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Review

Exploring Biomass Linkages in the Food and Energy Market—A Systematic Review

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Abstract: This study delves into the intricate landscape of biomass utilization within the food and energy markets. It entails a systematic review of the existing literature with the aim of unraveling the complexities of the food and energy discourse, especially in the context of significant market factors influencing biomass use for food and energy. We leveraged the Scopus database to examine 73 pertinent scientific articles carefully selected following the PRISMA framework. The articles were analyzed using the advanced qualitative data analytics tool NVivo 12 Plus. Furthermore, we employed the Biblioshiny R-package tool to extract valuable insights from the metadata, unveiling pivotal trends and providing descriptive statistical details. The findings offer comprehensive insights into the debate on biomass utilization from 2010 to 2023, tracing the influence of the COVID-19 pandemic. We identify regions that have made notable contributions and highlight those that require increased attention. The analysis underscores the collaborative nature of this field, with 281 authors contributing to 39 different sources. Surprisingly, the observed annual growth rate of −10.93% indicates a potential decline in research output in this field. Nevertheless, the sources identified in our research provide a valuable roadmap for further research exploration of the biomass–food–energy nexus.

Keywords: bioenergy; debate; competition; COVID-19; land use

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1. Introduction

Modern issues such as climate variability, geopolitical strife, and economic volatility have significantly disrupted the previously established equilibrium within the energy and food sectors. These issues, alongside the rising global population, have intensified the crises related to global food security and nutrition, simultaneously hindering progress towards adopting sustainable energy solutions. A 2023 report by the Food and Agriculture Organization (FAO) underscores this point; despite significant investments in food systems over the years, food insecurity is rising globally, posing risks even to nations previously considered food-secure [1]. The report indicates that approximately 12% of the global population is now experiencing chronic hunger, an increase from 7.9% in 2019. Moreover, nearly 30% of people worldwide face food insecurity and, in 2022, about 42% of the global population, or 3.1 billion individuals, could not afford a nutritious diet.

In a related context, the World Meteorological Organization [2] estimates that, to maintain global temperature increases within manageable limits, clean energy production needs to double in the next eight years. This escalation is critical to reduce more than two thirds of the energy sector's greenhouse gas emissions and to meet the objective of net-zero emissions by the year 2050. The current energy framework is deeply intertwined with food and agricultural resources, underscoring the urgency for efficient use and management of these resources. This urgency is amplified by the ongoing challenges of climate change,

economic turmoil, and conflicts. These interlinked crises reinforce each other and, if left unaddressed, they could lead to a potential breakdown of global food systems.

Hence, it is crucial to elevate the share of alternative energy sources to fulfil the energy requirements of the present generation. In recent years, the global landscape of energy and food production has experienced a significant shift towards sustainable practices. This shift is driven by the need to mitigate environmental degradation and address the challenges posed by depleting fossil fuel reserves. A key aspect of this evolution is the increasing utilization of biomass as a multifunctional resource offering potential benefits in both the energy and food sectors.

Biomass, derived from organic materials of plants, animals, or microorganisms, offers a renewable and potentially carbon-neutral source of energy and feedstock [3]. It plays a vital role in food systems, where it can function essentially from farm to fork. For instance, biomass is used as compost or organic fertilizer on the farm and constitutes indispensable elements of the food basket, contributing to sustainable and nutritious food. Similarly, it serves as a viable alternative to fossil energy as it helps reduce greenhouse gas emissions through its renewable and eco-friendly characteristics. Biomass can also be converted into various forms of energy, including heat, electricity, and biofuels. This multifunctionality of biomass, coupled with its regenerative ability that makes it renewable and sustainable, makes it an important resource in the quest for sustainability and climate change mitigation.

This research is designed to investigate the dynamic landscape of biomass utilization within the interconnected domains of food and energy markets in response to the intensifying interplay between these two areas. This study acknowledges the advancements and findings in the current literature, aiming to build upon and expand the understanding of this critical relationship. This is particularly essential as existing works have primarily focused on methods of biomass utilization with limited attention to the market linkage between biomass for food and energy. This gap is notable amidst increasing debate on the market dynamics affecting both aspects. This research seeks to unravel the most notable market factors that shape biomass utilization for food or energy through the lenses of the existing literature. Specifically, this research aims to:

- Offer a comprehensive understanding of the discourse surrounding the utilization of biomass for both food and energy over the past 10 years.
- Shed light on the impact of the COVID-19 pandemic and conflicts on the advancement of research in this area.
- Spotlight nations and regions that have made significant contributions to this field, as well as those that necessitate further attention.
- Uncover the most pertinent sources of scientific publications and highlight the thematic evolution within the nexus of biomass, food, and energy.

2. Literature Review

The theoretical availability of biomass is virtually limitless, yet its utilization for energy is constrained by competing demands for food, feed, and fiber. This is underscored by the fact that global primary biomass production annually captures and stores approximately 4500 exajoules (EJ) of solar energy and sequesters 125 gigatonnes of carbon dioxide [4]. The total biomass on Earth is estimated at around 1260 EJ/year, with 219 EJ/year allocated for food, feedstock, fiber, and other industrial purposes [5].

However, the potential expansion of biomass for energy production is significantly constrained by the limited land resources available for meeting the food requirements of a burgeoning global population. Currently, energy crops utilize a mere 25 million hectares, representing only 0.19% of the global land area and between 0.7 and 1.5% of agricultural lands [6]. Nevertheless, we posit that leveraging algae and by-products for energy could substantially diminish the land needed for energy cultivation.

Emerging trends such as demographic growth, religious practices, rising incomes, urbanization, and shifts in dietary preferences are leading to long-term structural changes in food demand [7]. Increasing living standards are driving up energy consumption,

particularly in developing nations [8]. Peng et al. (2022) [9] observed a direct proportionality between green energy demand and Gross Domestic Product (GDP) and an inverse relation with population density. Szőllősi et al. (2021) [10] emphasized the critical role of agricultural innovation and enhanced production efficiency in resolving the conflict between food/feed and energy production. However, the complexity of measuring efficiency, influenced by the selection of appropriate efficiency indicators (partial, complex, social, and corporate), significantly affects the conclusions drawn [11].

Research on biomass potential showed considerable growth after 2000, and the number of publications increased significantly after 2012 globally, especially in China and India. The most popular topic in biomass energy research is next-generation biofuels [12].

2.1. Energy, Food Security, or Animal Feeding Debate

Biofuels have emerged as a significant factor affecting food security, especially between 2005 and 2015. For instance, the United States allocated over 40% of its corn production to biofuels in 2007. This had a ripple effect on food prices and security globally. Additionally, countries such as Indonesia and Brazil play crucial roles in this debate, further intensified by environmental concerns associated with biofuels [13]. However, the increasing reliance on conventional biofuel production is not a sustainable long-term solution, given the associated risk to the food supply [14,15]. The two papers primarily addressed the economic aspects of transportation fuels, emphasizing that first-generation biofuels are viable only as short-term solutions. They noted that, while the use of nonfood biomass and newer technologies enhances environmental performance, it results in more costly end products. Conversely, utilizing by-products and co-products significantly boosts economic efficiency.

