as high-frequency keywords. Therefore, this study contributes to building global bioeconomy policies and encouraging the livestock sector to implement bioeconomy practices. The research gap identified in many countries should be the trigger for future research in this subject.

Keywords: bioeconomy; livestock production; bibliometric analysis; VOSviewer; literature review



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1. Introduction

The world's population is expected to exceed 9.7 billion by 2050 and 11.2 billion by 2100 [1]. This increase in population, combined with the emergence of the COVID-19 disease, has led to a worsening of global food insecurity [2]. There are three big challenges that humanity is facing today in relation to the future of our planet: (a) reducing dependence on fossil fuels, (b) mitigating the effects of climate change, and (c) achieving a sustainable, adequate, and safe food chain [3]. To overcome these challenges, bioeconomy has to play a key role in the reconciliation of the environmental and social difficulties and the enhancement of the economic development within the primary and secondary production sectors [4]. Policy stakeholders and the scientific community are turning their interest toward the bioeconomy as it seems to be the solution to all current concerning issues [5]. Globally, governments are increasingly focusing on developing national and international bioeconomies to meet the ever-increasing social, environmental, and economic challenges [6].

Bioeconomy has become an important area of interest in the European Union (EU) with a policy framework of multiple strategies, incentives, and regulations [7]. In the context of all these challenges, an important step was taken in 2015 when the United

Nations launched the 17 Sustainable Development Goals (SDGs), which focus on several subjects and targets while becoming drivers for governmental actions toward a better future [8]. The European Union with the Fifth Research and Innovation Framework Programme (1998–2002) provided the foundation of the term Knowledge-Based Bio-Economy (KBBE). While a few years later, before the launch of the Seventh Framework Programme (2007–2013), the KBBE concept emerged. All these encourage the EU to launch a strategy on bioeconomy in 2012 [9]. The goal was to obtain a bioeconomy that could achieve sustainable production, processing and storage, the utilization of biological resources, and recycling while mitigating environmental problems, climate change, dependency on fossil resources, and the increased needs of the growing population [5]. Bioeconomy requires interactions between several different policy domains. Muscat et al. [10] assessed interactions between bioeconomy and agro-food policies by studying potential coherence between bioeconomy and agro-food goals. They found that the policy goals of bioeconomy and agro-food are consistent and synergies outweigh conflicts. However, there are some trade-offs concerning waste and biobased industry [10].

The strategy of the EU emphasizes the concept of bioeconomy; therefore, it is important to note what this concept really means. In recent years, there have been various definitions of bioeconomy in publications, papers, and books [11]. According to the European Commission report [12], “the bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy”. Bioeconomy is based on the use of research and innovation in the biological sciences to create economic activity and benefits for society [13]. In a similar context to the green economy or the circular economy, a key feature is that byproducts return to the value chain and are integrated into the production of higher value goods and services [14]. According to OECD [15], “a bioeconomy can be thought of as a world where biotechnology contributes to a significant share of economic output. The emerging bioeconomy is likely to involve three elements: the use of advanced knowledge of genes and complex cell processes to develop new processes and products, the use of renewable biomass and efficient bioprocesses to support sustainable production, and the integration of biotechnology knowledge and applications across sectors.” Raw materials, such as fossil carbons, metals, minerals, and biomass, are produced into utilized products and enter the waste hierarchy by sharing, reusing, redistributing, and recycling [16].

The analysis of the concept of bioeconomy has many common perspectives, which are summarized in a common conceptual framework by Maciejczak [17]. This framework analyzes bioeconomy as the system in which primary resources are renewable resources and secondary resources are waste. These are transformed into products, processes, and services for the private and public sectors through knowledge, innovation, and technology applications. Development is ensured by scientific efforts, which meet public and private needs. The processes carried out in this system are ruled by regulations and policies [17]. A sustainable economy, bioeconomy, is a system that both strengthens the economy and industry and protects the planet. It includes the transition to biologically based alternatives and the utilization of bioscience and biotechnology while maintaining our natural resources [17]. Bioeconomy is not just a material sector, but it concerns industrial value creation based on biological resources and waste [18]. Through a report, FAO [19] gives five ways to transition to bioeconomy which are the reduction of food loss and waste, the decreasing of plastic pollution, the increasing of biodiversity, the promotion of biobased products as alternative fertilizer or pesticide, and the restoring of degraded lands and improving livestock management. Bioeconomy and circular economy are two concepts that are linked and can work complementary to each other. The circular economy is an economy with a high degree of recycling and reduction of materials and products while minimizing waste and maintaining the value of resources, products, and materials [20].

