Exploring Environmental and Economic Costs and Benefits of a Forest-Based Circular Economy: A Literature Review

Dimitra C. Lazaridou 1,*, Anastasios Michailidis 2 and Marios Trigkas 1

Abstract: The role of a forest sector in the transition to a circular economy (CE) is critical. Therefore, the purpose of this study is to summarize the main findings of the most important published articles and to provide insights on the interdisciplinary space at the interface of concepts related to a forest-based CE. Moreover, it attempts to assess the challenges raised from adopting the CE in forest sector. Through a systematic literature review, 69 scientific publications were selected and evaluated by two sights: (i) a descriptive analysis and (ii) a cluster analysis of the keywords related to the forest-based CE. The study highlights the need for additional survey on optimizing the interaction between forest ecosystem services and circular economy. Further discussion is also needed about the relations of the key factors associated with the forest-based circular economy, as they emerged from the cluster analysis and the co-occurrence network map.

Keywords: circular economy; forest sector; systematic literature review; network visualization

1. Introduction

The circular economy (CE) is currently being globally promoted as a sustainability avenue, promising to reconcile environmental protection with economic and social development. Several countries worldwide have adopted CE principles, as part of their future strategies, mainly to answer the problems of resource scarcity, economic growth, employment and environmental challenges [1,2]. In Europe the CE is among the key contemporary policy goals. Particularly, European Commission associates the move to a more CE with strategies such as: boosting recycling and preventing loss of valuable materials, protecting natural resources and industrial symbiosis, creating jobs and economic development, can move Europe toward zero-waste, reducing greenhouse emissions and preventing environmental degradation [3]. Estimations reveal that the circular economy could yield over €600 billion per year to European economies and generate an additional €1.2 trillion in nonresource and externality benefits that together could boost GDP by 7% [4].

A circular economy can be defined according to Kirchherr et al. [5] study as: “...an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations”. In other words, the main objective of a circular economy is to achieve a minimal input and production of system “waste” by rearranging the life cycle of the “product”, so economic actors would exert no impact on the environment [6]. As partially described, a CE is based on the 4R framework (“Reduce”, “Reuse”, “Recycle”, “Recover”), aiming at mitigating the negative effects on the environment and incorporating...
the “cascade” principle, attempting to use the raw materials according to a priority based on the added potential value [7–9]. In this context, the used CE concept can be extended to “forest-based circular economy”, which particularly means reduction in the input of virgin natural resources in production systems and reduction of CO$_2$ emissions as well, the reuse and lifetime extension of wood products, recycling by optimization of potential wood assortments (e.g., recycled natural fibers from medium-density fiberboard wastes), and nutrients and energy recover from the wood products.

Therefore, the forest sector can play a fundamental role in the transition of a traditional linear economy towards a circular economy. CE in the forest sector means an economy where raw materials and their value are employed as efficiently as possible, converting the under-valued forest residues and wood waste into value-generating market forest waste use [10]. This model provides opportunities for the forest sector along with environmental protection, new jobs creation and economic growth. Increased cascading of wood and waste wood recycling are among the practices that have been identified and are mainly associated with the CE [11,12]. On the other hand, CE could advocate in protecting forests through utilization of forest wastes that otherwise could be a potential source of wildfires or a growth media for forest pests. Forest-based industry could play an increasing key role in implementing CE principles. In particular, the forest products industry generates several residues apart from actual products, many of which can be used further after being properly treated.

Moreover, the forest sector would contribute to the potential development of new bioeconomy (BE) products such as advanced biofuels, biotextiles, intelligent packaging and biochemicals [13]. The concepts of BE and CE are increasingly combined to describe a “circular bioeconomy” (CBE) that emphasizes the value retention for renewable resources and implies a more efficient management of biobased renewable resources by integrating circular economy principles into the bioeconomy [14,15].

The aim of this study is to provide a critical review of the trend towards CE in the forest sector. In this framework, this paper does the following: (i) provides an overview of international approaches in the scholarly literature on the forest sector CE; (ii) highlights the trend of research through a keyword network analysis of the selected papers; (iii) critically assesses the shortcomings and opportunities of existing multiple perspectives concerning forest-based CE.

2. Methodology

A mixed approach was carried out in this review. Firstly, a systematic literature search was used to identify relevant works on the baseline aim, then the data were explored through a network visualization, and finally a discussion was conducted according to the number of clusters which produced in network visualization.

