

Systematic Review

Sustainable Supply Chains in the Forest Bioeconomy: A Systematic Review

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Abstract

The forest bioeconomy is an emerging global sector that uses forest material to make value-added bioproducts that range from pharmaceuticals to biofuels. Notwithstanding their capacity to advance various United Nations Sustainable Development Goals, forest bioproducts face considerable sustainability challenges in global supply chains associated with harvesting, processing, and transportation. Using a systematic literature review focused on challenges and solutions to sustainability in forest bioeconomy supply chains, we analyze 81 peer-reviewed studies to identify the primary sustainability challenges and their attendant solutions. We find that economic barriers to scaling the forest bioeconomy are the most commonly studied challenge, while social and environmental challenges are often marginalized. Increasing stakeholder engagement is the most commonly mentioned solution, but the limitations of stakeholder engagement are largely absent from scholarly discourse. Lastly, we identify significant gaps in the literature related to coverage of non-European countries and analysis of key sectors like mass timber construction. The results gesture to the need for more research on under-represented regions and sectors, greater attention to social and environmental supply chain challenges, and deeper engagement with adjacent literatures on the intersection of public policy with sustainable supply chain governance.

Keywords: forest bioeconomy; sustainable supply chains; bioproducts; biomass



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1. Introduction

The forest products sector is in a period of transformation as it moves from low value-added, conventional forest products like dimensional lumber, pulp, and paper to higher value-added products like bio-based plastic substitutes, plant extracts, nutraceuticals, and advanced polymers [1]. Forest product companies are looking to do more with each log, especially in North America, where the supply of old growth timber is increasingly protected or inaccessible [2]. In this context, many regions rich in biomass are pivoting to a focus on products and processes that require more processing and longer value chains, for example, extracting lignin and nanocellulose to make advanced plastic substitutes [3]. Similarly, with the advent of biorefineries, the branches, bark, and tops of trees can be converted into renewable bioenergy [4]. The byproducts of conventional forest products can be valorized for high-value applications in the food, nutraceutical, cosmeceutical, and pharmaceutical industries.

The focus in this paper is on addressing sustainability challenges inherent in supply chains in the forest bioeconomy worldwide. We adopt a relatively narrow definition of the forest bioeconomy as encompassing value-added products and services derived

from woody biomass. While this definition includes some conventional forest products (e.g., wood furniture and engineered flooring), we deliberately look for literature that moves beyond products like dimensional lumber, pulp, and paper. The rationale is that supply chain challenges are likely to be different between the forest bioeconomy and the conventional forest products sector due to the level of processing involved in value-added forest products and the differences in their respective markets. For example, a product like Pycnogenol (an extract from French maritime pine bark that is used in dietary supplements, multi-vitamins, and cosmetics) requires many more steps of processing (harvesting, cleaning and drying, extraction, purification, and standardization) than a piece of dimensional lumber [5]. Moreover, its supply chain is more likely to be heavily scrutinized given its usage in food and cosmetics, sectors that tend to attract more attention from consumers for chemicals used during processing [6]. Accordingly, value-added forest products will face different kinds of sustainability challenges within their supply chains than conventional forest products.

The value-added forest bioeconomy holds the promise of addressing a range of urgent global sustainability challenges, particularly when it is embedded into supportive public policies [7]. Here, we define ‘sustainability’ through the lens of the 17 United Nations Sustainable Development Goals (SDGs). A sustainability challenge is therefore defined as something that would impede humanity’s ability to meet these goals by their stated deadline of 2030. The SDGs are broad in nature and encompass economic, social, and environmental targets. The advantages of the value-added forest bioeconomy span all three dimensions of sustainability. Environmentally, bioproducts can substitute for petrochemical-based plastic products, thereby reducing humanity’s dependence on fossil fuels and supporting climate change mitigation [8]. Well-managed forests can also help conserve biodiversity and preserve vital habitat for terrestrial species. Socially, the forest bioeconomy can reduce rural poverty by adding jobs and building vital infrastructure in economically marginalized areas [9]. Economically, the forest bioeconomy can be an engine of economic growth and revitalization for stagnant forest industries [10].