Bioeconomy is mostly related with the primary production sectors; livestock production is one of them, although research issues are not as common as with the other

primary sectors (e.g., plant production and food sector). Focusing on the agri-food sector, agriculture uses the largest amounts of fresh water of the global water absorption, as well as energy to produce and supply food [21].

Bioeconomy improves and expands the role of agriculture and forest while protecting ecosystems. As proposed by goal 15 of the SDGs, “Life on Land”, forests should be kept intact and healthy in a global concern. There are indicators allowing the comparison of the different regions of origin without taking into account the forest management system [22]. In the study of Egenolf et al. [22], the Timber Footprint indicator is used for quantification of the roundwood equivalents and assessing the sustainability of bioeconomy. Water and energy footprints, as environmental indicators, are critical to agricultural sustainability [23]. Intensified global food production contributes to greenhouse gas emissions and utilizes large amounts of natural resources and contributes to the loss of biodiversity, given the fact that it is based on monocultures and aims for high yields [24].

In addition, the demand for food is increasing, while the resources available for food production are decreasing. By 2050, food production should increase by 60% (compared to 2005/2007 numbers), in order to meet the demand of the growing world population [25]. Livestock production is reported to produce 58 million tons of protein for human consumption annually [26]. Animal-source food demand is continuously increasing and will put much pressure on agricultural resources [10]. Developing countries show an increased demand for livestock products. This growth’s result is the production of manure in huge amounts. On the one hand, manure provides valuable nutrients to the soil; on the other hand, it could bring negative impacts to the environment [27].

Livestock production should help the revitalization of rural areas, the increase in employment, the preservation of biodiversity and landscapes, and the protection of cultural heritage. Each country has to promote the application of new technologies and processes in crop and livestock production [28]. Peyaud and Macleod [29] conclude that livestock is necessary as it contributes to the goals of sustainable development, while animals are recyclers by nature.

While livestock production contributes to these aspects, there are undoubtedly many sustainable ways to mitigate its negative effects, including the use of agro-ecological approaches, adoption of principles of organic farming, modern technology, and increased circularity [30]. The aim of bioeconomy practices for agriculture includes: (a) minimizing the use of primary natural resources (such as water and energy) throughout cultivation and animal production, (b) minimizing polluting activities and unsustainable practices (such as the use of synthetic fertilizers and unsustainable use of chemicals), and (c) recycling, transformation, and reuse of agricultural waste for the production of bioenergy, nutrients, and biofertilizers [21]. The goal of the European policies on sustainable production is to create more sustainable consumer and productive patterns, with an emphasis on the agri-food sector, in order to protect the environment and social welfare [31]. Considering the abovementioned factors, sectors that process and supply biomass, create bio products, exclude fossil fuels, and ensure sustainability need to be supported [18]. In this context, a transition from a fossil-based economy to a circular bioeconomy is the way to secure a sustainable future [7].

The agri-food sector in Greece is one of the most important sectors in exports, with a strong presence in Europe and a growing presence in the American food markets. It is also an industry with many Greek companies that have achieved significant market shares while combining traditional ingredients, marketing, innovations, and packaging. [32]. The livestock production sector in Greece is one of the two main sectors of primary production and represents about 25% of the total gross agricultural production of Greece [33]. There is a lot of unexploited waste in the agricultural and livestock sector in Greece. In fact, the annual production of waste in Greece from both sectors was estimated at approximately 57,983,751 tons/year. Overall, 53% of this waste comes from the agricultural sector and 47% from the livestock sector [34]. Although the importance of the bioeconomy has been recognized worldwide, in some countries, including Greece, it has not yet received the appropriate

attention. There is an enormous potential of the agricultural sector for development, and Greece can claim a significant role in the development of the bioeconomy both at the local and global level.