2.1. Search and Selection of Relevant Studies

A systematic literature search was held on three electronic bibliographic databases: Web of Science (URL http://www.webofknowledge.com), Scopus (URL http://www.scopus.com) and Science Direct (URL http://www.sciencedirect.com) on 5 January 2021. The terms “circular economy” AND forest* were entered in the search fields “Article title, Abstracts, Keywords”. Firstly, all studies derived from the three search engines (n = 359) were stored in a spreadsheet and they were checked if they were same with each other. Approximately, 97 in Scopus and most of publications in Science Direct (n = 19) were duplicated and included in the list of Web of Science, and therefore they were excluded (n = 116). Studies in other language than English were omitted (n = 22).

The articles that passed the first stage (n = 243) were continued to the second stage of assessment. At this stage, all studies were assessed by their title and abstracts, and obviously irrelevant publications and reviews were removed (n = 174). At a third stage, the remaining publications were downloaded and stored according to year, title, name of the journal/proceedings. This identified 69 relevant publications (57 articles, 2 early access
and 10 proceedings); this corresponds to percentage of 28.4% of the articles passed the first stage, in which their full text was read carefully and analyzed in-depth for this review (Figure 1). Special attention was given to the keywords.

**Figure 1.** Flow chart of successive stages in literature review process. Date of literature search: 5 January 2021.

### 2.2. Exploration and Visualization of Keywords

VOSviewer (version 1.6.16) was used in order to construct a network of scientific keywords, derived from relevant articles on CE and forest [16]. Keywords in this network connected by co-occurrence link. It is a freely available computer program that is especially useful for displaying large bibliometric maps in an easy-to-interpret way. The outcome maps were then used for visualization and exploration of network data. The map presents the keywords grouped into non-overlapping clusters, where the circles and keywords are connected by curved lines of various size (link strength). The higher the value and the thickness of line, the stronger the link between keywords. Moreover, the size of the circle is proportional to the co-occurrence of the keywords. The distance between keywords in the visualization map indicates the relatedness of the keywords in terms of co-occurrence links. This means, the closer two keywords are located to each other, the stronger the relatedness.

### 3. Results

The results were separated into two sections: (a) a descriptive analysis of the reviewed publications; (b) a thematic analysis, based on a cluster examination of the keywords related to the forest-based CE. The criteria considered for the descriptive analysis were summarized in the years of publication, the number of papers’ citations, the geographical distribution of the papers analyzed, and the journals that the reviewed papers were published in. At the same time, a thematic analysis was employed to compare the findings, which were extracted from the studies.

#### 3.1. Descriptive Analysis

The descriptive analysis confirms that the research for forest sector CE was boosted in recent years (Figure 2). Although only five papers were published from 2009 to 2015, a constant increase in studies examining this issue has been observed from 2016 until today. The concentration of papers and publications in the last three years reveals, among others, the current relevance of the revised subject. Considering that the forest-based CE has been evolving during recent years, this is not a surprising finding. This increasing interest may be related to the public policy, as well. Particularly, in 2015 the European Commission [17] actively promoted the CE through the adoption of Action Plan for the Circular Economy. In the same year a “Multi-annual implementation plan” [18] provided a concrete list of measures to enhance forest-based bioeconomy and forest-based industries.
Figure 2. Overview over studies by date of publication (literature review covers results until 5 January 2021).

Figure 3 presents the geographical distribution of the studies analyzed according the first author’s country. The European continent accounted for 75% (52 articles); Finland and Spain were the leading countries in terms of volume of publications related to forest-based CE. Italy and Portugal (each of them recorded 15.9% of the total reviewed documents) also had a predominant presence in the distribution of the publication in Europe. Then, Asia (China) concentrated nine articles, followed by Oceania and the rest of the countries of America.

Figure 3. Geographical distribution of the papers analyzed according the first author’s country (number of publications, n = 69). The darkest colors indicate countries with greater number of publications. A country’s minimum number of publications was 1 and maximum was 11 (Finland and Spain).

The variety of the journals that the analyzed studies were published in constitutes an additional indication for the multiple implementations of CE in the forest sector and the
numerous fields where it can be applied. Among these, energy, sustainability, recycling, technology and economics targeting journals dominate the research. Journals mainly cover topics such as renewable and sustainable energy, energy conversion and management, energy and policy (i.e., *Energies, Renewable and Sustainable Energy Reviews, Resources, Conservation and Recycling*). *Journal of Cleaner Production* reiterates the concentration of published papers. Economics and enterprise sectors are also included in the scientific relevance of the research (i.e., *Forest Policy and Economics, Ecological Economics*).