However, the growth of the forest bioeconomy is also accompanied by an array of sustainability challenges that may limit its ability to scale. In terms of economic challenges, the economic viability of the forest bioeconomy is a key obstacle given the complexity of bioproduct supply chains. The costs of harvesting and processing biomass vary widely according to region. In many cases, biomass is harvested in remote areas and requires transportation to biorefineries or biofuel plants. Transportation is often the most expensive cost associated with the bioproduct supply chain; thus, the value of the end product must exceed the considerable costs of transporting it [4].

In terms of environmental challenges, the significant energy required to process bioproducts and transport them to their intended markets also creates a higher product carbon footprint. For example, the process of extracting plant resources like polyphenols, tannins, and amino acids for use in advanced cosmetics or dietary supplements is incredibly energy and water intensive [11,12]. Moreover, efforts to plant fast-growing tree species suitable for large-scale biomass harvesting can reduce biodiversity and diminish the value of forests for cultural and religious practices [13]. These factors, in and of themselves, create a barrier to broader uptake of some forest bioproducts.

Social challenges also exist upstream in the supply chain. The expansion of areas required for forest biomass extraction can lead to conflicts over land tenure with indigenous groups and, in extreme cases, the displacement of indigenous communities or restrictions on their usage of traditional lands [14]. The augmented value of woody biomass can also increase the incentives for illegal logging operations [15].

To date, there has been a dearth of research examining sustainability challenges within the forest bioeconomy as a whole. While some studies focus on sustainability challenges related to particular regions [16] or particular sectors [17], few have examined cross-cutting sustainability challenges inherent in forest bioeconomy supply chains [18]. The goal of this study is to survey the scholarly literature on sustainable supply chains in the forest bioeconomy to better understand which challenges, solutions, regions, and sectors have been studied and where further attention is warranted. Specifically, we outline four objectives:

1. Understand the primary sustainability challenges confronting supply chains in the forest bioeconomy.
2. Examine which solutions are being proposed or implemented in response to these challenges.
3. Analyze regional and sectoral variation in sustainable supply chain challenges in the forest bioeconomy.
4. Identify biases or blind spots in extant scholarly literature on this topic.

We proceed as follows: first, we explain our approach to a systematic literature review by describing the research questions, search strategy, dataset, and analysis. Second, we review the findings for each of the four primary research questions. Third, we discuss the implications of our findings for the extant literature on sustainable supply chains in the forest bioeconomy. Fourth, we conclude by outlining some areas for future research.

2. Materials and Methods

We use a systematic literature review to provide a high-level snapshot of the existing scholarly research on sustainable supply chains in the forest bioeconomy. The approach follows the guidelines set out in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19], although the report is not registered and a review protocol was not prepared. We did not formally register a PRISMA protocol because this practice is less common amongst environmental social scientists and because this study is not eligible for inclusion in the PROSPERO systematic review registry because it does not involve health outcomes. The PRISMA 2020 statement consists of a 27-item checklist designed to increase the accuracy, transparency, and relevance of literature reviews for readers. Consistent with this approach, we began by identifying the research objectives and specific research questions before outlining a search strategy and obtaining/analyzing the data. We provide a PRISMA flow diagram (Figure 1) in Section 2.2.

2.1. Research Questions

The broader objective of this study is to identify patterns and trends in the scholarly literature on sustainable supply chains in the forest bioeconomy. Following this objective, the research questions structuring this study are as follows:

1. What are the primary sustainability challenges affecting forest bioeconomy supply chains?
2. Which solutions exist for these challenges?
3. How do challenges and solutions vary across regions and product types?
4. What blind spots or biases exist in scholarly research on sustainable supply chains in the forest bioeconomy?

2.2. Search Strategy

The search strategy combines four major elements, operationalized through the following key terms: forests, bioeconomy, sustainability, and supply chains. We connect these major elements through the use of the Boolean operator 'AND' in the search strings. We also endeavour to capture variations in the language used to characterize each of these

elements. For forests, we include the Boolean operator ‘OR’ to include alternate terms like wood, forestry, woody biomass, and timber. For bioeconomy, we use the ‘OR’ function to capture alternate spellings like bio-economy and biobased economy. For sustainability, we use the wildcard ‘sustainab*’ to capture variations on the word sustainable. We also include an ‘OR’ function for the term ‘SDG’ to capture references to the United Nations Sustainable Development Goals (SDGs), which is currently the dominant paradigm for conceptualizing sustainability [20,21]. Finally, for supply chains we use the ‘OR’ operator to include the terms ‘value chain’ and ‘logistics’ in the search, since the term ‘value chain’ has emerged as a conceptual alternative to ‘supply chain’ in political economy research [22,23]. To ensure that all of these four elements are central to the papers included in this study, we limit the search to the title, abstract, and key words associated with each study. Following other studies that have used a parallel approach, we use Scopus and Web of Science as the two focal databases [24]. The search string, databases, and filters are summarized in Table 1.