One of the most critical methodologies that are widely used to show the research development in a concerned field is the literature review [35]. The object of this paper is to visualize the definition of bioeconomy regarding livestock production, through the bibliometric networks of international scientific literature. The current research and studies in Greece on this subject are limited. For this reason, our research sample concerns all publications in the international literature. This research is expected to contribute to the scientific literature as it presents and analyzes all the publications worldwide in the Scopus database that examine issues for bioeconomy and livestock production. The fact that the subject of bioeconomy and livestock production does not appear as much in the international scientific literature as other subjects was a challenge.

The remainder of this paper is organized as follows: The material and methods section describes the performed systematic literature review method, bibliometric analysis, and the research keywords. The next section presents the results of the scientific literature analysis. Finally, there are the sections of discussion and the conclusions of the study.

2. Materials and Methods

In this study, a systematic literature review was employed, this being the bibliometric analysis, which is a relatively recent application for analyzing a sample of research documents. Bibliometric analysis is an innovative, effective, and extensive qualitative method that can calculate the contribution of different aspects in a specific research topic [35]. The bibliometric analysis is defined as the process of identifying, analyzing, and measuring the scientific productivity of individuals, groups, organizations, and countries on a special topic [36]. There are studies that have employed the same method for the topic of bioeconomy but in different subjects. Konstantinis et al. [36] conducted a bibliometric analysis to identify the different bioeconomy strategies continents. Guo et al. [37] employed bibliometric techniques on smart cities research. Zhang and Yuan [35] performed the same analysis in energy performance contracting research from 2008 to 2018. In addition, Biancolillo et al. [38] performed a literature review on forest bioeconomy with a bibliometric network analysis. Bibliometric analysis was also used for the purpose of this study, using VOSviewer version 1.6.16 [39]. The VOSviewer software was developed by Van and Waltman [39] for the creation, visualization, and exploration of maps based on the bibliometric network data [38].

The aim of the literature review was the analysis of peer-reviewed publications (books, book chapters, articles, and papers published in conference proceedings) concerning the livestock production bioeconomy topic. The publications were retrieved from the Scopus database (<https://www.scopus.com>) on 2 August 2021 using “animal production” OR “livestock production” AND bioeconomy as the search keyword. These search keywords were selected for two reasons. First and for most, there were no other studies on this subject in the international literature, and second, both terms “animal production” and “livestock production” are used in the literature; therefore, they were both included as keywords. This keyword was searched in all fields of the publications. The time frame was set from 2004 to 2 August 2021. All the data were exported as “comma-separated values” (csv) files and processed through a bibliometric network analysis using the VOSviewer software.

The Systematic Review and Post-Analysis Statement (PRISMA) statement was published in 2009. Its goal is to support and help systematic reviewers report transparently why the review was conducted, what the authors did, and what they found [40]. A simplified form of PRISMA was applied as the systematic literature review method for the purpose of this study. More specifically, it was properly modified to be compatible with VOSviewer and study’s objective (Table 1). All the results and analysis in this paper are based on 39 studies.

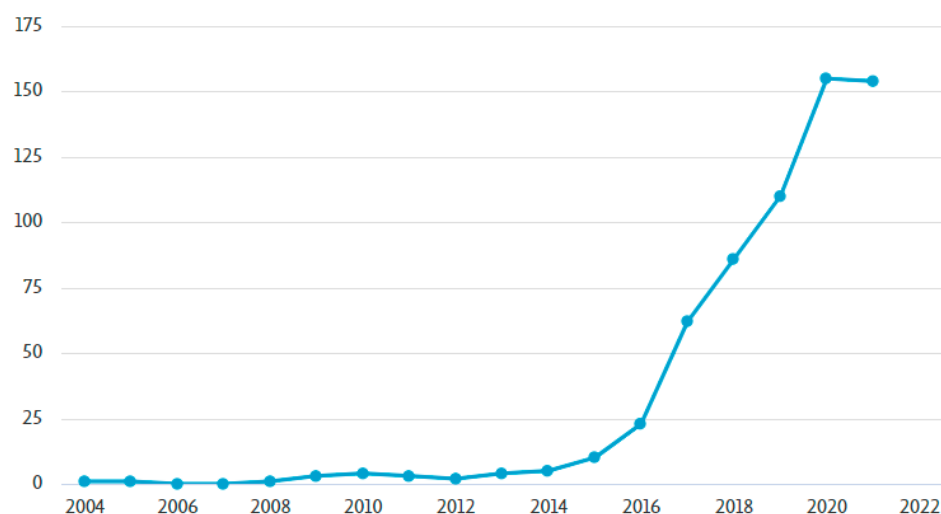
Table 1. PRISMA flow table for the new systematic literature review.