The citations constitute a crucial measure of the influence of academic papers in each field. Therefore, Table 1 lists the most cited articles. In the first position, the study of Hamelin et al. [19] reveals, through their article, the importance of forestry residues as a key feedstock for the European bioeconomy. Then [20] analyzed the three concepts of circular, green, and bioeconomy and identify the linkage among BE, CE and forest sector companies. Husgafvel, Linkosalmi and Dahl were the most prolific authors, who contributed with the two most cited articles. The prevalence of research takes place in European countries, and mainly in Finland, whereas the assessment of the potential for wood cascading and the perspectives of CE in forest-based companies attract the higher research attention.

**Table 1. List of publications with the highest number of citations.**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Number of Citations</th>
<th>Journal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamelin et al. [19]</td>
<td>A spatial approach to bioeconomy: Quantifying the residual biomass potential in the EU-27</td>
<td>39</td>
<td>Renewable Sustainable Energy Reviews</td>
</tr>
<tr>
<td>Näyhä [22]</td>
<td>Transition in the Finnish forest-based sector: Company perspectives on the bioeconomy, circular economy and sustainability</td>
<td>24</td>
<td>Journal of Cleaner Production</td>
</tr>
<tr>
<td>Molina-Moreno et al. [23]</td>
<td>Pellet as a technological nutrient within the circular economy model: Comparative analysis of combustion efficiency and CO and NOx emissions for pellets from olive and almond trees</td>
<td>23</td>
<td>Energies</td>
</tr>
<tr>
<td>Husgafvel et al. [11]</td>
<td>A regional study on sustainability driven competitive advantage and an assessment of the potential for cascading recovered solid wood</td>
<td>19</td>
<td>Journal of Cleaner Production</td>
</tr>
<tr>
<td>Jarre et al. [12]</td>
<td>Transforming the bio-based sector towards a circular economy—What can we learn from wood cascading? Ashes from fluidized bed combustion of residual forest biomass: recycling to soil as a viable management option</td>
<td>18</td>
<td>Forest Policy and Economics</td>
</tr>
<tr>
<td>Cruz et al. [24]</td>
<td>Recycling industrial residue streams into a potential new symbiosis product—The case of soil amelioration granules</td>
<td>16</td>
<td>Environmental Science and Pollution Research</td>
</tr>
<tr>
<td>Husgafvel et al. [25]</td>
<td>Agroforestry in Europe: A land management policy tool to combat climate change</td>
<td>15</td>
<td>Journal of Cleaner Production</td>
</tr>
<tr>
<td>Mosquera-Losada et al. [26]</td>
<td>The use of forest-based materials for the efficient energy of cities: Environmental and economic implications of cork as insulation material</td>
<td>14</td>
<td>Land Use Policy</td>
</tr>
<tr>
<td>Sierra-Pérez et al. [27]</td>
<td>A review of biomass ash properties towards treatment and recycling</td>
<td>13</td>
<td>Sustainable Cities and Society</td>
</tr>
<tr>
<td>Voshell et al. [28]</td>
<td>Benefits of adding forestry clearance residues for the soil and vegetation of a Mediterranean mountain forest</td>
<td>11</td>
<td>Science of The Total Environment</td>
</tr>
</tbody>
</table>
One remarkable point about the reviewed publications on forest-based CE is the extremely wide subjects they relate to. The literature is fragmented into surveys ranged from the development of optimization models to minimize the costs and greenhouse gas emissions of cascaded utilization of wood resources [30], to quantitative surveys about the perceptions of use forest biomass residues in the energy market [31], or to qualitative surveys among business managers to investigate the potential of a transition to a forest-based circular bioeconomy [14]. Following, the review presents the major groups of topics and results that are repeatedly investigated in the publications.

