Review

Innovations in Forest Bioeconomy: A Bibliometric Analysis

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Abstract: Innovations are a key component of the forest bioeconomy. Many types of innovations are needed for an efficient forest bioeconomy to be deployed. This article aimed to analyze the scientific literature on the topic of innovations in the forest bioeconomy, to understand where we are and where we are likely to be in the future, considering technologies, business models, etc. First, the scientific literature, in the form of peer-reviewed articles indexed in the Web of Science, was compiled in a comprehensive dataset, on which we analyzed the most important authors, their affiliations, regions they come from, journals where papers were most commonly published, and under which categories the papers were indexed. The total number of papers matching the keywords was 161. We found that the number of papers published on the topic is increasing and that, on average, each paper was cited 18 times. A total of 504 authors dealt with the topic, presenting a rather small community. This finding was reinforced by the outcomes of the analysis of regions where the authors of the papers were affiliated—Europe being the region to which most papers were affiliated. We conducted a qualitative synthesis of the literature on forest bioeconomy innovations. We found that authors dealt with the necessary adaptation of policies, while innovations were mainly focused on biorefining, biotechnology, production of various biomaterials, as well as innovations of business models and stakeholder interactions.

Keywords: innovation types; biorefining; cascading use of wood; wooden buildings; bibliometric analysis

Citation: Jankovský, M.; García-Jácome, S.P.; Dvořák, J.; Nyarko, I.; Hájek, M. Innovations in Forest Bioeconomy: A Bibliometric Analysis. *Forests* **2021**, *12*, 1392. <https://doi.org/10.3390/f12101392>

Academic Editors: Alessandro Paletto, Zuzana Dobsinska and E. Carina H. Keskitalo

Received: 30 August 2021
Accepted: 8 October 2021
Published: 12 October 2021

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1. Introduction

Environmental damage has gradually become one of the common concerns worldwide, and topics such as climate change, food and energy security, resource scarcity, and industrial restructuring have been brought to the attention of governments, industries, and academic circles which are trying to avoid the increasing repercussions in nature and society [1]. With a better understanding of environmental issues, public awareness of environmental protection is increasing. The only relatively effective efforts towards a partial solution to these challenges resulted in a focus on sustainable development and holistic strategies to tackle them. Not long ago, new concepts were proposed which integrate economic, environmental, and social aspects of sustainable development [2], one of them is the bioeconomy. The concept of the bioeconomy plays a significant role in a novel solution for old problems [3]. It encompasses all activities related to the production, use, and transformation of renewable biological resources (bioresources). These activities aim at sustainably meeting food needs and some of the material and energy needs of societies while preserving natural resources and ensuring good quality environmental services through innovation [4].

Being a knowledge-driven concept [5], the bioeconomy has the potential to substantially contribute to solving global problems in an integrated framework [6]. It relies on strong science and technology bases and a dynamic and innovative approach, supported

by the public sector, market, and social pull, encouraged by industry and investors as well as by policymakers and civil society [3]. A whole spectrum of innovations is needed to deploy a functioning and efficient bioeconomy. They range from (i) product-based innovations that enable the private sector to offer products that tackle the global challenges; (ii) optimization of the use of biomass as feedstock; (iii) innovations in the supply chains to increase the efficiency of production and decrease the pressure on land; (iv) innovative cooperation between previously segregated sectors; (v) social innovations that change the way consumers use things and services and many others [6]. In short, the change from a fossil-based economy to a bioeconomy carries the need for profound innovations.

Innovation, thus, plays a central role in the transition towards a sustainable bioeconomy both on the supply side (new technology and products) and the user side (consumption and waste patterns) [7]. The rather complex transition will require an interplay between multiple innovative technologies that use bioresources as feedstock and innovative modes of consumption, resulting in the need for close cooperation of a multitude of actors from multiple sectors [8]. The open innovation approach [9,10] seems appropriate for use in the conditions of increasing globalization, intensifying technology, new business models, and the radical and disruptive innovations associated with bioeconomy transition. Open innovation can be defined as the purposive inflow and outflow of knowledge to accelerate internal innovation and expand the markets for external use of innovation [11]. According to [12], successful adoption of the open innovation approach necessitates (i) choosing relevant stakeholder groups that are important in innovation processes; (ii) having a well-developed and managed innovation strategy; and (iii) matching organizational prerequisites that facilitate open innovation.