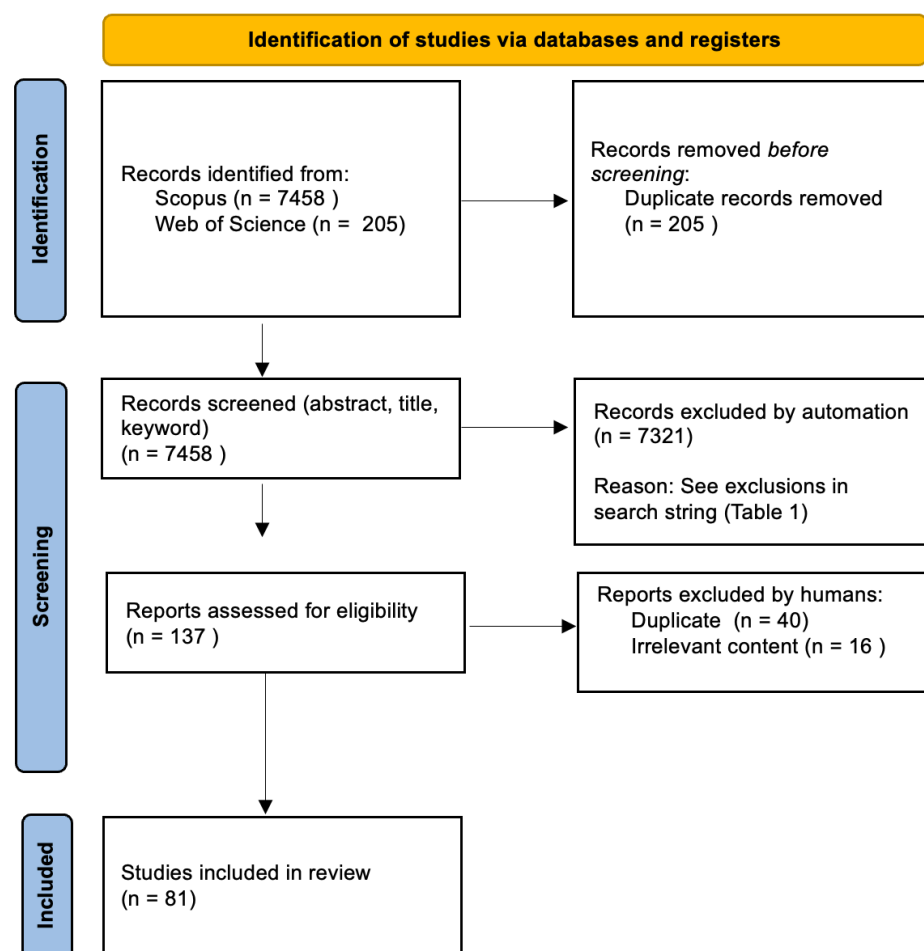


Figure 1. Flow Diagram of systematic search and selection process based on the PRISMA guidelines.

We apply several inclusion and exclusion criteria to data collection using the filter functions in each database. Temporally, we limit the search to articles published from 2011 onward, since this is when the term ‘forest bioeconomy’ first came into common usage. Linguistically, we limit the results to papers published in English. In terms of document type, we limit the results to research categorized as an ‘article’ by the databases. In terms of disciplinary focus, we exclude papers that tend to focus on formal modelling or highly technical processes related to the forest bioeconomy such as computer engineering, computer science, chemistry, math, medicine, immunology, and physics.

This search strategy carries a number of risks. The inclusion of ‘bioeconomy’ or its variates as a required search term risks excluding relevant supply chain challenges that affect the conventional forest products sector, about which much has already been written. However, given our focus on value-added products, we see this as necessary for achieving our research objectives.

Table 1. Search Strategy.