A wide breadth of papers covers subjects related to the multifarious utilization of forestry wastes and forest biomass from CE perspectives. Some of the recorded utilizations of biomass related to the following: sugars production, wood residues utilization as raw material for fertilizers and soil liming agent, utilization of by-products resulting from street trees’ pruning operations for creation of insulation panels, use of fly ash from forest biomass combustion as a potential additive replacing calcite in cement-based mortars, and development of wood–plastic composite material and others [24,25,27,31–43]. In the same framework, Voshell et al. [28] explored forest and wood residues properties towards treatment and recycling. Among the proposals have been discussed for alternative utilization of forest residues, there is one that demonstrates the use of reclaimed urban wood in the tourism activities (i.e., such as use of plywood for signs and educational boards, wildlife observation platform) [44].

The role of a biorefinery in sustainable development displays a convergence of interests among scholars. In particular, there is a group of papers assessing broader topics on the economic, social and environmental impacts of biorefinery processes on the existing forest industry [15,45–47]. In the same spirit, [33] explored the economic and environmental advantages arising from the improvement of the existing methods that applied for utilization of forest derived biomass for energy production.

Other scholars focus mostly on the investigation of the chances for new value chains creation, by using by-products of forestry operations. This topic covered by surveys illustrated how the incorporation of biobased additives on bonding properties of synthetic adhesives can create materials with better mechanical and environmental resistance [48], or how the extraction of bioactive phenols from forest residues by applying eco-friendly protocols can be attained [49]. In the same line, [50] assessed, by using the multicriteria analysis, the forest-wood chain at the local level, following the circular bioeconomy approach.

There are also publications that attempt to identify the major challenges and main driving forces of increasing the use of forest-based biomass for energy [51] and to estimate the sustainable potential of wood fuel from forests [52]. Another group of articles estimates the production of wood-based biomass, addressing material flow analyses, or carrying out supply chain modeling. Another publication [30] proposes a sustainable logistics network for wood flow considering cascade utilization. Similarly, based on the mode of resource recycling in forest industrial enterprises, [53] suggests such a kind of flowchart to promote the reduction of resources use and harmless production. Besides, material flow analysis constitutes a widely used technique for enhancing cascade biomass utilization in the CE [54]. In this context, two surveys present methodologies for wood-based biomass material flow analysis as a way that can support companies’ decision-making processes [50,51].

As inferred from the thorough search, there exists a growing interest about the Life Cycle Assessment and certainly from different research approaches. In particular, Ref. [55] used LCA to evaluate the environmental impacts of a wood-based bioenergy plant, utilizing residues from forestry operations. In another publication, [56] try to assess the level of extension of goods and resources life cycles in the forest industry to conserve natural resources.

In addition, as would be expected, another topic that gathered great research interest is the role of CE in enforcing sustainable forest development. There are numerous surveys that investigate how CE could benefit the forest sector [14,57–59]. It is pointed out that
the existing processes lead to improvement of forests or new afforestations, through employing local organic waste, composts or forest clearance residues to substitute the mineral fertilizers of soil [27,29,60].

The national and regional development constitutes a crucial issue for each country [61] as well. As a consequence, the reviewed literature largely focused on assessing the potential impact of CE and CBE on European, national and regional development, on creation of local added value and local jobs, and on poverty alleviation as well [19,26,62–68].

The adoption of the CE principle in forest-based companies and firms is a cutting edge for the current surveys. The application of new economic models, such as circular bioeconomy in the forest sector, implies a more efficient resource management [14,69]. There is a variety of studies exploring the elements of a CE business model as a key condition for its successful implementation in forest-based companies [70,71], whereas other authors selected to investigate the structural aspects for the transition to circular business value systems [72]. Furthermore, many scholars focus on the possibilities, perspectives and limitations for forest-based companies to align with CE concept [11,21,22,73–75]. For conducting these studies, questionnaire surveys, mainly qualitative, were undertaken in large and small forest and bioproduct sector companies. The Delphi method and SWOT analysis are among the most prominent techniques applied to company executives, managers or experts of forest-based sector companies and firms to investigate the above perspectives. This group of surveys elicits knowledge from decision makers about how their firms understand the concepts of CE and CBE and their linkages to sustainability [22]. In general, questionnaire surveys have been widely conducted not only focused on forest-based sector businesses but also in several focus groups. In particular, a quantitative questionnaire survey was undertaken to explore consumers’ preferences for buying eco-friendly products, and especially forest-based products [76].