As can be seen, innovation is not, as traditionally perceived, a simple, linear process, where fundamental research is followed by applied research, followed by market deployment [13]. Instead, innovation systems research describes it as an intricate collaboration between multiple actors, such as firms, research institutions, government bodies, associations, NGOs, entrepreneurs, and users, who develop networks, enabling the transfer of knowledge, beliefs, and visions [14]. Among other vital components, knowledge transfer and close cooperation are likely to play a key role, creating a need for new formal networks, as classic sectors (in this case forestry, wood processing, or agriculture) are expected to shift, allowing new cross-sectoral actors to cooperate, form networks, and reveal emerging interest groups [7,15]. Because of the complexity of the innovation process and the associated networks and institutions, each phase has its own pitfalls that can prohibit the innovation from market success. So, it does not come as a surprise that many new technologies did not surpass the so-called “valley of death”—a phase between a successful demonstration and introduction to market [14]. Besides the new technology itself, its adoption depends on many factors, such as cognitive and social lock-in to well-known solutions, the alignment of the innovation to existing regulatory frameworks, technical constraints, or other socio-political and economic factors [16,17]. This points to a need to prepare the current policy and regulatory frameworks for the transition to a sustainable bioeconomy.

With this paper, we aim to identify the main clusters of researchers dealing with innovations needed for the deployment of an effective forest bioeconomy, where they are located and what the trends are in publication numbers. Therefore, we conducted a bibliometric analysis of the available peer-reviewed literature that deals with forest bioeconomy innovations (Section 3). The section identifies countries, institutions, persons, and publications important to the field of innovations in the forest bioeconomy. Additionally, we supplemented the bibliometric analysis with a qualitative synthesis of the literature, on which the bibliometric analysis was based. The synthesis served to provide a more in-depth view into the literature, describing the policy changes, stakeholder involvement, focal areas of innovations in the forest bioeconomy, as well as the modes and types of innovations that we found in the analyzed studies.

2. Materials and Methods

Bibliometric Analysis

To provide the readers with a broader outlook on the state of innovation in the forest bioeconomy, we conducted a bibliometric analysis of the papers contained in the Web of Science. We chose to limit the bibliometric analysis to papers included in the Web of Science database for the sake of comparability of results. Web of Science is a comprehensive database that covers multiple fields of study. It includes multiple journals deemed the most prestigious in their respective fields and provides a common ground for comparisons of papers, authors, and institutions through simple and well-known metrics, such as the number of citations.

To create the dataset, we researched the keywords: bioeconomy innovation, bio* innovation, bio-based economy innovation, bioeconomy technology innovation, forest technology innovation, and their truncated and hyphenated versions. We included papers in all research areas that fit the keywords. Besides author keywords, we included papers that contained the keywords from the list above within the article title, its abstract, or, after close inspection of the abstract of the papers for appropriateness, the “keywords plus,” as generated by the Web of Science. The papers included were restricted to the year range 2010–2021. Citation data were obtained from Web of Science in June 2021.

Based on the papers included in the dataset, we calculated the following indicators:

- Number of papers per year;
- Total number of citations;
- Citations per paper;
- Mean citations per paper and year since publishing;
- Number of papers published per journal;
- Number of paper citations per journal;
- Number of papers published per author;
- Counts of affiliations of authors;
- Counts of papers related to the type of institution, divided to (i) University; (ii) Research Institute; and (iii) Other institutions (e.g., Government agencies, Ministries, Private companies, etc.), based on the affiliations of the authors;
- Counts of papers published by authors from particular countries based on the affiliations of the authors;
- Counts of papers published by authors from particular world regions based on the affiliations of the authors.

The overall approach to the dataset consisted of the following steps: (i) identification of records in the database ($n = 203$); (ii) removal of duplicate records ($n = 161$); (iii) screening of records for the bibliometric analysis ($n = 161$); (iv) full-text assessment of studies for eligibility ($n = 161$); (v) exclusion of studies for the qualitative synthesis; (vi) synthesizing the contents of eligible studies in the qualitative synthesis ($n = 47$).

The qualitative synthesis part of the paper focused on identifying the most important innovation areas, as provided in articles used within the bibliometric analyses. Papers that met the following criteria were included in the qualitative synthesis: (i) the studies addressed innovations related to the forest bioeconomy; (ii) the study adopted an empirical approach; (iii) they discussed the subject of innovation pathways in the forest bioeconomy. The papers were read by at least two co-authors in their entirety, and their outcomes, conclusions, and implications were discussed by the authors. Subsequently, the information gathered from the papers was synthesized into a coherent text.

3. Bibliometric Analysis of Scientific Literature on Innovations and Technological Trends in Forest Bioeconomy

The Web of Science Core Collection contained 161 papers for the specified temporal range and keyword combinations that deal with technological innovations in the field of the forest bioeconomy. The mean number of papers published and included in the Web of Science database per year was 13, with an increasing trend, though, as Figure 1 shows,

the trend is erratic and contained several decreases in the number of papers published per year.