Ahmed et al. (2021) [16] provide an in-depth analysis of the intricate interplay between bioenergy production and food security. This comprehensive examination encompasses 224 scholarly articles that met the inclusion criteria for assessing the impact of various bioenergy feedstocks on critical food security aspects, specifically availability, pricing, and production. The synthesis of these studies indicates that 56% of them identified a detrimental effect of bioenergy on food security metrics. Notably, the nature of the feedstocks, classified as either edible or nonedible for human and animal consumption, does not significantly influence the overall impact on food security. Although bioenergy production might yield localized benefits, such as augmenting the revenues of small-scale farmers, it poses substantial negative repercussions at broader scales, including heightened consumer prices and intensified competition with other agricultural commodities designated for food and feed purposes.

Muscat et al. (2020) [3] conducted an analysis of 75 studies spanning from the 1996 to 2017 time interval and categorizing them based on scale, methodology, biomass source, and resource competition, while considering the synergies and possibilities in circularity. A noteworthy finding was that 37% of these studies did not propose a specific solution. They primarily focused on the interplay between "food-feed-fuel"; the most frequently used relation was food and fuel, representing 47% of the selected articles.

The paper by Benites-Lazaro et al. (2020) [17] offers a comprehensive examination of the intricate interconnections among land, water, food, and bioenergy production, specifically focusing on sugarcane ethanol in Brazil. The study underscores that these elements are pivotal in policy discussions, especially concerning the distribution of land and water resources. They introduce the water–energy–food (WEF) nexus as a promising framework for managing these resources in an integrated manner.

Di Paola et al. (2017) [18] highlighted the significance of the source in protein production. Their study indicates that animal proteins derived from intensive farming require between 2.4 and 33 times more land and water resources compared to plant-based proteins.

In their 2021 study, Brown et al. [19] delve into the multifaceted dynamics between food and fuel production within the North American agricultural framework. The research underscores how concerns regarding energy security and environmental sustainability have catalyzed the growth of the biofuel sector, offering grain producers an alternative

avenue for crop utilization. This development, however, has ignited the "food versus fuel" discourse, which critically examines the allocation of arable land for either food or energy production. The study deduces that biofuels serve as a pivotal nexus between energy market trends and agricultural commodity pricing in the foreseeable future. This conclusion is in concordance with other scholarly findings, which have observed a pronounced escalation in the correlation between oil prices and grain market values subsequent to the ethanol industry's expansion.

Khan et al. (2021) [20] present a comprehensive overview of the complex and often contradictory findings in existing biofuel research. This issue is especially prominent in the debate surrounding food security and biofuels. The production of first-generation biofuels using edible feedstocks such as corn and sugarcane has heightened concerns regarding food security. They also highlight the concept of Energy Return on Energy Invested (EROEI) as a crucial metric for assessing the energy balance of biofuel production. This regional variability in EROEI underscores the importance of considering local conditions and feedstocks when evaluating the sustainability and efficiency of biofuels.

Martínez-Jaramillo et al. (2019) [21] present a nuanced examination of the intricate relationship between biofuel production and food security, offering a distinct perspective. Their research extends to an in-depth consideration of the four pillars of food security: availability, access, utilization, and stability. The study acknowledges existing threats to food availability, including demographic expansion, land degradation, and climatic variations. The authors contend that the influence of biofuels on food security is relatively marginal, estimating a diminution of food security by no more than 4%. This refined conclusion provides a critical counterpoint to the often-dichotomized discourse on the interplay between biofuel production and food security.

Meijaard and Sheil (2019) [22] provide a detailed analysis of the ethical dimensions that accompany the development of the oil palm industry. Although this development can result in economic gains and improved livelihoods for local communities, it also poses significant environmental risks, such as deforestation and biodiversity loss. This creates an ethical paradox, where the same activity can be viewed as both beneficial and detrimental, depending on the ethical lens through which it is examined.

Another study carried out an extensive analysis of the potential for converting agricultural waste into bioethanol in Iran [23]. They investigate the environmental benefits of replacing fossil fuels with bioethanol, particularly with respect to the reduction in greenhouse gas emissions. They argue that substantial quantities of residues are annually produced by various crops currently cultivated. Typically, these agricultural by-products are left in the fields and disposed of through burning. The study posits that repurposing these residues for bioethanol production creates value-added products and offers an environmentally sustainable and efficient solution for waste management.

Swaraz et al. (2019) [24] explored the potential for bioethanol production in Bangladesh using wild dates as raw materials. Their study is framed within the broader context of energy security and the "food versus fuel" debate, particularly in developing countries like Bangladesh, where food security remains a critical concern. The findings have significant policy implications for countries grappling with biofuel production's ethical and practical challenges. It is recommended that governments should consider alternative, non-food crop sources for bioethanol to mitigate the ethical dilemmas associated with its production.

Timilsina (2012) [25] analyzes the food versus fuel debate, focusing on the impact of biofuels on food security and prices. The study acknowledges that biofuels contribute to increasing food prices, yet it also points out that the extent of this impact varies based on the models and assumptions employed. The document concludes that, while biofuels put pressure on food security and prices, their impact is not as substantial as commonly perceived. It suggests that, with appropriate regulation, biofuels could become a viable component of a sustainable solution, particularly in countries where the availability of land is not a constraint.

The study by Viccaro et al. (2022) [26] presents a comprehensive framework for evaluating the sustainability of bioenergy production, particularly focusing on the water–energy–food (WEF) nexus. The study highlights the importance of irrigation in achieving greater efficiency in using land and energy resources. This finding resonates with the broader literature on the WEF nexus, which often identifies water as a key factor in sustainable energy management and land resources.

2.2. Effects of Pandemics

Kovács et al. (2023) [27] characterize the period of the COVID-19 pandemic as emblematic of the Volatile, Uncertain, Complex, and Ambiguous (VUCA) era. They contend that, in such a world, change occurs at a swift, relentless, and unforeseeable pace. This era is marked by a plethora of external environmental factors impacting various sectors, necessitating rapid adaptation to maintain sustainable operations.

Lele et al. (2021) [13] provide a comprehensive analysis of the food crisis that transpired between 2007 and 2008, including its enduring repercussions. Their research further assesses the proportionality of responses to the challenges presented during this period, a question that has gained heightened relevance due to the COVID-19 pandemic. The study notes that the restrictions and regulatory measures imposed during the pandemic have significantly influenced both everyday life and the global economy [28]. The pandemic has intensified pre-existing vulnerabilities, particularly in nations such as India and Nigeria. Moreover, the disruptions caused by the pandemic pose a risk of precipitating another food crisis, similar to the one experienced in 2007–2008.

Due to the pandemic, innovative solutions have come to the fore in biomass utilization in food (3D-printed foods), in energy (photovoltaics and next-generation biofuels), and in other industrial (bio-based packaging) areas [12,29].

According to Khan et al. (2021) [20], COVID-19 and war could have significant implications for biofuel production and consumption. The pandemic has disrupted global supply chains, potentially affecting the availability of feedstocks and the distribution of biofuels. Likewise, geopolitical conflicts have the potential to affect the stability of regions that are major producers or consumers of biofuels, thereby adding further complexity to an already intricate landscape.