Upon examining the literature, it is noted that great interest attracts the analysis of policies about the forest CBE, at the national and EU levels. It could be particularly worthwhile in the transition toward CBE because it can provide overarching frameworks to guide the policy mixes, such as the combination of climate mitigation policies with sustainable forest management policies, or Research and Development (R and D) policies, in support of the European CE and bioeconomy [77–79]. Policy mixes can also support the innovation in environmentally friendly technologies and related technological innovation systems [80]. In this context, [23] tried to shed light on how new technology (specific operations of biomass systems) can produce high combustion efficiency values. Finally, Ref. [81] attempted to combine the CE concept with digital solutions by trying to transform a forest-based bioeconomy into a digital platform industry.

Upon examining the literature, the benefits of adopting the CE principle in the forest sector are summarized in environmental and economic sectors as well. The most important environmental benefit of increased wood cascading comes from the avoidance of resource extraction from the natural environment [82]. It also enables and promotes the material use of wood [83]. Among the greatest advantages of cascading is the lifetime extension of wood products and the postponed release of carbon stored in products into the atmosphere [12]. One remarkable view is that the energy produced from wood is carbon neutral. In particularly, it is demonstrated that the combustion of wood does not emit additional CO$_2$ into the atmosphere because of previous carbon sequestration in the wood [12]. Other findings suggest the contribution of wood cascading to reducing greenhouse gas emissions (GHG). According to Bais-Moleman et al. [84], the GHG emissions per ton (wet weight) woody raw material input in the wood sector companies is higher for natural fibers compared to recovered fibers. Summarizing, the reuse of forest products means consumption of fewer resources, less energy, and less labor compared to the creation of products from virgin materials [1,85].

Energy and material efficiency seem to provide a competitive advantage for forest sector companies. Besides, cascading use of woody biomass provides economic benefits to companies because it reduces the amount of waste produced and the costs of disposal [1].
It also merits attention that circular economy practices on wood would create value, based on a sustainably sourced material flow, local jobs and more professional and qualified employment [58,66,86].

However, there are some concerns about the generalized implementation of the forest-based CE. The greatest issue is the maintenance of a balance between transition to CE and protection of biodiversity, avoiding potentially harmful impacts on land erosion, biodiversity loss and food scarcity associated with the utilization of significant amounts of biomass [58]. The increased demand of biomass might lead to increased pressures on wood resources and forest ecosystems [84]. There are surveys expressing uncertainties related to reduction in GHG emissions, whereas others propose to take into account the emissions produced by transportation of biomass materials, as well as the collection of waste materials [84].

3.2. Keyword Network Analysis

The analysis of the keywords revealed 393 results for the forest-based CE. However, only 26 keywords had at least three co-occurrences and met the threshold. The most cited keyword was “circular economy” (a frequency of 17.33%), followed by “sustainability” (a frequency of 8.00%) and “biomass” (a frequency of 6.67%). (Table 2).

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Co-Occurrence</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular Economy</td>
<td>26</td>
<td>17.33</td>
</tr>
<tr>
<td>Sustainability</td>
<td>12</td>
<td>8.00</td>
</tr>
<tr>
<td>Biomass</td>
<td>10</td>
<td>6.67</td>
</tr>
<tr>
<td>Bioeconomy</td>
<td>8</td>
<td>5.33</td>
</tr>
<tr>
<td>Bioenergy</td>
<td>8</td>
<td>5.33</td>
</tr>
<tr>
<td>Life Cycle Assessment—Ica</td>
<td>8</td>
<td>5.33</td>
</tr>
<tr>
<td>Systems</td>
<td>8</td>
<td>5.33</td>
</tr>
<tr>
<td>Future</td>
<td>6</td>
<td>4.00</td>
</tr>
<tr>
<td>Management</td>
<td>7</td>
<td>4.67</td>
</tr>
<tr>
<td>Technology</td>
<td>7</td>
<td>4.67</td>
</tr>
</tbody>
</table>

Similarly, the co-occurrence network map presents these 26 most used keywords (Figure 4). The network maps show clusters in different colors, indicating that grouped items are more frequently linked with each other and characterized by a higher level of connection. The size of the circles represents the weight of items based on total link strength. In the current network map, there are three clusters highly interconnected.