Figure 1. Number of papers per year included in the Web of Science database ($n = 161$).

In total, the papers included in our dataset were cited 2953 times. On average, each paper was cited 18 times, though the distribution was uneven—the ten most cited papers were cited 1232 times (42%) (Table 1), while 21 papers (13%) were uncited and the bottom 50% (80 papers) were each cited up to six times. The number of citations a paper achieved per year was six, with the number of citations of the top 10 most cited papers reached 27 citations per paper and year.

Table 1. Ten most cited papers and top 10 papers with most citations per year.

Most Cited Papers		Most Cited Papers Per Year	
Reference	Times Cited	Reference	Times Cited
[2]	338	[2]	85
[1]	221	[1]	44
[18]	148	[19]	41
[20]	96	[21]	30
[21]	91	[22]	29
[23]	88	[24]	25
[25]	66	[18]	25
[26]	64	[27]	23
[28]	63	[29]	23
[30]	57	[23]	22

There were some differences between the lists of most cited papers overall and those most cited per year since publication, with five papers appearing in both lists (Table 1). This had to do with the age of the papers—on average, the ten most cited papers overall were published two years before the ten papers with the most citations per year—as older papers had more time to gather citations than newer papers. On the other hand, a small core of impactful publications was visible.

Although a total of 504 authors were listed in the dataset, the impactful publications were written by a rather compact group of 26 (most cited papers overall) or 36 authors

(papers with most citations per year), many of whom have contributed to several papers (Table 2). On the other hand, almost 87% (438) of authors in the dataset contributed to one paper.

Table 2. Eleven authors with more than three publications in the dataset.

Author	Number of Papers
Toppinen, A.	10
Stern, T.	6
Hellsmark, H.	5
Bauer, F.	4
D’Amato, D.	4
Hansen, T.	4
Korhonen, J.	4
Ladu, L.	4
Ludvig, A.	4
Soderholm, P.	4
Weiss, G.	4

The authors of papers focused on the forest bioeconomy innovations primarily came from universities. Of the 255 institutions listed in the dataset, 133 were universities, 82 were other types of institutions, such as government agencies, government bodies, international organizations, companies, etc., and 40 were research institutes. In the top ten institutions, considering the number of papers in the dataset, only the European Forest Institute was a non-university type of institution (Table 3).

Table 3. Institutions with the most papers in the dataset.

Institution	Number of Papers
University of Natural Resources and Life Sciences Vienna	11
University of Helsinki	10
Lund University	8
European Forest Institute	7
University of Freiburg	6
Swedish University of Agricultural Sciences SLU	5
University of Graz	5
Oregon State University	5
University of Eastern Finland	5
University of Canterbury	4

The authors of the papers included in the dataset were affiliated with institutions from 43 different countries. Considering the countries to which the authors were affiliated (Table 4), most were European, with Germany (33; 15%), Finland (28; 13%), and Sweden (18; 13%) leading the list. Overall, authors affiliated with European institutions contributed to 66% of the papers, followed by authors affiliated to institutions from North American (14%), Oceanian (8%), South American (6%), African (3%), and Asian (3%) regions.

The 161 papers dealing with innovations in the forest bioeconomy were published in 59 journals. Almost two-thirds of all papers were published in twelve journals that contained at least three papers, and more than three-quarters of all citations were of papers that were published in these journals (Table 5). This shows that authors focus on publishing in a rather specific group of journals that attract considerable attention of the scientific community dealing with innovations in the field of the forest bioeconomy.

Table 4. The ten countries with the most authors of the papers included in the dataset.

Country	Number of Papers
Germany	33
Finland	28
Sweden	18
USA	18
Austria	16
Canada	10
Italy	8
New Zealand	8
Spain	8
UK	7

Table 5. Journals with at least three papers published.

Journal Title	Number of Papers	Share of All Papers	Number of Citations	Share of All Citations
Forest Policy and Economics	28	17%	352	12%
Sustainability	22	14%	686	23%
Journal of Cleaner Production	17	11%	740	25%
Forests	8	5%	38	1%
Croatian Journal of Forest Engineering	5	3%	98	3%
New Biotechnology	5	3%	123	4%
Environmental Innovation and Societal Transitions	5	3%	85	3%
Biofuels Bioproducts and Biorefining	3	2%	94	3%
Environmental and Climate Technologies	3	2%	44	1%
International Journal of Forest Engineering	3	2%	15	1%
Technological Forecasting and Social Change	3	2%	17	1%
International Forestry Review	3	2%	8	0%

A similar focus can be seen when looking at the Web of Science publication categories (Figure 2). Though journals are often listed in several categories, only 25 unique categories were identified for papers included in the dataset. Naturally, most papers were published in journals categorized under Forestry (25%), followed by Environmental studies (17%), Environmental Sciences (14%), Green and Sustainable Science and Technology (13%), while journals categorized under Textile, Ecology, Science, and Technology or Developmental studies only had one paper published in them. A clear focus on natural and technological sciences can therefore be seen.