The agricultural biomass sector had to face serious disruptions due to uncertainties in transportation, supply chains, and logistics [30]. Consequently, the pandemic significantly increased the demand for local products and emphasized the importance of short food supply chains [31]. The growing number of COVID fatalities adversely impacted employment across the clean energy sector, specifically in biomass, electric vehicles, microgrid systems, and wind power. COVID hospitalizations show the same negative tendency in job vacancies in the biomass and wind sectors but did not affect the other four sectors [32].

According to Sertolli et al. (2022) [12], COVID-19 did not alter the long-term trends regarding the number of scientific articles in the area of biomass potential and utilization. This scientific output proves that more effective biomass use has increasingly gained prominence, irrespective of extreme events.

2.3. Effects of Energy Policies

Kinda (2021) [33] conducts an extensive analysis of the intricate interplay between green economy initiatives and food security across 35 Sub-Saharan African countries over the period 2001–2015. The study posits that, although renewable energy sources have the potential to enhance food security, the production of biofuels might exert a negative impact. The research specifically identifies that biofuels contribute to a decline in food security by intensifying competition for key production resources such as labor, water, and land. This competitive dynamic can prompt a transition from food crop to biofuel crop cultivation, adversely affecting food availability. Conversely, the adoption of renewable energy sources can potentially improve the capacity of economically disadvantaged and vulnerable groups to purchase food in local markets. The paper concludes by underscoring the dichotomous

effects of green economy indicators, particularly biofuels and renewable energy, on food security dynamics.

Trade policies and price stabilization are contentious topics. While some experts argue that these policies are inefficient and poorly targeted, others believe they are essential for macroeconomic stability. Despite its generally open trade regime, Indonesia's protectionist stance on rice underscores the sensitive nature of food security in the country's policy landscape. This is in line with the broader argument that stable consumer and producer prices are economically beneficial and politically rewarding, introducing a political dimension to the economic and social considerations [13].

Viccaro et al. (2022) [26] highlight the need for more targeted policy measures considering local geographical and climatic conditions. This could include promoting specific farming practices that are more suited to local conditions, thereby reducing the environmental impact of bioenergy production.

Zaky (2021) [34] presents a viable strategy for sustainable biofuel production, offering a solution to the "food versus fuel" dilemma. The study primarily investigates the feasibility of a Coastal Integrated Marine Biorefinery (CIMB) system, which represents a more sustainable alternative to traditional biofuel production methodologies. This system employs oceanic resources such as seawater, marine biomass (especially seaweed), and marine microorganisms (like algae), which are considered ideal raw materials for the generation of bioenergy and the synthesis of high-value chemicals (HVCs). The CIMB system proposes a potentially more cost-efficient and sustainable route for biofuel production by obviating the need for fertile terrestrial land and freshwater resources.

3. Methodology

3.1. Data Collection

Systematic reviews are distinguished from integrative and narrative reviews by their commitment to minimizing bias and enhancing the rigor and transparency of the review process [35]. This systematic review followed the five-step methods proposed by Briner and Denyer (2012) [36], which include review planning, locating studies, contributions appraisal, information analysis and synthesis, and reporting.

The existing studies on biomass utilization underwent meticulous analysis and synthesis, leading to the development of a comprehensive plan based on their insights and recommendations. Practically, in the planning stage, an initial search was conducted on various databases, such as ScienceDirect, Google Scholar, and Scopus, to determine the most relevant keywords in studies involving biomass for food and energy. Findings from this search formed the basis for identifying relevant keywords to facilitate literature search and data extraction. Additionally, specific inclusion criteria for the literature were established. Finally, the literature search was conducted, taking into consideration similarities, contextual relevance, and overall importance in tandem with Ukpabi and Karjaluoto (2017) [37]. This step is crucial as it provides the overall framework for the study, enhancing the identification of research gaps for further research and identifying key nuances in existing studies.

The inquiry was carried out using the Scopus archives, recognized as one of the most expansive, multidisciplinary academic databases globally and a principal repository for an extensive array of journal publications related to energy and food systems. The main search terms used in the data collection consisted of three keywords that were confirmed to be highly relevant to this research theme. These keywords were connected in the Scopus database search bar using Boolean operators as indicated by the query "(TITLE-ABS-KEY (biomass) AND TITLE-ABS-KEY (food AND market) AND TITLE-ABS-KEY (energy AND market))". The search encompassed titles, abstracts, and keywords.

Diverse exclusion criteria were employed to ensure the selection of only the most pertinent articles. The study specifically concentrated on articles published between 2010 and 2023 to capture the latest and most insightful perspectives on the use of biomass for food and energy. This time frame was chosen to encompass the final phase of the implementation

of the Millennium Development Goals (MDGs) and the onset of the sustainability and net-zero era. This period also witnessed improved legislation and policy development, sparking debates on the competitive use of biomass for food and energy. Additionally, it witnessed rapid advancements in biomass technology, alongside unprecedented food and energy crises caused by war and global pandemics [38,39].

The review specifically focuses on journals within the disciplines of agriculture and biology, social sciences, and energy. This approach ensures thoroughness, rigor, and exclusivity in the concise coverage of the most important literature pertaining to the competitive use of biomass for food and energy. It also captures the most relevant economic connections that existing studies have drawn on the subject matter.

3.2. Data Analysis

The systematic search of the Scopus database yielded a substantial number of results. To ensure the rigor and transparency of the review process, the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines were followed [40]. This is crucial for ensuring the reliability of the results. Various exclusion criteria were employed, as depicted in Figure 1, to minimize bias while narrowing down and focusing on the most relevant studies. Additionally, a thorough examination of article titles, keywords, abstracts, and sections was undertaken to select studies whose objectives are closely aligned with the aims of this research. Furthermore, studies conducted in English were exclusively chosen to facilitate the generation of comprehensive insights from the most relevant and practical situations. In line with the assertions of Younas et al. (2022) [35] and Briner and Denyer (2012) [36], both of whom independently emphasized the necessity for systematic reviews, we maintained transparency and rigor throughout our review process for identifying, analyzing, evaluating, and interpreting all relevant findings impartially and in a reproducible manner. This approach allowed us to disclose the details of the process comprehensively.