The purple cluster describes the environmental sustainability and the forest-based CE, focusing on their balanced coexistence and evolution. It examines the potential impacts of forest-based CE on the biodiversity conservation. Some findings highlight that CE can have negative impacts for biodiversity if not carefully planned [87]. The same authors noted the need to have complementary policies and planning for biodiversity protection. However, CE has emerged to meet growing demand without the environmental degradation that related to linear resource exploitation [75]. Many of the reviewed papers show a positive relationship between CE and conservation of ecosystems, stating that CE can ensure the sustainability of forest ecosystem services [34,55,58,88]. Indeed, the relationship between CE and the environment is interactive and forest ecosystem services can benefit in different ways—not only by reducing the demand for natural resources, but also through employing suitable management approaches to improve the nutritional state of forests, i.e., use of chestnut forest green waste as valuable seeding media for sustainable cultivation, use of organic by-products and composts to substitute the mineral fertilizers and substrates in Pinus halepensis forestry, and utilization of urban green waste compost or municipal waste compost for soil improvement in afforested land [39,89,90].
The red cluster attributes the correlation between CE and wood-based bioenergy production. The forest sector contributes to CE, prominently with the provision of wood biomass. Wood is highly significant in a CE in terms of material products and energy provision. Besides, there are miscellaneous alternative sources of waste biomass that could be used further, such as the municipal forestry and greening wastes or wood industrial residues [28,49]. Indeed, forestry waste is the main circular characteristics for bioenergy production [53,71].

The use of wood biomass for bioenergy production can entail important economic and environmental benefits, including improved energy security due to a smaller dependence on fossil fuel supply, mitigation of climate impact, and revitalization of rural economies connected to new job opportunities [33,37,55,65]. However, the move to a forest-based CE requires a forest management strategy that will increase the life cycle of wood products by means of the valorization of the timber collected [50]. Moreover, achieving this transition required introduction of innovations in production, based on the organization of utilization and processing of waste from the forest industry [91].

Nevertheless, there are several environmental and socio-economic concerns about the further use of wood biomass for bioenergy production. The concerns focus on greenhouse gas emissions [91], soil quality degradation and biodiversity loss [55]. The above findings point out the need for environmental, economic, and social sustainability in bioenergy production, which can be assessed through a set of multicriteria indicators [55]. Therefore, Life Cycle Assessment (LCA) can be used to explore the environmental performance of bioenergy production [55], to estimate the environmental impacts of cascaded wood utilization [30] and to treat the biogenic CO₂ emissions [91].

Strategies for implementation of the wood-to-energy supply chain for CE system were varied. A crucial issue for these strategies is the integration of innovative systems, the integration of economic, environmental and social aspects in the value chain’s assessment, the optimization of raw-material use and the development of energy modeling methodologies, to minimize environmental impacts and achieve cleaner production by CE [27,47,70,79,92]. These kinds of methodologies are based on the development of models that calculate waste in terms of quantity, energy and cost while considering techno-economic and environmental restrictions [33].
The green cluster focuses on the relation between the bioeconomy and forest biomass extraction. The forest bioeconomy can play a crucial role because it links the entire forest value chain, from the use of natural resources to the delivery of products and services [22,79]. This role is noted by the EU that set the transition to a BE as a strategic goal [93]. Besides, forest industries and biorefineries are recognized as core components in the adoption of BE in the forest sector [15,94]. In this context, the literature on bioeconomy often discusses the importance of implementing innovative business models in forest industry [70].

Regarding the yellow cluster, it mainly focuses on technological innovations geared toward the CE. The point of the thematic convergence regards the involvement of technology into the supply chain network, mainly to optimize the supply of biomass to biorefinery [47].

4. Discussion

In the last years, publications on the forest sector CE have rapidly increased, demonstrating the continuity of knowledge production in the area. However, after outlining what existing studies contributed to deep understanding of the CE concept and its implementations, the conclusion of this paper will highlight some major challenges for confirming that the forest sector CE offers significant benefits in terms of environmental protection, economic development and social enhancement, and limitations need to be considered in applying it as well. The main contribution of this article is exclusive to analyzing what has already been done in forest-based CE in order to inform the interested parties (forest industry, managers, researchers, decision makers, etc.) about possible transformation pathways to adoption a CE.

CE aims at the transformation towards environmentally sustainable modes of production and consumption, especially for the wood. In this framework, cascaded wood utilization could help to bridge the gap between the rising wood demand and fresh wood availability mainly for covering energy needs [30]. In this direction, there are papers that acknowledge the role of the wood industry to perform energy, decreasing greenhouse gas emissions [2,84].