Our analysis showed that innovations in the forest bioeconomy are gaining traction in the scientific community, and the community of researchers connected to forestry and forest-based industries is beginning to adopt the terminology related to the concept of the forest bioeconomy. We found that while higher education institutions, i.e., universities, hosted the most authors, a considerable portion of authors were affiliated with other types of institutions, such as government agencies, private companies, associations, etc., as well as research institutes. Moreover, much of the research was conducted in distinct regional clusters located in Europe (mainly North and Central Europe), North America (mostly USA), and Oceania (New Zealand), where forestry research is traditional and strong. As with the whole concept of the forest bioeconomy, the research is strongly topical, and the authors published their papers mostly in journals dealing with matters of forestry, the environment, sustainability, or economy, and to a smaller extent with biotechnology, engineering, material sciences, all of which are at the core of the focus of forest bioeconomy innovations.

Figure 2. Share of papers published in journals listed in Web of Science categories; 15 most prominent categories listed.

4. Innovations in Forest Bioeconomy

The bioeconomy, as a novel and integrative concept, covers a variety of fields and disciplines, from health and the chemical industry to agriculture, forestry, bioenergy, and more. Engineering and natural science have a central role in the bioeconomy, generating a strong impact in the three types of bioeconomy visions, as identified by [1]. First, the biotechnology vision is based on the importance of the application and commercialization of biotechnology in different sectors of the economy. Second, the bio-resource vision focuses on processing and upgrading bioresources coming from forestry, agriculture, and fisheries that establish new value chains. Finally, the bio-ecology vision highlights sustainability and ecological processes. These visions present a complementary strategy resulting in synergies in terms of research and innovation. However, it is important to consider the societal and economic implications following the principles of regional and national context [1].

Although the bioeconomy is based on using bioresources in manufacturing and services, it is not inherently sustainable and brings new challenges to face. To make the bioeconomy sustainable, it needs a strong social and ecological perspective, though this is frequently not sufficiently addressed in the connected strategies. Ecological viability, economic feasibility, and social acceptance are the sustainability targets that can be achieved through economic growth and innovation. Albeit, this last statement is difficult to accomplish without decoupling economic growth from environmental degradation [21,29,31]. For instance, the increasing demand for bioresources will put a lot of pressure on the limited biomass and land resources, potentially causing several sustainability problems. Here, using novel technologies can reduce the negative impact of the large-scale use of biomass. On the other hand, these innovative technologies should not be taken as an immediate solution to this problem. Innovation needs to go hand in hand with ecological and social responsibility in optimal combination and implementation to alleviate the competition for land use, as well as deforestation, water, and land footprints, and others [2,31].

Innovations function as one of the most important drivers to foster more political and environmental support needed to meet the sustainability embedded in the bioeconomy. Although many national strategies stress the ecological benefits of bioeconomy innovation, not all innovations lead to intended improvements in terms of sustainability. This is a result of a substantial number of uncertainties that go along with the design and implementation

of innovations. Therefore, innovations require a gradual, adaptative, and credible commitment plan to approach this transition in the best way. Innovation is, thus, a double-edged sword—partly the problem, partly the solution to reaching sustainability of the forest bioeconomy [2,31].

To provide sustainable alternatives for technologies and products, as well as adjustments to the consumption and waste generation patterns, a range of innovation types are needed [8,32]. The literature distinguishes four distinct innovation types (IT), classified by their development status, in the bioeconomy [32]. Innovation type 1: “Substitute products” is based on the replacement of fossils-based products by bioresources. Innovation type 2: “New processes” promotes bio-based production and value chains. Innovation type 3: “New products” focuses on bio-based materials with new functions. Finally, IT4: “New behavior” describes a new way of doing things, either concerning interactions or actions of the customers, or new ways of collaborating with stakeholders, etc. (Appendix A). To succeed, ITs require combining different knowledge areas and overcoming challenges concerning interdisciplinary development, such as market uncertainties, value chains, resources, innovation capacities, knowledge integration, or attracting end-users/consumers. So, innovations require anticipation, reorganization, and, related mainly to the IT4, balancing their economic and ecological benefits. To figure out their dynamics and understand what policy measures result in noticeable improvements or fill an existing gap, monitoring the activity for particular ITs is also needed. From an economic systems perspective, systems undergoing broad, disruptive innovations need a high degree of resilience to adapt to the associated disruption accompanying innovations, especially when the bioeconomy competes with the established economic systems dependent on fossil resources and products [3,12].