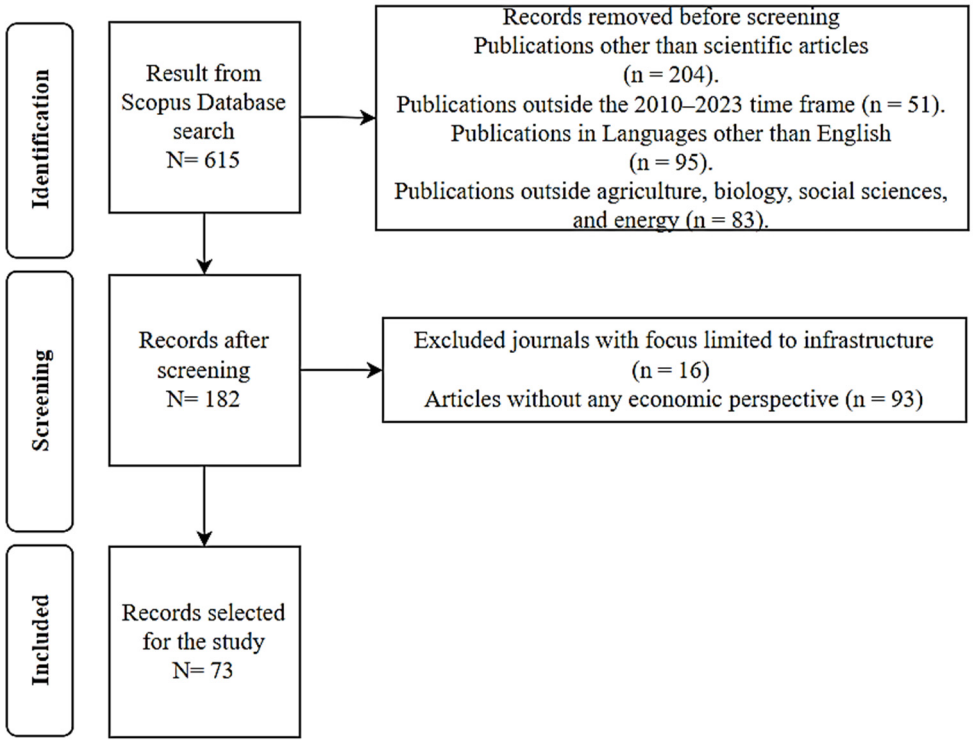

Figure 1. A flow diagram of the methodological progression. Source: authors' own construction.

Following the final screening, a total of 73 articles were identified as relevant to the study. Subsequently, we conducted a qualitative analysis of the articles using NVivo 12 Plus coding feature. This latest version of the computer-assisted qualitative data analysis software has had a long reputation for its high level of efficiency in supporting qualitative data analysis [41,42]. The complete 73 articles were retrieved from the Scopus database and imported into NVivo 12 Plus. The software's auto-coding tool was then utilized to code the imported texts and generate themes. In addition, we analyzed the metadata of the selected articles to identify key trends and gather descriptive statistical details. The Biblioshiny R-package (version 4.1) tool, known for its remarkable capabilities in analyzing bibliometric data [43], was used to extract relevant metadata, such as publication trends, authorship patterns, and keyword frequency, offering a comprehensive overview of the literature landscape [44]. The results were thoroughly reviewed to identify the most prominent and relevant trends and themes. These were then categorized under descriptive characteristics and market factors, respectively, in the results and discussion section. The identified themes were carefully examined to generate a coherent narrative based on the extracted content from the literature. This combination of approaches was essential in this study as they complement each other, offering deep insights and aiding in achieving the research objectives.

Accordingly, abductive reasoning, a cognitive process where individuals deduce and apply implications from a context to their specific circumstances [45], was employed as the basis for analyzing the codes generated from the articles. To further ensure reliability, two measures were implemented. First, cross-checks were conducted on the codings for the 73 selected articles. Second, the results were independently scrutinized and reviewed by co-authors to ensure that no relevant information was overlooked [46]. This scrutiny aimed to provide a coherent discussion on the competitive use of biomass for food and energy, as well as the extent of the existing literature.

4. Result and Discussion

4.1. Descriptive Characteristics

4.1.1. Summary of Metadata

Figure 2 presents summary statistics spanning a 13-year period from 2010 to 2023. This timeframe is particularly significant for our research as it coincides with the advent of strategic regional and global sustainability policies that have significantly influenced the energy transition landscape. It marks the transition from the end of the Millennium Development Goals (MDGs) era to the beginning of the Sustainable Development Goals (SDGs) era. Additionally, the decade under review has been characterized by multiple crises, including economic upheavals, a global pandemic, and conflicts, which have notably impacted the food and energy markets [38,39].

The summary in Figure 2 further reveals that the 73 documents included in this study were derived from 39 different sources, featuring a total of 281 authors. Notably, 21.92% of these authors engaged in international co-authorship, while only 9 documents were authored by a single author. On average, there were 3.93 co-authors per document, and a concerning negative annual growth rate of −10.93% was observed. The explanation for this surprising tendency lies in the economic crisis situation in 2008 and 2009, when the high food prices were significantly attributed to the rapid expansion of corn-based bioethanol and the novelties of next-generation biofuels were analyzed in many scientific articles.

Our analysis also revealed that the authors utilized a compilation of 287 unique keywords in their works. The average age of the documents analyzed was 8.62 years, indicating the relevance and applicability of the research findings over time. Moreover, each document, on average, garnered an impressive 51.73 citations.

Figure 2. Summary statistics of the analyzed documents. Source: authors' own construction.

The three-field plot in Figure 3 shows a three-dimensional connection, mapping the top 20 publication sources to the most outstanding keywords and countries. This connection highlights "biofuel", "bioenergy", and "biomass" as the three dominant keywords associated with the United States (USA), United Kingdom, and Netherlands and published mostly in "Applied energy", "Biomass and bioenergy", and "Biofuels, bioproducts and biorefining" journals. The result also revealed several other prominent keywords, sources, and connecting countries.