	Identification	Screening		Included
	Reports Identified from Scopus (n)	Data Assessed for Eligibility (n)	Data Excluded (n)	Studies Included in Review (n)
Publications	624	624	0	39
Research subject area	624	11	8	39
Document's type	624	7	5	39
Main sources	624	290	15	39
Main journals	624	45	39	39
Main countries	624	83	49	39
Active research organizations	624	160	155	39
Active authors	624	157	147	39
Top keywords	624	2.225	2.213	39
High-frequency keywords	624	2.225	2.160	39

Data excluded: Reason 1: No strong interconnections. Reason 2: No co-occurrence. Reason 3: No high relation with the subject. Reason 4: Absence of many citations.

3. Results

A comprehensive search in the Scopus database on the bioeconomy of the livestock production resulted in 624 publications. There is a notable, almost linear increase, in scientific publications on bioeconomy from year 2014 onward, achieving the highest peak in year 2020 for about 155 publications (Figure 1).

**Figure 1.** Publications on the livestock production bioeconomy at the international level (2004–2021).

In the database, 11 research areas and 7 different document types were identified. These publications, based on what research area they deal with, can be categorized as follows: (a) agriculture and biological sciences (167 documents, 26.80%), (b) environmental science (112 documents, 18.00%), and (c) veterinary (66 documents, 10.50%). The majority of these publications (463 documents, 74.20%) were articles, while 111 documents (17.80%) were reviews. The sources publishing in livestock production bioeconomy research were identified and analyzed (Figure 2). The sources connections were visualized based on the number of publications. The minimum number of documents published was set at 1. The analysis resulted in 290 sources but only 275 of them appear interconnections. The journals with more publications were *Animals* (33 papers), *Sustainability Switzerland* (28 papers), *Animal Feed Science and Technology* (20 papers), *Annals of Animal*

It is easily observed that Poland, Germany, Norway, and Italy are the most active countries with 167, 102, 92, and 74 papers, respectively (Figure 4). Similar research on the bioeconomy of the livestock production in Greece seems to be less frequent, seeing as currently there are only 11 scientific publications available. Based on the interconnections among different countries, this proves that cooperation is prevailing in Europe when research is conducted.