In addition, the specific situation of technology and innovation management (TIM) transcends national, regional, and sectoral boundaries, thus encompassing IT2. In line with this, [8] lists bio-based chemicals and wooden-based buildings, categorized as complementary and competing TIMs. Aside from the requirement to anticipate and reorganize the market or integrating knowledge, TIM also stresses that the need to support niches and indirect demand-pull is essential in bringing technologies forward, as is the use of large-scale deployment support for creating new bridging markets. In addition, it is necessary to keep in mind that networks, public-private intermediaries, or other stakeholders can ease the transition while innovations are being implemented. Thus, proving the need for proper planning and preparation in the complex innovation implementation process [12].

Aside from political vision and innovative technology, the role of actors from the private sector, especially innovative entrepreneurs, is crucial for the transition. Entrepreneurs enable transformation not only through introducing new products and services but also through reestablishing the process of value creation and redesigning business models for enhanced efficiency and sustainability. Interaction of activities on a micro-, meso- (entrepreneurial ecosystems or clusters), and macro- (governmental vision) levels result in acknowledging the importance of entrepreneurship perspectives. The interaction also serves as an essential resource for societal and economic transformation, motivated by creating and reconfiguring value chains while seeking stable solutions [33].

Considering the crucial role of entrepreneurs and industrial stakeholders in bioeconomy innovations, they should be incentivized to opt-in on a long-term scale. However, this is often not the case. Lovric et al. [34] found that most innovations are far from a market application, and the organizations that participate in the European forest bioeconomy projects only participate once. After the initial, low technological readiness level innovations, no project follows up to bring the innovation to the market, and there are few innovation cases in the later stages of development. Furthermore, innovations in several Central European countries are seldom funded; the support was given by different external stakeholders, which shows a lack of finances [34]. Finally, the authors [34] concluded that different from “routine and safe” types of innovation, bioeconomy innovation should be backed by policy spheres.

Several authors have recognized the need for more investment in research and development, policy strategies, and incentives to boost the bioeconomy [32,35]. However, great care should be given to developing political frameworks because if inappropriately deployed, overuse of bioresources can have severe negative environmental impacts, resulting in unsustainability and possible political conflicts. Despite a considerable body of literature on bioeconomy policies, more research is needed, focusing on the analysis and concrete comparisons of cases and emerging policies in this field to strengthen transition-oriented innovation systems [8,36]. According to [36], there is a need to identify key causal mechanisms in bioeconomy politics to reveal underlying power relations, conflicts of interest, and relevant impacts on the environment and more consistent, homogeneous, and less fragmented policies.

Bioeconomy strategies often describe the roles of entrepreneurs in detail. Nonetheless, the level of detail, as well as the definition and the focus on products and market, found in a strategic document will vary depending on the scale (e.g., national or regional) of the implementation [37]. Most of the bioeconomy strategies were made in the EU, and the most recent were proposed by UK, Finland, Czech Republic, France, Italy, Latvia, Norway, and Spain. Despite the different approaches in different parts of the world, whether it is related to bio-based buildings (The Netherlands), using biomass for energy, wood-based biorefining (Italy), or macro-regional bioeconomy policies (Latin America and Eastern Africa), the aim of the strategies is alike. The strategies aim to promote collaboration between similar regions (in terms of resource availability and economic power), increase the value of local bioresources, create job opportunities, and improve regional innovation systems as a base for sustainability [37]. Bezama et al. [37] promoted the concept of “economies of scope”, in which bioeconomy regions could have a wide range of bio-based industries cooperating within networks and clusters while having a diversified product basket, based on a regional smart specification strategy, thus creating a region of collaborators.

Another study in the area of forest-based bioeconomy focused on the services and activities that cover primary production and manufacturing–processing, service outputs from tangible products, and services as strategies (business model with value creation) [38]. The analysis was conducted at the European level, not national and regional strategies. According to the authors, most of the bioeconomy strategies mention the importance of natural ecosystem services and their contribution to society. The strategies will improve the contribution of the ecosystem services to resource efficiency and solving the challenges associated with climate change, land use, and global food security. For example, to unlock the potential of the UK’s bioeconomy, innovation efforts are needed in the country [39]. These include amending the public procurement guidelines to promote biobased products, promoting joint public–private investments with an emphasis on attracting large innovative companies into the UK, and achieving wider public consensus and support. Biotechnology and innovation were identified as the main drivers of the development of the Czech forest bioeconomy. Still, the country needs to ramp up funding and financial and political support to increase the efficiency of bioeconomy deployment in the country [24].