Databases	Filters	Search String
Scopus, Web of Science	2011- EN Articles only Excl.: computer engineering, computer science, chemistry, math, medicine, immunology, physics	TITLE-ABS-KEY (((forest* OR wood* OR forestry OR timber* OR “woody biomass” OR “wood biomass”) AND (bioeconomy OR bio-economy OR “biobased economy” OR “bio-based economy”) AND (sustainab* OR sdg) AND (“supply chain” OR “value chain” OR logistics))) AND (EXCLUDE (SUBJAREA, “CENG”) OR EXCLUDE (SUBJAREA, “COMP”) OR EXCLUDE (SUBJAREA, “CHEM”) OR EXCLUDE (SUBJAREA, “MATH”) OR EXCLUDE (SUBJAREA, “MEDI”) OR EXCLUDE (SUBJAREA, “IMMU”) OR EXCLUDE (SUBJAREA, “PHYS”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (PUBYEAR, 2025) OR LIMIT-TO (PUBYEAR, 2024) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012) OR LIMIT-TO (PUBYEAR, 2011)) AND (LIMIT-TO (LANGUAGE, “English”))

2.3. Data Selection

Both databases were searched on 29 October 2024. Prior to screening, our search string yielded 7458 results on Scopus and 205 on Web of Science. We then applied a two-stage screening process. In the first stage, we applied filters with our inclusion/exclusion criteria in the databases; we were left with 71 studies in Scopus and 66 in Web of Science. In the second phase, both authors manually identified 40 duplicate records and eliminated 16 additional studies (by consensus) for reasons of content relevance that were not captured in our disciplinary filters. For example, some of the 16 studies fell into excluded subject areas like immunology but were not captured by the filters in our search string. Following manual screening, we were left with 81 papers that met our criteria for analysis. All studies included in our sample are listed in Supplementary Materials.

2.4. Analysis

To answer our research questions, we manually coded the 81 articles in our database according to 7 variables. All coding was performed by one of the authors between 1 October 2024 and 15 November 2024. The seven variables are:

1. Sustainability challenges mentioned in the article
2. Sustainability challenge foregrounded in the article
3. Solution foregrounded in the article
4. Regional focus
5. Sectoral focus
6. Journal
7. Publication year

For variables 1 and 2, we use the 17 SDGs as a typology of the types of sustainability challenges that can be referenced in an article. For each SDG, we used the ‘Find’ function in Adobe Acrobat to search for direct references to an SDG (e.g., SDG 15), the wording

of the SDG (e.g., ‘life on land’), or 3–5 terms associated with the SDG (e.g., biodiversity, conservation, degradation) in each article. If either the specific SDG or terms associated with it are found in the article, we added an annotation to the bibliography to indicate its presence. We then coded each article according to which SDGs were foregrounded in the article by determining which had the highest count data for mentions in an article. In cases where more than one SDG had an equal number of mentions, we made a qualitative decision about which topic was more central to the article. All coding decisions are visible in Supplementary Materials.

Our approach to coding variable 3, solution, was inductive. We did not begin with predefined coding categories for solutions. Rather, one author read the abstract, introduction, discussion, and conclusion to each paper to qualitatively determine which solution was foregrounded most prominently. This was an iterative process. The author first read a sample of 40 papers and assigned preliminary codes before rereading the full dataset of papers to refine coding categories and assign solution codes.

Variables 4–5 were coded according to which region or solution was mentioned most frequently in the abstract, introduction, discussion, and conclusion of each paper. Within the region category, we coded both supranational entities (i.e., the European Union) as well as individual countries mentioned in publications. For sectors, we did not begin with a pre-defined list of sectoral categories. Rather, we proceeded inductively, following a parallel approach to variable 3. Variables 6 and 7 were coded according to an article’s publication year and journal title as listed in Scopus and Web of Science. The number of articles per journal and publications per year are presented in Figures 2 and 3, respectively.