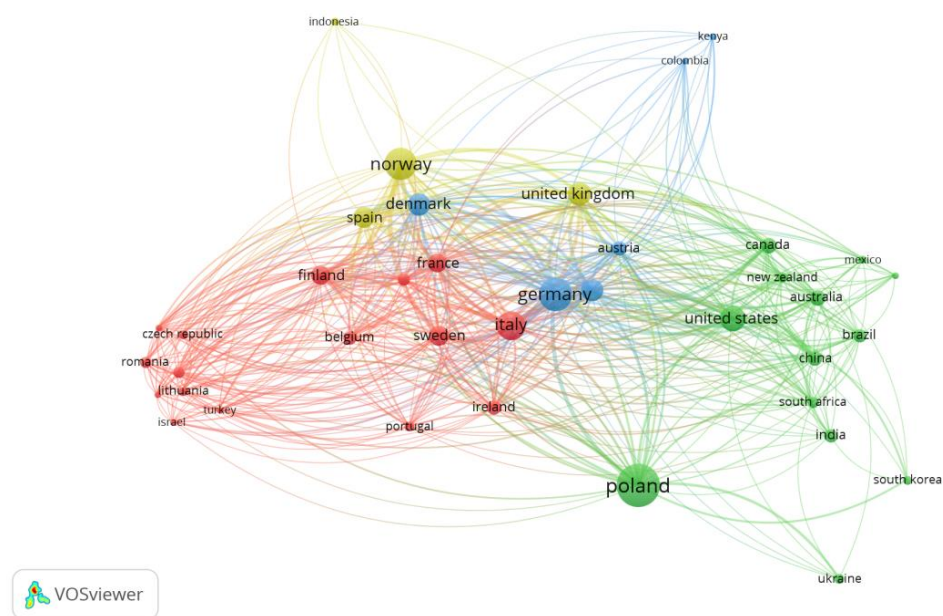


Figure 4. Network demonstration of main countries in livestock production bioeconomy research.

The number of publications produced within the period 2004–2021 (2 August) on the bioeconomy of the livestock production is derived from 160 research organizations (universities and research institutes). Specifically, the five most active organizations are the University of Life Sciences in Lublin, Poland (124 documents), The Norwegian Institute of Bioeconomy Research (72 documents), Leibniz Institute for Agricultural Engineering and Bioeconomy in Potsdam, Germany (51 documents), Wageningen University and Research in the Netherlands (35 documents), and Norwegian University of Life Sciences (29 documents).

By observing the data by author, the 10 most active authors were obtained (Table 2). The analysis demonstrates that the mainstream authors' affiliations are from Poland and Germany, which is closely related to the existing bioeconomy policies of these two countries.

Table 2. Top 10 authors related to the livestock production bioeconomy.

Author	Number of Publications	Total Number of Publications	<i>h</i> -Index *	Affiliation	Country
Ognik, K.	20	124	15	University of Life Sciences in Lublin	Poland
Amon, B.	16	72	20	Leibniz Institute for Agricultural Engineering and Bioeconomy in Potsdam	Germany
Amon, T.	14	92	21	Free University of Berlin	Germany
Jakubczak, A.	13	50	8	University of Life Sciences in Lublin	Poland
Strachecka, A.	13	68	13	University of Life Sciences in Lublin	Poland
Hoffmann, G.	12	48	11	Leibniz Institute for Agricultural Engineering and Bioeconomy in Potsdam	Germany
Listos, P.	12	38	7	University of Life Sciences in Lublin	Poland
Borsuk, G.	11	53	12	University of Life Sciences in Lublin	Poland
Jankowski, J.	11	193	23	University of Warmia and Mazury in Olsztyn	Poland
Kozłowski, K.	11	86	12	University of Warmia and Mazury in Olsztyn	Poland

* The *h*-index is based upon the number of documents and number of citations.

Author keywords in our research sample were also explored and analyzed by using the VOSviewer software to demonstrate the keywords with a high frequency, as well as keyword relationships. The analysis of the keywords generated 2.225 results. However, only 67 keywords have at least five co-occurrences. The most important keywords (occurrence higher than 10) are bioeconomy (1.21%), sustainability (1.17%), and agriculture (1.12%) (Table 3).

Table 3. Top keywords related to the livestock production bioeconomy.

Keyword	Occurrences	Frequencies (%)	Total Link Strength	Links
Bioeconomy	27	1.21	40	21
Sustainability	26	1.17	49	32
Agriculture	25	1.12	33	19
Circular economy	13	0.58	17	10
Climate change	12	0.54	18	12
Anaerobic digestion	11	0.49	8	7
Biomass	11	0.49	12	9
Livestock	11	0.49	15	410
Microalgae	11	0.49	17	15
Bioenergy	10	0.45	16	13
Dairy cow	10	0.45	4	4
Seaweed	10	0.45	16	11

The co-occurrence network map of keywords related to the livestock production bioeconomy (Figure 5) shows the 65 most-used keywords. The minimum number of occurrences of a keyword was set at five. The size of the circle is relative to the co-occurrence of that item; the shorter the distance is among the items, the stronger their relation is. The color of the circle shows the time slot in which it occurred. The keywords with lighter colors are highlighted more recently. It is easily observed that researches started to pay more attention to the terms “sustainability” and “bioeconomy” from 2019. The six red arrows show the lighter areas with eight keywords, “air pollution”, “waste management”, “biorefinery”, “manure”, “circular bioeconomy”, “fermentation”, “growth performance”, and “nanoparticles”. Those keywords have the highest frequency among all the keywords analyzed in our research during 2020, indicating the new focusing directions in livestock production bioeconomy research.