Outside the EU, innovations being implemented are focused differently, as in the US, where the bioeconomy has gained interest too recently. In contrast to the EU, which emphasizes sustainability, the trend in the US includes genomic sequencing for individuals and a stronger focus on life science [33]. In 2012, the government released a document, “National Bioeconomy Blueprint” recognizing biotechnological innovation as a strong driver of bioeconomy growth. The document focuses on the necessity to develop more efficient biorefining technologies and co-producing fuels, chemicals, fibers, polymers, heat, and electricity. Thus, commercial production of bioethanol, biodiesel, biogas, bioheat, and biopower, as well as manufacturing commercial bioproducts, such as biopolymers, biochemicals, biopharmaceuticals, and bio-adhesives, are to be widely practiced. Commercial production of lignocellulosic ethanol, renewable diesel, green jet fuel, and other advanced biofuels is at the demonstration stage, demanding improved cost-effectiveness and eco-

nomic viability. On the other hand, barriers, such as the high cost of biomass feedstock, lack of cost-competitive bioproducts that function at least as well as their petrol-based counterparts, and unstable biofuel and bioproducts market, still need to be overcome. Thus, it is crucial to integrate biorefining processes (bioenergy and bioproducts) under one roof [40].

The innovations listed (Appendix A) are similar in involving a variety of industries in leading to specific changes that improve the various sectors of the bioeconomy. They often focus on biotechnology as a substantial part of the engine that drives growth, innovation, and increases productivity. Products or processes from other branches of the bioeconomy need to pass through some form of biotechnological or biorefining process to generate the final product [41,42]. In short, industrial biotechnology and biorefinery go hand in hand with the use of bioprocesses for greener products and are interconnected [41].

The biotechnology area involves novel sources of biomass and blue technology, where terrestrial and marine-derived materials need to be co-bioprocessed. Industrial biotechnology (or biorefining) is applied in segments that range from specialty chemicals, bio-based plastics, biolubricants, biosurfactants, to biofuels, bioenergy, and other biomaterials. High-value products are always the preferred outputs of biorefining, so a boom in new enzymes with applications in the medical, environmental, food, and chemical sectors is expected [14,41].

These new products are to be produced by resource-efficient biotechnological methods rather than conventional ones. The fact is, however, that there are only a handful of operational biorefineries capable of production of these products, and their value chains differ from one to the other in aspects such as volume/price, potential advantages, product characteristics, maturity, and sector [42]. In this, industry partnerships will help, by allowing more combinational and recombinational modes of innovation, though interdisciplinary and intersectoral collaboration will be required as well [14].

An example of a sector well underway of transitioning from fossil-based products to bioproducts is food packaging, with evidence backed by research [43,44]. The bioplastics used for food packaging are compostable and could be used circularly. This serves as a model for other industries, such as textile and technics, to pursue this transition. A recent study [45] suggested that textile manufactures should transition in cooperation with the retailers, thus providing better market access. Whether the textile industry cooperates in price or cost, both should increase the average clothing sustainability. Furthermore, cooperation between the textile and food sector constitutes a win-win situation, where new knowledge and new models to be implemented are acquired, as well as the ability to put less pressure on the environment by removing the trend of fast fashion.

Cooperation, support, and learning from other sectors is a circular experience that makes the bioeconomy transition smoother and friendlier. For instance, the forest bioeconomy is an important sub-sector of the overall bioeconomy, under which forests are managed in a sustainable mode. They are projected to provide a significant contribution of biomass and have “classic” applications, such as wood processing or pulp and paper [7,46]. However, the forest sector was perceived as a conservative industry, with traditional business culture and little experience collaborating with other industries, unlike the companies they partnered with. Recently, this perception of forestry has shifted towards an image of a welcoming industry, which may lead to the incorporation of forest-sector companies into other supply chains, creation of new partnerships, sharing best practices, and facilitating innovation. Ultimately, collaborating with firms from other industries may lead to an improved capitalization of forest companies in the growing bioeconomy [18,47,48].