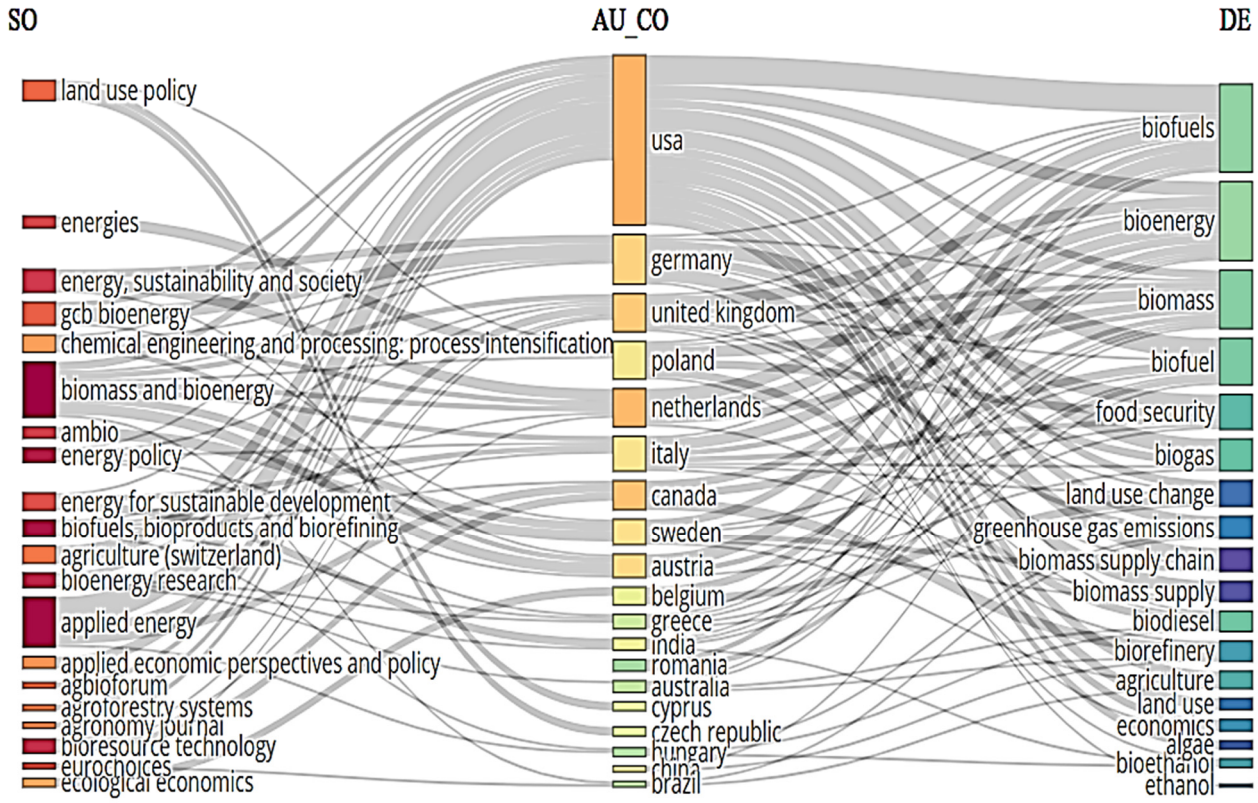

Figure 3. Relationship between scientific areas, countries, and authors' keywords. Source: authors' own construction.

The three-field plot analysis depicts the interrelationship among sources of scientific publications, countries, and author keywords. It utilizes three fields, namely sources (represented by "SO") on the left, countries (represented by "AU CO") in the middle, and author keywords (represented by "DE") on the right. The height of the boxes indicates the publication density, while the thickness or thinness of the connecting lines signifies the strength of the associations between these variables. Most authors conduct research in the USA and publish in a great variety of journals, excluding Land Use Policy and Energies. These journals, however, are particularly popular in the Polish and Czech research communities.

The implications of these findings extend beyond mere mapping, offering a nuanced understanding of how regional concentrations impact publication preferences and the interconnectedness or collaborative exchange in global bioenergy research. The high volume of publications associated with the USA suggests the preference of researchers from this country towards biomass-related research pertaining to bioenergy. Meanwhile, the pronounced association between the Polish and Czech research communities in their publications in *Land Use Policy* and *Energies* journals reflects their collaboration, knowledge-sharing, and publication preferences within the scientific networks in the same regions, especially as both countries are in the central EU subregion. Researchers and policymakers can leverage these insights to foster collaboration, identify emerging trends, and strategically contribute to the advancement of sustainable bioenergy solutions.

4.1.2. Relevant Scientific Publications

This study encapsulates an analysis of the top 10 journals, as detailed in Table 1. While these journals encompass a variety of subject areas, the selected articles predominantly align with themes pertinent to "Renewable Energy, Sustainability, and the Environment". An analysis of Table 1 indicates that a majority of the research articles are published in Q2 journals. These journals are classified within the second quartile of top-tier publications in the relevant subject domain, closely followed by those in the first quartile (Q1). This result challenges a simplistic hierarchy of journal quartiles, encouraging researchers to consider a diverse range of sources. While Q1 journals are traditionally perceived as having a higher impact, the prominence of Q2 journals suggests that valuable contributions and impactful research can be found across a broader spectrum of outlets. Additionally, the journals featured in this research are distributed across five prominent scientific databases: Elsevier, Springer, Wiley, MDPI, and Allen Press. These databases are esteemed for their publication of rigorous scientific literature in the realm of renewable energy and sustainability, with a focus on topics such as biomass, energy markets, and food markets. Hence, researchers can leverage this diversity of subject areas to inform interdisciplinary approaches and foster holistic solutions. Overall, the extensive data presented in the table highlights the caliber and influence of the scientific sources included in this study.

The temporal analysis of scholarly output, as depicted in Figure 4, provides an overview of the publication trends in the specified field spanning from 2010 to 2023. Remarkably, the data suggest a declining trend in scientific production, characterized by notable variability over this period. A detailed observation reveals a marginal decrease in the volume of publications between 2011 and 2012, followed by a zenith in 2014 and, subsequently, a pronounced downturn. This trend markedly diverges from the findings of Sertolli et al. (2022) [12], particularly in terms of trends, journal contributions, and the geographical prominence of research outputs, notably from India and China. A plausible explanation for this discrepancy lies in the differing research foci. While both studies investigate biomass-related literature, Sertolli et al. (2022) [12] concentrated on the potential of biomass, whereas the current analysis is centered on the specific discourse surrounding the food–feed–energy nexus, which may not currently be as prominent in biomass-related research. The decline might also be attributed to the growing interest and development in alternative energy sources, such as photovoltaic and wind power, among other renewable energy options. These alternatives have garnered significant research attention and have

helped to ease the intense debate over the competitive use of biomass for both food and energy purposes.

Table 1. Most relevant scientific sources.

Journal	Publisher	Country	H-Index	SJR	No. of Articles
Biomass and Bioenergy	Elsevier	United Kingdom	199	Q2	10
Applied Energy	Elsevier	United Kingdom	264	Q1	8
Biofuels, Bioproducts and Biorefining	Wiley	United Kingdom	95	Q2	4
Energy Policy	Elsevier	United Kingdom	254	Q1	4
Bioenergy Research	Springer	United States	69	Q3	3
Bioresource Technology	Elsevier	United Kingdom	341	Q1	3
Energy, Sustainability and Society	Springer	United States	36	Q2	3
AMBIO	Allen Press	Netherlands	141	Q1	2
Energies	MDPI	Switzerland	132	Q2	2
Energy for Sustainable Development	Elsevier	Netherlands	76	Q2	2

Source: authors' own construction.

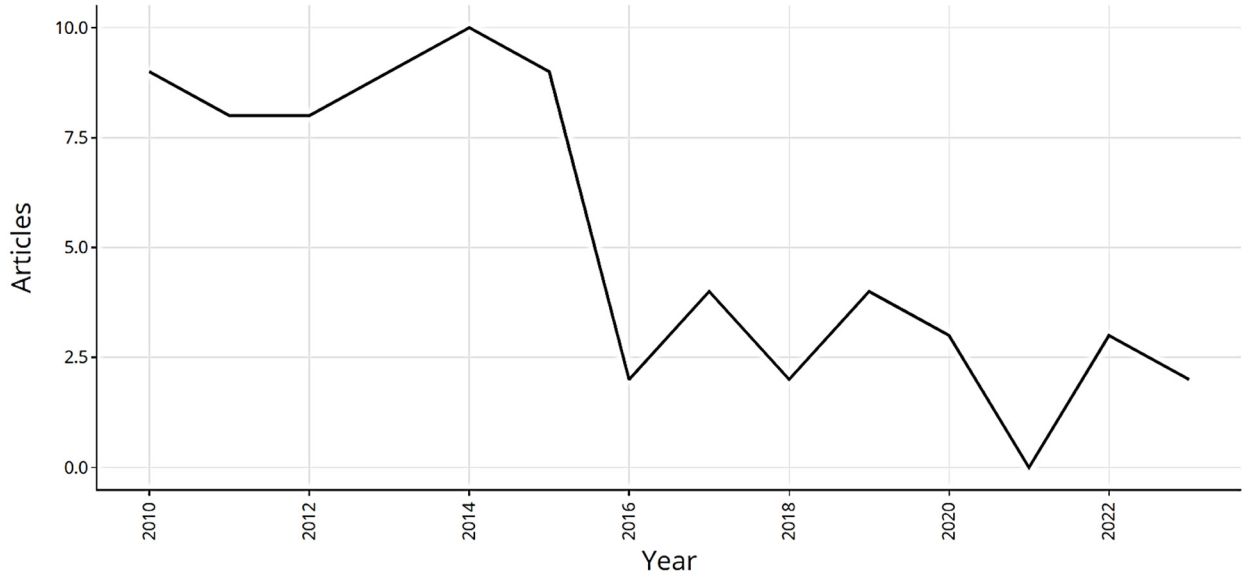

Figure 4. Annual number of scientific articles on biomass, food, energy, and market areas (2010–2023). Source: authors' own construction.