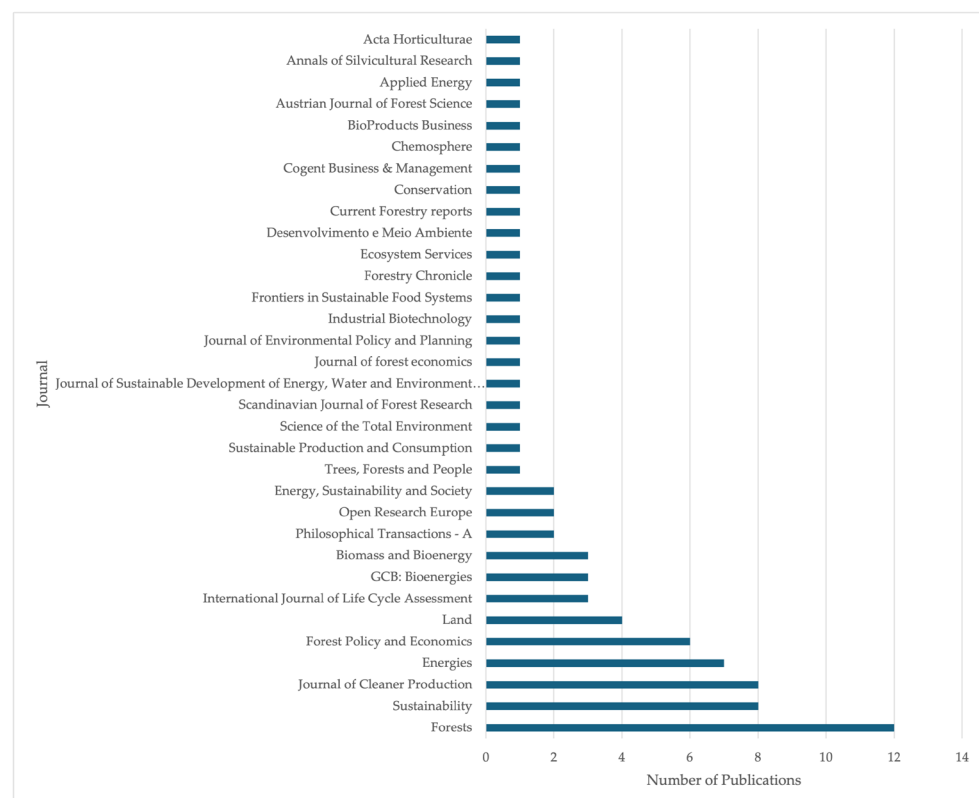


Figure 2. Publications by Journal.

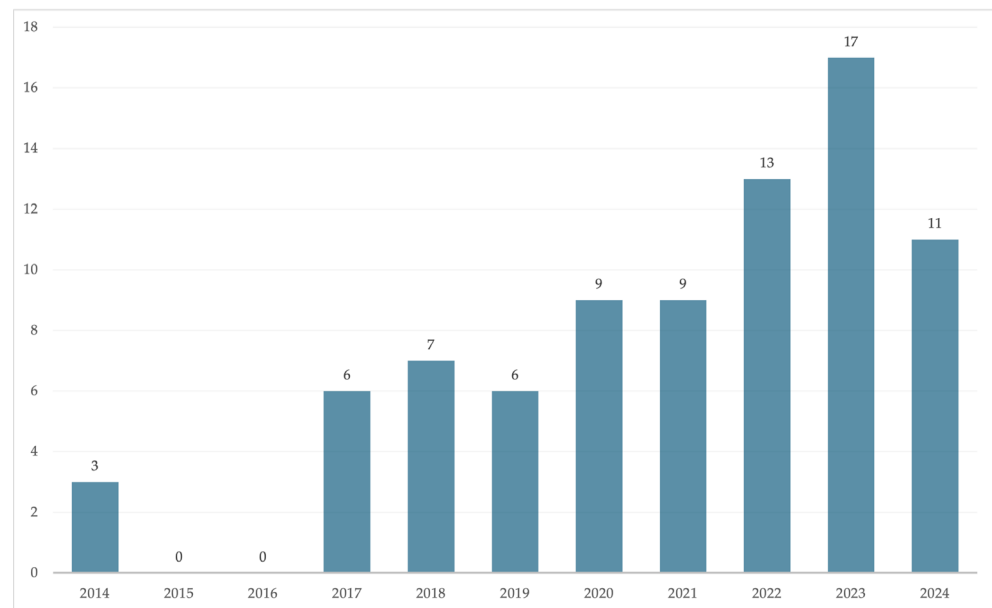


Figure 3. Publications by Year.