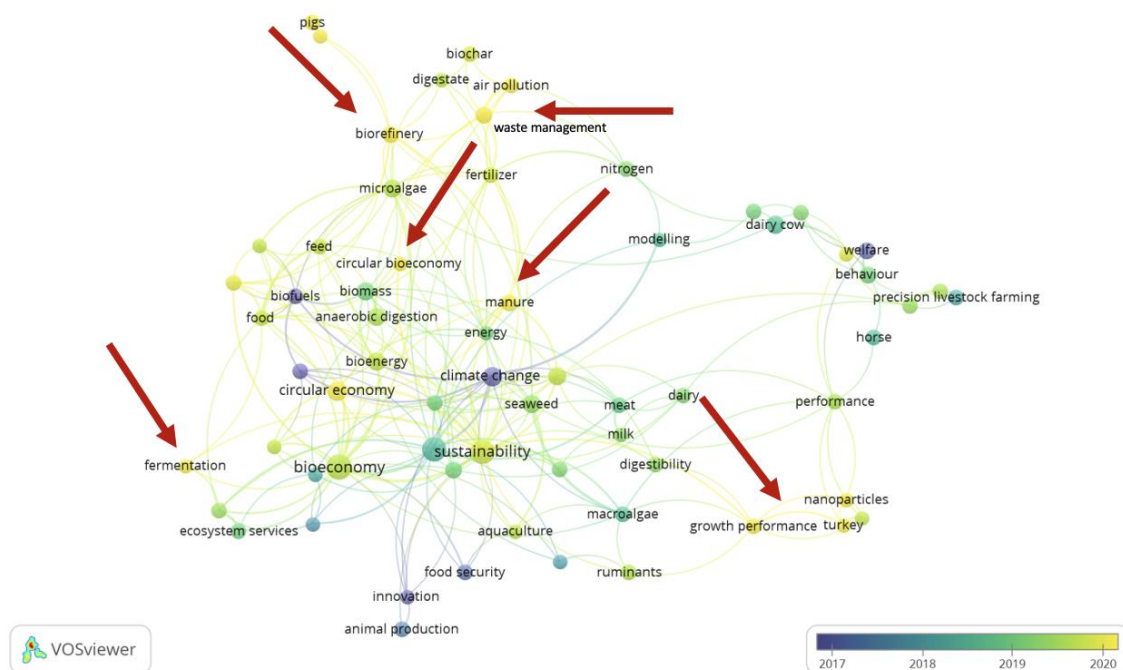


Figure 5. The overlay visualization map of high-frequency keywords in livestock production bioeconomy research.

4. Discussion

This study evaluated the global research trends in bioeconomy of the livestock production sector publications from 2014 to 2021. The performed method was the bibliometric network analysis. This research emphasizes the importance of the innovative applied methodological approach that provides an extensive review of the literature included in the Scopus database. The possibility of this method is the advanced analysis of a topic in a very short time, and taking into account the huge number of publications, that is not feasible to be performed manually. This method's advantage is the capability to analyze the multidimensional nature of bioeconomy through a large database of the literature.

During the last decades, the publications on the research area of bioeconomy have increased rapidly confirming that both research community and international policies have recognized bioeconomy as an important activity for the production of goods, services, and energy and as one of the main solutions toward sustainable economic growth of the livestock sector. Although the bioeconomy of the livestock production has attracted an international interest, the intensity of the research seems to vary among different variables. It is therefore important to identify the distribution of research globally through the analysis of papers published in different countries, authors, and universities. These can serve as an indicator to imply the demand for more studies in the regions concerned.