Notably, the lowest levels of output were recorded in 2021 following the outbreak of the COVID-19 pandemic in 2020. However, 2022 showed a tendency for growth with increased production. We anticipate a significant increase in publication growth over the next decade, driven by the unprecedented events of the last few years. These events, including natural disasters, the COVID-19 pandemic, and the Russia–Ukraine crisis, have exacerbated the global food and energy challenges. Consequently, research and development efforts are likely to be intensified to address these critical challenges and enhance sustainability. Moreover, the growing trends of the energy transition, circular economy, and bioeconomy, where biomass plays a central role, are expected to further stimulate growth in this research area, potentially reversing the recent negative trend.

4.1.3. Trend Topics and Thematic Progression

This section elucidates the thematic evolution and topical advancement in publications pertinent to the research focus. Figure 5 presents a thematic mapping that categorizes four primary topical domains across four distinct quadrants, distinguished by colors and the size of the circles that represent the centrality and density of the topics and keywords contained within them [47]. Centrality, plotted on the horizontal axis, measures the importance or prevalence of a theme within the body of research, with high centrality indicating well-established and integral themes to the field's structure. Density, detailed on the vertical axis, refers to the internal development of a theme, including the saturation of research and the interconnectedness of studies, with high-density signifying themes that are well developed and extensively researched.

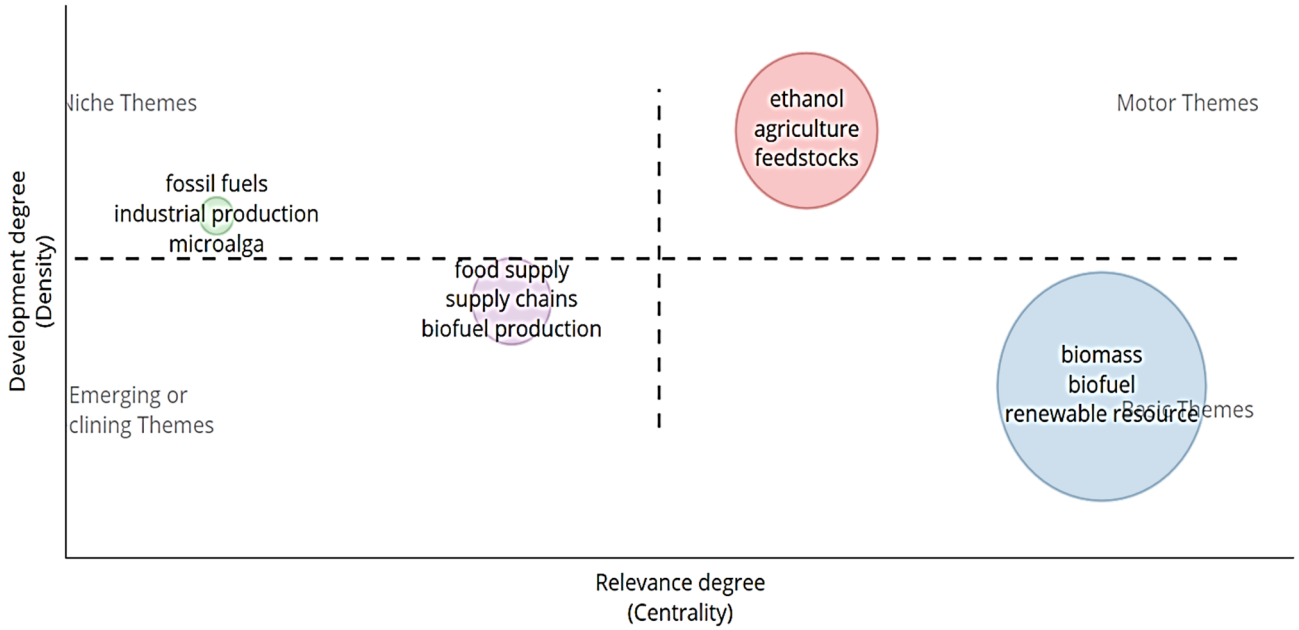

Figure 5. Thematic map of the research trajectory. Source: authors' own construction.

The "motor themes", situated in the first quadrant (upper right), are marked by high centrality and density, demonstrating their mature and foundational nature, critical to structuring research within the field. Notable keywords here include "ethanol", "agriculture", and "feedstock". In contrast, the second quadrant (upper left) comprises "niche themes" like "fossil fuel", "industrial production", and "microalga", which, despite their high density, have low centrality, indicating their specialized focus but limited influence on the broader field.

The third quadrant (lower left) contains "emerging" or "declining themes", characterized by low centrality and density, signifying either nascent areas of research or those diminishing in relevance, with keywords such as "food supply", "supply chain", and "biofuel production". Conversely, the fourth quadrant (lower right) houses themes like "biomass", "biofuel", and "renewable resources", which, while central, are not densely developed, pointing to their significance and potential for growth in multidisciplinary studies.

These quadrants collectively reflect the diversity of themes: "motor themes" indicating mature and central topics, "niche themes" representing specialized yet less central research areas, "emerging or declining themes" suggesting areas that are either growing in interest or diminishing in focus, and "basic and transversal themes" that are significant but still evolving. To facilitate reader comprehension, the manuscript should articulate each axis' definition and explicate how the themes' placement within the quadrants denotes their role and development in the research landscape, thereby illuminating the strategic positioning and interrelations of various research themes.

Figure 6 provides insights into the evolutionary path of research trends related to the three essential pillars of this study: biomass, the energy market, and the food market. The results show an emerged and evolution of the trend and focal points over the years. Initially, in 2010, the focus was on the European Union, competition, and lignocellulose. This focus shifted in 2011 to biofuels as the most significant topic and, in 2012, there was a strong emphasis on ethanol, biofuels, and bioenergy. It is important to note that these trends often coexist and overlap across consecutive years, demonstrating the growing breadth of research in addressing fundamental aspects related to biomass for food and energy. The trend also indicates that biomass became the central focus as the most prominent topic from 2013. Meanwhile, in 2014, keywords such as renewable resources, biomass power, and agriculture gained significant relevance within the research landscape. In 2015, topics like commerce, cultivation, and climate change emerged as the most prominent. Starting in 2016, the focus expanded to include cost, decision making, and biogas unfolded, thereby signifying the emergence of a new research domain with an emphasis on economic and managerial perspectives. These shifts in research topics may partly explain the decline in the annual scientific publications related to biomass for food and energy, as recent topics tend to be more focused on market indicators and managerial factors.