3. Results

3.1. Sustainability Challenges

Amongst the sustainability challenges mentioned most frequently in the forest bioeconomy supply chain literature, SDG 8 on decent work and economic growth exceeds all others. As illustrated in Figure 4, the challenge of economic growth is foregrounded in 23/81 publications included in our sample. The majority of these publications focus on regional bioeconomic development [25–28]. This emerged as a cross-cutting theme, transcending different regions of study (e.g., North America, Europe, Asia, and South America) and areas of sectoral focus. Within these articles, a key focus is on ensuring supportive economic conditions for the best use of biomass feedstock upstream in the bioproduct supply chain. Scholars focus on the ability of biomass to rejuvenate stagnant regional economies and generate employment opportunities.

The second most commonly referenced sustainability challenge is SDG 7 on affordable and clean energy, which is referenced in 13/81 articles. Here, the literature emphasizes affordability questions associated with clean energy transitions with much of the emphasis on the economic viability of bioenergy. There are concerns about the efficiency and affordability of energy use during the processing phase in which biomass is converted to bioenergy [29], the ability of bioproducts to ‘drop in’ to existing supply chains [30], as well as the variable quality of supplied biomass for value-added products [31]. Several scholars note the upfront costs of high value-added forest bioproduct production are unfeasible in the absence of government subsidies and supportive public policy [32,33].

Of the remaining SDGs, SDG 12 on responsible production and consumption represents the third largest sustainability focal area within our sample. The literature focuses on the extent to which the forest bioeconomy uses residual materials that would otherwise be discarded as waste [34]. Authors examine the challenges of using the byproducts of dimensional lumber products for bioenergy [35] as well as the capacity to reduce other forms of waste by substituting inorganic materials for biodegradable ones [36].

Notwithstanding the challenges of high-carbon footprints in bioproduct supply chains, extensive water usage during plant resource extraction for pharmaceuticals and cosmetics, and threats to biodiversity upstream in forest supply chains, fewer of the publications in our sample foreground environmental challenges. Only 8/81 articles focus explicitly on

climate change as a challenge and only 3/81 on terrestrial biodiversity. No articles focused on implications for clean water access associated with the forest bioeconomy. Research is even more sparse on the social challenges that confront forest bioeconomy supply chains. While many articles mention the need to engage indigenous communities in a respectful and equitable manner [25,27,37–39], few articles focus on this challenge explicitly.

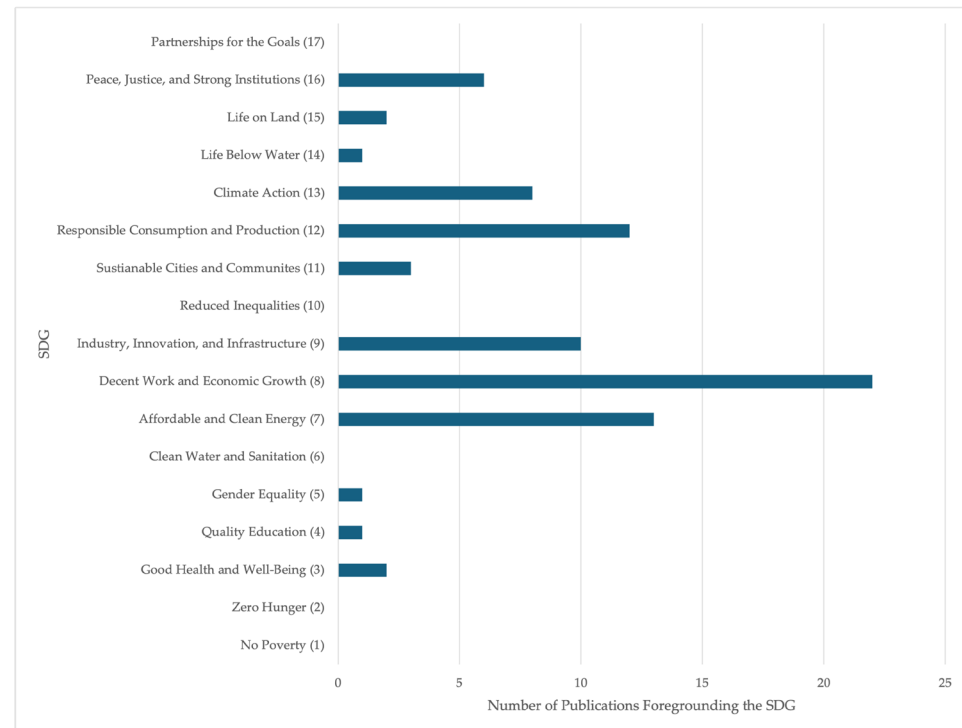


Figure 4. Primary Sustainability Challenge by Number of Publications. SDG 8, Decent Work and Economic Growth, emerged as the most prominent sustainability challenge in the sample. Environmental and social challenges were more peripheral.