The research emphasizes the existence of countries and universities that are more active and specialized in the field of bioeconomy and livestock production. Apart from the four most active countries mentioned in the results, the rest showed few studies. In addition, it should be noted that two authors and one university are the most productive and influential in this issue. This led to the fact that each country should encourage universities and researchers to promote studies and projects on this topic in order to improve the diffusion of knowledge globally and compare such policies. The countries and universities that are specialized with more publications and studies on bioeconomy and livestock production may be used as a guide for future collaborations, in the specific field.

An interesting fact would be to find out the development of high-frequency keywords in the past decades, which would help researchers to understand the main trends in this research topic. The analysis of the keywords revealed the new directions in livestock production bioeconomy research. According to Zhang and Yuan [35], keywords are used to identify the aspect/topic of each paper and are useful for readers to comprehend the researching contexts. The most interesting result was obtained from the overlay visualization while observing the most frequent keywords during 2020. In particular, "waste management", "biorefinery", "manure", "fermentation", "nanoparticles", and "circular bioeconomy" are the more valuable. These practices could be the future directions all global policies should focus on in order to succeed the sustainable growth of livestock production following practices of bioeconomy.

Bioeconomy and circular economy are related by the most recent scientific references. The synergetic actions and principles of both the bioeconomy and circular economy would be ideal for the environment and the economy. According to Kardung et al. [20], a new term "circular bioeconomy" has been introduced, combining the concepts of bioeconomy and circular economy and highlighting the use of a circular approach to the bioeconomy while showing overlap limitation. The importance of our research keywords "manure" and "biorefinery" is strengthened with the study of Khoshnevisan et al. [27], about livestock manure management technologies. They are suggesting the necessity of forming a sustainable circle where manure management enters into the biorefinery concept integrating with manure nutrient recycling. This establishes the environment for circular bioeconomy development with reduced environmental risks and maximum profits [27].

Shifting toward bioeconomy requires an acknowledgment of all possible interactions between different policy goals and sectors. Particularly, all the interlinkages of different policies in different sectors lead to the fact that governance should accept uncertainty and integrated policies embrace complexity, identifying ways to reduce conflicts and foster synergies [10]. The global transition to sustainable, post-fossil-carbon societies requires a

balance that creates long-term profitability and promotes this development. The sustainable hand, as it is proposed by D'Adamo et al. [41], is the only long-term sustainable approach that looks for the social optimum within a market. In this context, the greater challenges are the changes that should happen in the essential renewables such as biobased materials and products, on the basis of sharing resources. It is also emphasized that all these transitions need local, regional, national, and global coworking [41].

5. Conclusions

Based on the increasing interest that appears in the literature about bioeconomy issues in the last years and the concerns for sustainability in livestock production, this paper provides a holistic view on this research topic over the past decades. However, the limitations of this study should be addressed. The fact that some publications may be missing from the current study due to the use of keywords is one of the main limitations. The search for publications through VOSviewer is based on specific keywords. Another limitation is the database, as the data collection used only scientific papers included in the Scopus database. Other international databases such as the Web of Science should have been integrated. Furthermore, the publications analyzed with this method do not include grey literature (working papers, masters' and bachelors' theses, project reports, deliverables, etc.). Based on these limitations, a deeper analysis is recommended for further research. It would be very useful in future research to review and compare the literature in other large databases such as Web of Science but also to include the grey literature. In addition, a more detailed analysis would be useful regarding issues such as the type of publications (open-access journals), cooperations among authors, institutes, etc.

The research findings revealed limited studies and projects that will be able to support and diffuse the bioeconomy development. The evolution of the scientific literature analysis in the future may be analyzed more in terms of content, as well as in bioeconomy and especially in relation to livestock production. It seems that it has not yet received the attention of researchers, who seem to deal with it within the bioeconomy of the agricultural sector in general, which is not right. It is necessary to further intensify research toward this direction and attempt a deeper content analysis in the future on the bioeconomy of the livestock production. From the political side, new legislation and national policies are needed to address challenges that the livestock production sector is going to encounter, protect national resources, and introduce efficient waste management. Finally, we suggest that policy directions should encourage multidisciplinary programs, innovation, and knowledge developments, to provide skilled experts in the field of the livestock production and its associations with bioeconomy. This may contribute to addressing the acceptability and legitimacy of issues that are central to sustainability science and practice.

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