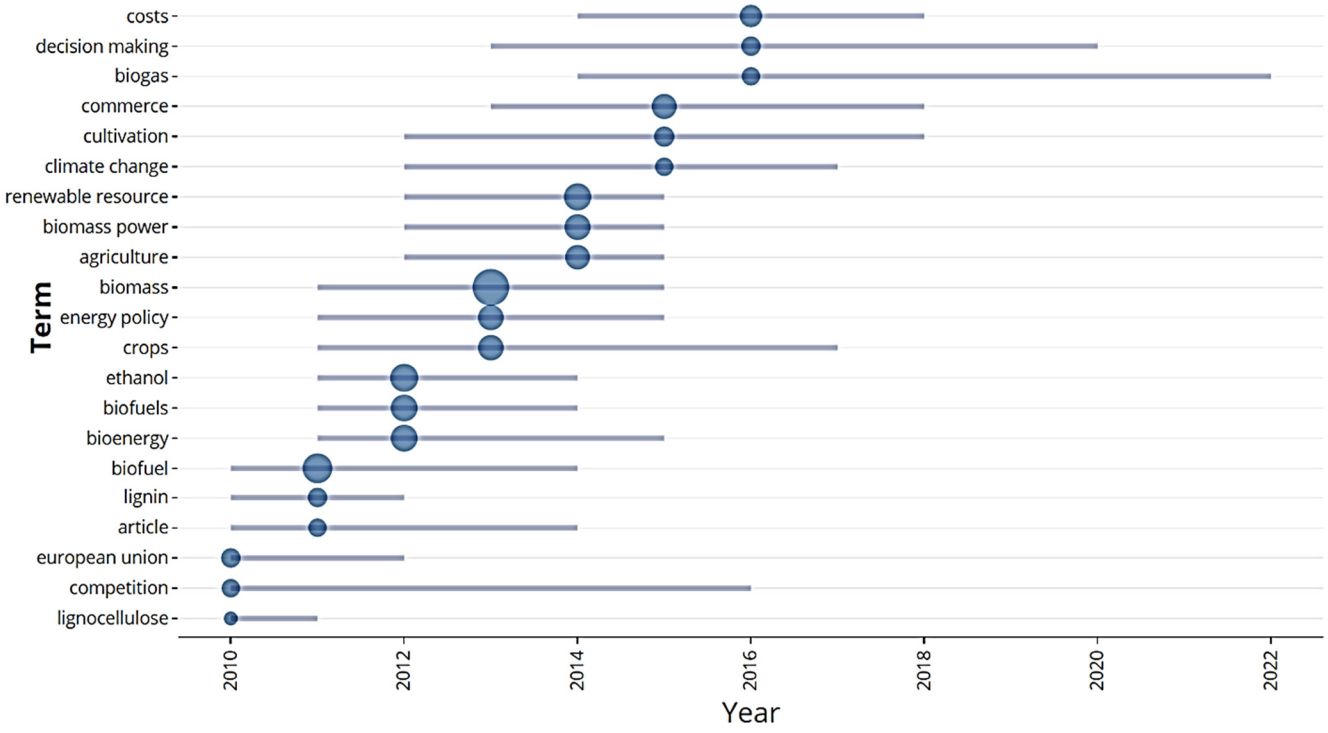

Figure 6. Research trend topics. Source: authors' own construction.

4.2. Market Factors

The 73 articles in this study shared various perspectives on the economic relationships between biomass use for food and energy, especially in connection with important market characteristics. The most prominent themes, which will be discussed below, have emerged from the reviewed literature. The emergence of these hot topics, which aligns with the trending topics and thematic map, demonstrates the far-reaching impact of the circular economy and bioeconomy agenda, which is driving increasing interest in the market aspects of biomass use in research. The conceptual diagram in Figure 7 succinctly summarizes the interconnectedness of the two market contexts described in this section.

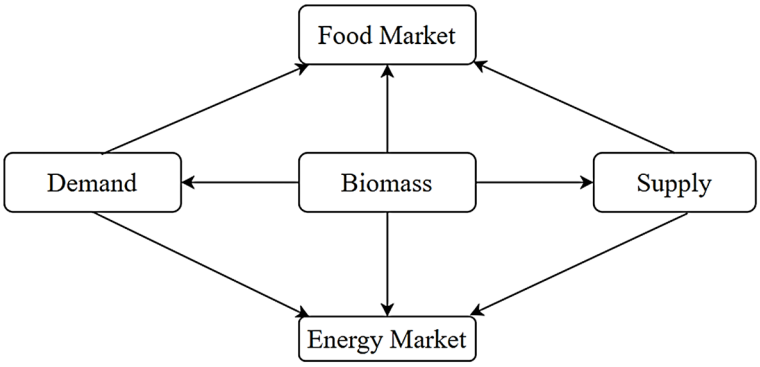

Figure 7. Conceptual framework. Source: authors' own construction.

4.2.1. Most Important Cost Elements

Cost is one of the most significant themes appearing as a market factor in about 84% of the 73 articles examined. The papers discussed the importance of cost considerations in determining the feasibility and profitability of biomass for bioenergy, biomass for food, and waste-to-energy sectors. The analysis highlights how market dynamics influence the economic viability of bioenergy derived from biomass, with variable prices dependent on factors such as energy value and conversion costs. The relationship between biomass and food costs is alluded to, emphasizing the trade-offs and considerations associated with land use. Various aspects of cost, including fuel, transportation, machinery, and opportunity costs, are extensively explored in the studies. They identify feedstock cost, high production cost, and market fluctuations as critical challenges facing the biomass market. For instance, Gallagher (2014) [48], Goh et al. (2014) [49], Lin et al. (2013) [50], and Maroun and La Rovere (2014) [51] all acknowledge that the commercial use of maize for bioethanol production triggers an increase in corn price.

Ethical concerns regarding the use of food resources for energy generation and its subsequent impact on prices are also highlighted in the literature [52–55]. These sources discuss economies of scale, government policies, technological uncertainties, and long-term projections as important cost elements. A notable example is the estimated cost of future microalgae biofuels, which varies widely between USD 2 and USD 7 per gallon. This variation indicates significant uncertainty in production costs [56–58]. The evaluation provides valuable insights for policymakers, industry stakeholders, and researchers in building a sustainable and efficient biomass utilization system.

4.2.2. Demand Tendency

The analysis of market dynamics in the reviewed articles places significant emphasis on the concept of demand, particularly concerning bioenergy. The research underscores the profound impact of bioenergy demand on several critical aspects, such as food security, land utilization, and water resource management. Notably, the articles delineate the intricate interplay among agricultural practices, bioenergy production, and food crop cultivation, highlighting the strain that escalating demand exerts on these interconnected resources.