3.2. Sustainability Solutions

Within the sample, the most common solution to the sustainability challenges confronting forest bioeconomy supply chains is stakeholder engagement, by which we mean efforts by members of the forest bioeconomy value chain to involve any party affected by their actions in decision-making. The literature is equally divided in prioritizing two different forms of stakeholder engagement. On one hand, many publications mention the need for increased government, industry, and academic collaboration [31,40–49]. On the other hand, many publications focus on increased dialogue with local and indigenous communities affected by the forest bioeconomy [25,50–54].

A second theme to solutions focuses evenly on either adapting bioeconomies to regional social and environmental conditions or deepening international integration. The integrationist literature focuses on standardizing policies and procedures across countries and further integrating forest bioproducts into global value chains [42,51,55–58]. By contrast, the regionalist literature focuses on the need to tailor supportive strategies to unique local conditions [59–62]. For example, why it may make sense to build small-scale biorefineries in some regions, but not others.

Lastly, supportive public policy emerges as a key solution to the high costs in forest bioeconomy supply chains. Public policy is viewed as a key to unlocking scaling potential at many different points in a forest bioproduct supply chain, from increasing research into forest bioproducts, to subsidizing emerging products, to publicly funding infrastructure development [32,33,43,63–67]. If, per the previous section, costs are the primary sustain-

ability challenge confronting supply chains in the forest bioeconomy, then there is broad consensus that governments must play a role in bringing costs down.

3.3. Regional and Sectoral Variation in Sustainable Supply Chain Challenges

While many of the articles eschewed a single sectoral focus, the most common focus was on wood products, meaning all non-bioenergy related wood products, wood furniture, and wood-derived polymers (e.g., lignin). As illustrated in Figure 5, in total, 16/81 articles touched on wood products. These articles were relatively evenly distributed across geographic regions and focused on a diverse array of sustainability challenges. The wood products literature tended to focus on social sustainability more than other sectors. Articles touched on the capacity of laminate flooring value chains to improve gender equity, increase worker health and safety in dimensional lumber production, and use social life cycle analysis to measure community outcomes [44,68,69].

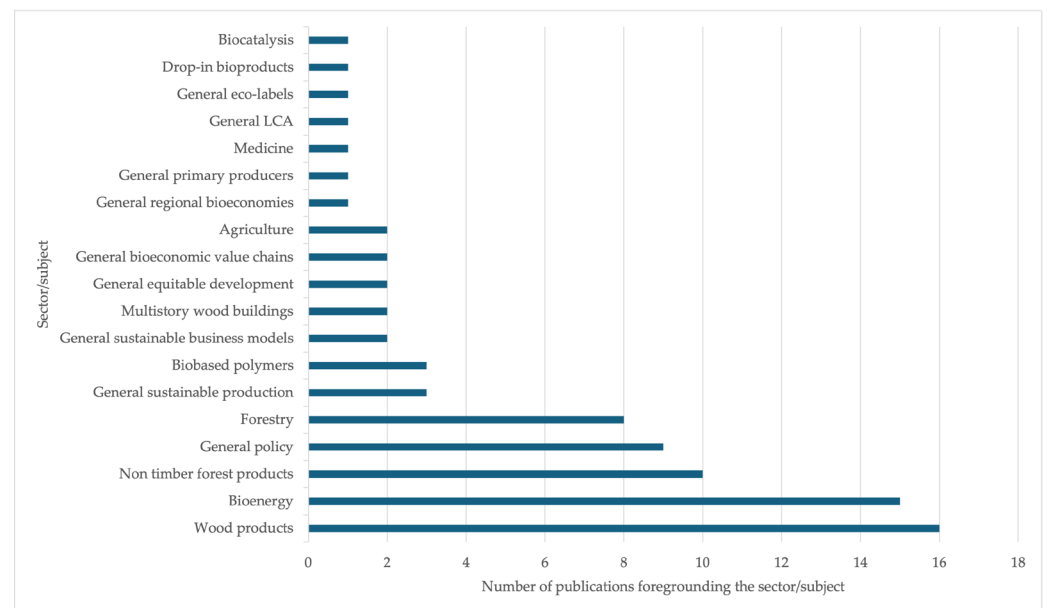


Figure 5. Primary Sectoral/Subject Focus by Number of Publications. Value-added wood products (generally) and bioenergy are areas of heavy sectoral focus. Mass timber construction was a notable blind spot in the sample.