To reach collaboration between the sectors, an innovative process was needed to realize the future bioeconomy of products. Though any sector welcomes new ideas being introduced, these frequently underdeliver, regardless of how good they seemed to be on paper. A key could be to ensure adequate extension amongst the target audience. This fosters a requirement for a successful implementation of innovation and encourages the forestry community to engage in innovation [46]. The innovations summarized in

Appendix A show that innovations in the forest bioeconomy range from ‘classic products’, passing through improvements in forest data management and usage, harvesting both timber and non-timber forest products, to biorefining. Some of these products are more familiar than others. In summary, this set of innovations served as a reference point to analyze all possibilities that forest-based sectors offer to our society.

5. Concluding Remarks

This paper focused, first and foremost, on analyzing the state of innovations in the forest bioeconomy in scientific literature. Besides the unsurprising high share of papers being published in journals related to the forestry category, many were published in journals that deal with environmental studies and sciences. This points to the prominent role of sustainability and environmental responsibility associated with the bioeconomy. Another encouraging fact was that green and sustainable science and technology or other technical publication categories were among those with high publication numbers. This points to concrete technological innovations being reported in the literature. On the other hand, though the increasing interest of the scientific community in the topic is laudable, we found that most papers were published in just a few regional and institutional clusters. Further efforts are therefore needed to increase the output and improve its quality in regions outside Europe and North America.

From the literature analyzed, it was apparent that the transition to the forest bioeconomy will be accompanied by substantial innovation efforts. Besides their more talked about benefits, these innovations will likely cause disruptions and, as any substantial economic shift, will create a complex web of winners and losers. To minimize these negative effects, bioeconomy transition will require not only profound technological innovations but also adapted policies and strategic documents, as well as innovations of the way stakeholders collaborate. The scientific community is aware of the necessity to precede innovations with appropriate and complex adaptation of policy frameworks based on science, which can be seen in the number of papers dedicated to changes of policies and strategic documents connected to bioeconomy transition.

Concrete innovations will likely cover all innovation types, ranging from substitute products through new processes, new products to new behaviors. Such innovations were already introduced to certain sectors, e.g., the case of bioplastics in packaging and their introduction in the textile and technics industries. Another example of an ongoing shift to bio-based solutions can be seen in the construction sector and the increasing share of wooden buildings in Europe. Biorefining, on the other hand, represents a case with slower uptake. This is caused by the complexity of the case regarding technologies, supply chains, inadequate regulatory frameworks, or lock-ins to existing solutions from potential consumers of biorefining products. In short, the transition to the bioeconomy is a complex issue, with numerous bottlenecks and problems that need to be solved. However, with well-devised regulations, resilient economies, and innovation-driven industries, the efforts will ultimately lead to the deployment of an efficient and sustainable forest bioeconomy.

Author Contributions: Conceptualization, M.J. and M.H.; methodology, M.J., J.D. and M.H.; software, M.J.; formal analysis, M.J., M.H. and I.N.; investigation, M.J., I.N., S.P.G.-J. and J.D.; resources, M.H.; data curation, I.N.; writing—original draft preparation, M.J., J.D. and S.P.G.-J.; writing—review and editing, M.J., J.D., S.P.G.-J., M.H. and I.N.; visualization, M.J.; supervision, M.J.; project administration, M.H.; funding acquisition, M.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Národní Agentura pro zemědělský výzkum, grant number QK1920391 entitled “Diverzifikace vlivu biohospodářství na strategické dokumenty lesnicko-dřevařského sektoru jako podklad pro státní správu a návrh strategických cílů do roku 2030”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data, upon which this paper is based is available at the authors upon request.

Acknowledgments: This research was funded by the Národní Agentura pro zemědělský výzkum, grant number QK1920391 entitled “Diverzifikace vlivu biohospodářství na strategické dokumenty lesnicko-dřevařského sektoru jako podklad pro státní správu a návrh strategických cílů do roku 2030”.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of forest bioeconomy innovations across their different areas.