A focal point of the analysis is the exploration of the relationship between the demand for bioethanol and fluctuations in food prices. This examination posits a potential linkage between the allocation of food crops for biofuel production and its consequent effects on food supply chains. Moreover, the global repercussions of energy policies, particularly in the context of utilizing agricultural by-products like rice husk for bioethanol generation, are identified as significant factors influencing biomass demand.

Further, the articles delve into the progress in biomass processing technologies and energy system advancements, along with addressing the logistical challenges inherent in biomass transportation. In light of these findings, the research underscores the necessity of strategic regional planning for renewable energy deployment. It advocates for the

optimization of existing biofuel production models and the efficient management of land resources to bolster the sustainable utilization of biomass.

Importantly, the present-day energy and food sectors are interdependent, especially in the context of resource utilization [51,59–62]. This nexus suggests that an increase in biomass demand for energy could impact food resources. Conversely, biomass for bioenergy also faces competition from alternative energy sources. Implicitly, there is a need for robust policies, strategies, and dynamic approaches to balance the increasing demand for bioenergy with food security. Additionally, the potential consequences of increased biomass demand, such as deforestation and biodiversity loss, pose serious threats to the ecosystem.

4.2.3. Supply Tendency

A significant portion of 33 out of the 73 articles analyzed revealed various connections or relationships between biomass supply for food and energy. The integration of biomass as an energy source has had profound effects on both the energy supply and food supply systems. In response, developed nations have implemented strategic plans to achieve a specific percentage of their energy supply from biomass. Similarly, different regions are introducing various models to determine the most economically optimal structure for energy supply, considering energy service requirements and environmental policies [63].

Carbon taxation mechanisms are pivotal in promoting the utilization of biomass as a renewable energy resource. However, their design necessitates careful consideration to avert any inadvertent detrimental effects [63,64]. The harmonization of policy frameworks across different economic landscapes is critical to ensure a cohesive transition within the global energy supply chain. The reform of energy systems and the incorporation of biofuels into the expansive energy matrix are interrelated elements that significantly impact the worldwide energy supply dynamics. Achieving an equilibrium between the supply and demand of biofuels is essential to optimize the efficacy of biomass exploitation.

4.2.4. Food–Energy Competition

Existing sources extensively categorize biomass competition into two main strains. Extensive studies have focused on the category of resource-based competition, which centers on the utilization of natural resources. However, the aspect of market competition, pertaining to the contest within the market for products and services, has received only limited attention. Meanwhile, the concept of global food security is closely linked to the balance between food and bioenergy production [51,52,60,65]. Concerns arise as resources are increasingly directed towards biofuel production to meet the growing energy needs, potentially reducing the accessibility and affordability of food. Therefore, it is crucial to strike a balance between the two to ensure that both food and biofuels can coexist without negatively impacting global food security.

Approximately 53% of the analyzed articles discuss various significant aspects of competition in the market dynamics surrounding the use of biomass for bioenergy and food. These articles highlight the potential of bioenergy to contribute to the reduction in greenhouse gas emissions and to address climate change, which is a major factor driving the use of biomass for energy. It also sheds light on the impact of market forces on mode selection and the competition between food and fuel markets, raising concerns about food security and prices. However, a comparison between first-generation and second-generation bioethanol supply suggests that the use of second-generation biofuels may not pose significant competition to the food market. This emphasizes the necessity of circularity in achieving sustainability.

Furthermore, utilizing non-food crops such as mesquite and rangeland shrubs as biomass for bioenergy feedstocks presents a significant advantage; it eliminates competition with food markets [52,66]. Practically, the comparison between lignocellulosic ethanol and food-based ethanol indicates that ligno-ethanol may be a more appealing alternative. This consideration is especially important given the growing demand for both food and energy.

Therefore, the use of biomass that is not directly consumed as food can minimize the conflicting interest and competition between energy production and food availability, thereby mitigating potential negative effects on global food security. In addition, the exploration of the biofuels market in developing countries also holds considerable potential for improving their socio-economic conditions. Hence, achieving a balance is the most important element in managing this competition.

5. Conclusions

In conclusion, this research elucidates the importance of biomass in contributing to food and energy security within current development. The preliminary findings have revealed various perspectives and connections, highlighting the emergence of distinct research themes over the years. It is noteworthy that the analysis has uncovered a negative growth trend with significant fluctuations spanning from 2010 to 2023, indicating a need for further empirical studies.

The review identifies key trends, niche interests, and the dynamics of knowledge production in connecting renewable energy, sustainability, and the environment. Economic and managerial perspectives have become a focal point, evident in themes such as cost, decision making, and biogas. The increasing emphasis and investments in energy transition, circular economy, and bioeconomy, with biomass at its core, are anticipated to stimulate further growth in this research area, potentially reversing the negative trend observed.

However, unprecedented factors like the COVID-19 pandemic have significantly impacted research within the field of biomass utilization. During this period, research output reached its lowest point, with an alarming annual growth rate of −10.93%, suggesting a potential decline in research output related to this subject. This trend underscores the urgent need for renewed attention and investment in this field.

The present findings underscore the need for further research to explore the long-term economic feasibility of utilizing biomass as a viable alternative to contemporary liquid fuels. While biomass has shown promise in terms of its potential as a renewable energy source, it is crucial to gain a comprehensive understanding of the variables that impact the costs associated with various biomass cultivation systems. This deeper investigation will provide valuable insights into the economic viability of biomass utilization and inform decision-making processes.

Additionally, there is a significant research gap regarding the potential connections between biomass utilization for both food and energy, particularly in the context of market competition within the biomass sector. Previous studies have primarily focused on Europe, North America, and Oceania, with some progress observed in Asia and South America more recently. However, there is a specific urgency for comprehensive research in Africa, where the reviewed articles did not reflect any relevant studies, emphasizing the need for global inclusivity in research.

To address these research gaps, interdisciplinary collaborations between researchers, policymakers, industry stakeholders, and local communities are crucial. A more holistic understanding of biomass utilization can be achieved by combining expertise from various fields, including agriculture, energy, economics, and environmental science. Such collaborations can also facilitate the development of sustainable and efficient biomass cultivation and utilization practices that take into account local contexts, socio-economic factors, and environmental considerations.

Furthermore, the potential of biomass utilization extends beyond its role in energy production. It also has significant implications for food security, particularly in regions where biomass resources can be harnessed for both energy and food production. Exploring the synergies and trade-offs between biomass utilization for food and energy is essential for maximizing the benefits and minimizing potential negative impacts. This requires integrated approaches that consider the entire value chain, from biomass production to processing, distribution, and consumption.

Finally, the importance of biomass in contributing to food and energy security cannot be overstated. While there are challenges and research gaps that need to be addressed, the increasing emphasis on energy transition, circular economy, and bioeconomy provides opportunities for further growth in this research area. Therefore, by conducting comprehensive research, fostering interdisciplinary collaborations, and considering the social, economic, and environmental dimensions, biomass utilization can be harnessed as a sustainable and viable solution for meeting the growing global demand for food and energy. Prioritization of investments and attention in this field by policymakers, researchers, and stakeholders is crucial for a resilient and sustainable future.

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