However, there are studies that raise questions on whether the CE is in fact truly sustainable. Their concerns focused mainly on the current forest management strategy that did not optimize the productive function because the wood harvested is wholly allocated for bioenergy production [50]. Moreover, the transition to a narrow CE which can see the forest sector as perfectly circular may not be sustainable. For achieving sustainable CE, it is crucial to take into account all alternative uses of resources and leaving enough biomass for other needs, such as restoring soil or feeding biodiversity [58]. In addition, some authors underscore the difficulty of distinguishing where progress towards a low-carbon, environmentally sustainable and CE is real from where it is an artefact of biased accounting practices [46].

There exist additional publications that present ominous signs for the wide adoption of CE, especially at the forest company and industry level. In particular, it is noted that the implementation of a CBE is still lagging, and companies are struggling to develop effective business models [70]. Although the adoption of innovative circular business models could play a crucial role in a successful shift to a bioeconomy, the discussion about this issue seems to be still fragmented and immature [70]. The knowledge gap regarding technology and the market prospects is proven to be an additional impediment for the wood biorefinery development [74].

The studies examined in the current review reveal another research gap. There is an absence of concepts related to financial incentives, in the form of subsidies or tax breaks, that could promote circular economy approaches in the forest sector. Therefore, we suggest further research for the incentives that could spur investments in forest-based industry. There is also the need to be investigated if the introduction of green tax benefits could support market creation for biobased products.
However, it is recognized that CE has a certain potential to develop further in forest-based businesses. It may require substantial investments, financial measures, green tax incentives, adequate legislation, policy coordination, research and innovation actions, reinforced stakeholder engagement, technological implementation, market penetration and enhancement of competitiveness. The industrial sector needs further support in the forms of policies and financial instruments for making the required investments economically feasible and manageable [86].

5. Conclusions

Through a systematic literature review, 69 scientific publications were selected and evaluated. The review’s findings indicate that CE framing can help the forest sector become more sustainable, but there is still a lack of consistency in the manner that CE concepts and forest sector can be associated and applied. Future surveying is suggested to optimize the interaction between forest ecosystem service and a circular economy, and further discussion is needed about the relations among the key factors of forest-based circular economy, as they emerged from the cluster analysis presented in the current survey.

One of the most basic limitations for the present study is its exclusive reliance on the existing academic research that is published. Furthermore, it based on a keyword search of the published papers, which limits the results significantly. Finally, although the inclusion criteria were explicitly defined, the selection of the reviewed publications eventually analyzed might be subject to researcher biases.

Author Contributions: The individual contributions of the authors were divided as follows: conceptualization: D.C.L.; methodology: D.C.L.; formal analysis: D.C.L., A.M. and M.T.; investigation D.C.L., A.M. and M.T.; writing and original draft preparation: D.C.L., A.M. and M.T.; writing, review, and editing: D.C.L., A.M. and M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Data Availability Statement: The data presented in this study are available in the research articles displayed along the text.

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

References

1. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. J. Clean Prod. 2016, 114, 11–32. [CrossRef]
7. Proskurina, S.; Sikkema, R.; Heinimö, J.; Vakkilainen, E. Five years left—How are the EU member states contributing to the 20% target for EU’s renewable energy consumption; the role of woody biomass. Biomass Bioenergy 2016, 95, 64–77. [CrossRef]
8. Van Buren, N.; Demmers, M.; van der Heijden, R.; Witlox, F. Towards a circular economy: The role of Dutch logistics industries and governments. Sustainability 2016, 8, 647. [CrossRef]
15. Temmes, A.; Peck, P. Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives. For. Policy Econ. 2020, 110. [CrossRef]
23. Molina-Moreno, V.; Leyva-Diaz, J.C.; Sánchez-Molina, J. Pellet as a technological nutrient within the circular economy model: Comparative analysis of combustion efficiency and CO and NOx emissions for pellets from olive and almond trees. Energies 2016, 9, 777. [CrossRef]
38. Torreira, Y.; Pérez, L.; Piñeiro, G.; Pedras, F.; Rodríguez-Abalde, A. The role of energy valuation of agroforestry biomass on the circular economy. Energies 2020, 13, 2516. [CrossRef]


47. Ouhimmou, M.; Rönqvist, M.; Lapointe, L.A. Assessment of sustainable integration of new products into value chain through a generic decision support model: Application to the forest value chain. *Omega* **2021**, *99*. [CrossRef]