Area	Location, Reference	Materials	Description
Based on “classic” products (woodwork, pulp and paper)	Europe [22]	Pulp and paper industry (PPI) and other cellulose-based products.	Transformation of the actual business model to increase its profitability with value-added bio-based products, while contributing to climate change mitigation. Potential strategies that are proposed: Evaluation of strategic options; Marketing to address new customers; Optimization of biomass; Research cooperation and new value chain; Policy support.
	World [49]	Lignocellulose-based products; Cellulose chemical; Cellulose textile fibers	Substitution of fossil-based materials with lignocellulose-based products in the chemical and textile industries. Inclusion of lignocellulosic products into global forest sector scenario modeling. The elasticity estimates the import demand and consumption can be used synonymously as, e.g., demand elasticities for adaption of economic equilibrium models for the forest products market. TIS approach, only an exploratory work.
	Germany [7]	Lignocellulose biorefinery	Main importance to actors’ perception (forest and wood industry, chemical industry, and energy sector). Policy integration issue is one of the biggest obstacles due to cross-sectorial concepts, such as biorefinery. Forest biorefineries are still far from competitiveness in Germany. Technology readiness is crucial for the transition.
	US [50]	Cellulosic biofuel pathways	Hypothetical future containing additional cellulosic ethanol produced from two-near commercial pathways. Cellulosic biofuel pathways may not be environmentally beneficial across all metrics but are likely to provide net socioeconomic benefits. The associated relatively higher costs and lower sugars yields hinder the adoption of these lignocellulosic biomass pretreatment technologies. TIS approach and four policy measures are the following:
Biorefinery	Sweden [28]	Biorefinery development	Implementation of deployment policy for creating domestic niche markets; Enhanced policy timing and more structured coordination among governmental agencies. Stronger incentives for mature industries to invest in R&D and improve their absorptive capacity. Improved organization and financing of existing research infrastructure.

Table A1. Cont.

Area	Location, Reference	Materials	Description
Bionergy	Pan-European [51]	Emerging Biorefinery technologies	<p>Knowledge developed at Pilot and demonstration projects (PDPs) is very important for emerging biorefineries technologies.</p> <p>Innovating actors active in biorefinery TIS create and shape the sustained change in a forest-based circular bioeconomy with strategies directed at the construction and operation of PDPs.</p> <p>Actor strategy could be the link between organizations and innovation systems.</p> <p>The PDPs have a strong technological focus on chemical and biochemical conversion as well as on biopolymers processing in high-profile plants.</p>
	Italy Norway Sweden Finland [52]	Biogas	<p>ER fast processes of biogas adoption, but they experience harmful consequences despite “good” expectations. When the actors involved do not fully cooperate or coordinate their actions—decisions to reach common goals and issues, then an active role of municipalities and knowledge centers can foster learning processes, the inclusion of better conflict resolution.</p> <p>Exploited their knowledge of local economic and social base to include a variety of actors.</p> <p>Foster links between old and new industries (industrial symbiosis).</p>
	World [53]	Big data and remote sensing	<p>Big data make easier to monitor forest and make informed decisions over their use and management, at lower cost, user-friendly formats, actionable and timely.</p> <p>There are many ways that forest data can be generated: from high-resolution satellite images to the mining of the “Twittersphere”, and genetic fingerprints, and it is harder to keep information hidden.</p> <p>Tools for forest monitoring are spatial resolution, temporal resolution, repeatability, and affordability.</p> <p>Augment geospatial data gathered through remote sensing.</p> <p>Site: Petawawa Research Forest (PRF) Supersite</p>
Harvesting	Ontario, Canada [54]	Remote sensing	<p>Data records are digital terrain model, canopy height model, airborne imagery, satellite remote sensing time series, and ground plot data, among others.</p> <p>Public data allow more users to directly access and use the data for further research and education purposes, also addressing new questions not previously conceived.</p> <p>Supersites can foster increased collaboration, sharing resources in the development of remote sensing applications. Benchmarking is one of the key applications, enabling efficiencies and reducing investment risk for stakeholders.</p>
	Europe New Zealand North America Other parts of the world [55]	Winch-assist harvesting	<p>Winch-assist system is considered as a major innovation in steep terrain harvesting.</p> <p>In steep terrain, harvesting operations have increased by removing workers from the hazard of manual and motor-manual work.</p>
			<p>It is considered more productive than conventional steep terrain harvesting and economic viable</p> <p>It could be a solution to shortening operating seasons and soil impact concerns.</p> <p>It is a relatively young technology, and the system productivity seems to be good but is often limited in their scope systematic comparison of productivity and costs.</p> <p>This is the first step to follow with the next stages in the forest bioeconomy.</p>

Table A1. *Cont.*

Area	Location, Reference	Materials	Description
Non-timber	China [56]	Non-timber products	<p>There is a trend of feminization in forest management, and it is more common in developing countries. This is because of the migration of rural male laborers for off-farm work.</p> <p>Feminization has affected rural households' decisions, and they are inclined to adopt labor-saving technologies (LSTs) and less inclined to adopt labor-intensive technologies in forest production.</p> <p>Due to the new technology adopted, new seedlings technology increases the non-timber forest products (NTFP) outputs due mainly to the higher quality of seeds, and that it requires less labor input than the other two labor-saving technologies.</p> <p>Government supportive policies can improve households' adoption of new technologies; the subsidies are for machinery and seedling purchases and continued investment in forest production.</p>

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