The second most common sectoral focus within the literature is bioenergy, representing 15/81 articles in the sample. The geographic focus of articles about bioenergy is evenly dispersed, with at least one article focusing on a region on every continent. There is also variation in the sustainability challenges discussed in bioenergy articles. Some articles discuss the ability of bioenergy to substitute for non-renewable energy sources [32,43,60,70] whereas others focus on the economic challenges inherent in building a bioenergy value chain [29,53,67]. The most common solutions to the economic feasibility challenge are subsidies [9,32,53,71] and engagement between industry, academia, and government [27,42,47].

Outside of wood products and bioenergy, there is also significant interest in non-timber forest products (NTFPs), especially in middle-to-low-income countries. Publications focused on NTFPs tended to focus on regions in the Global South more than publications on other sectors. The reason for this is opaque but may be partially due to conservation efforts surrounding intact forests in the Global South, or due to the fewer financial barriers to harvesting and processing NTFPs in comparison to timber.

Per Figure 6, an overarching theme is that economic growth was a central challenge across all regions and sectors of the forest bioeconomy. The research was divided relatively

evenly between increasing the growth of non-timber forest products and wood products. Similarly, government subsidies were recognized as a solution to the challenge of economic growth across a number of sectors and regions.

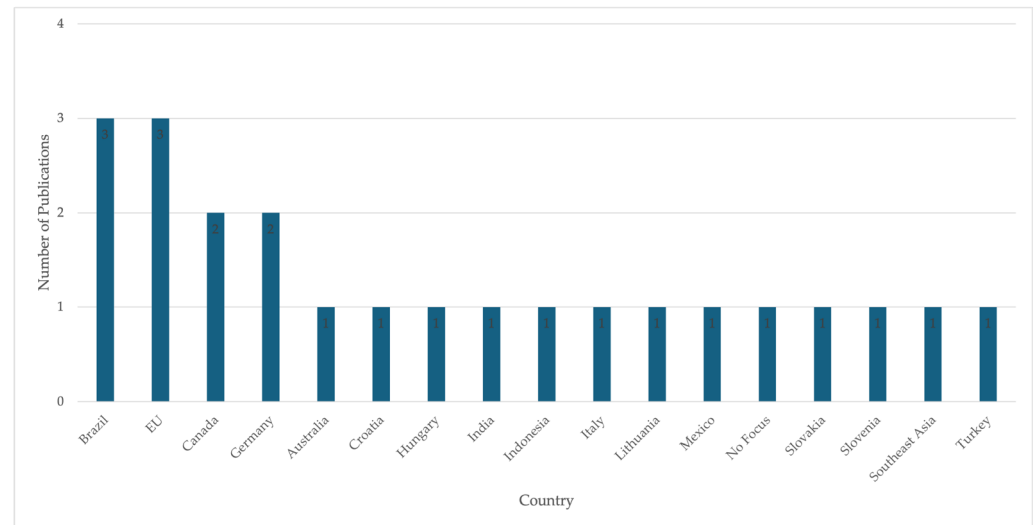


Figure 6. Economic Growth Focus by Country. Economic growth is a central challenge across all regions and sectors of the forest bioeconomy. Government subsidies were recognized as a solution to the challenge of economic growth across a number of sectors and regions.

Of all the regions, the literature on Brazil tended to skew more recent and had a greater focus on social sustainability. Research on the Brazilian forest bioeconomy addresses cultural preservation, traditional knowledge, smallholder engagement, and minimally invasive agroforestry: topics that are seen much less frequently in research that focuses on Europe [25,37,39,72,73].

4. Discussion

Our fourth research question addresses blind spots and biases that exist in scholarly research on sustainable supply chains in the forest bioeconomy. To address this question, we focus on how our literature review can be interpreted in the context of previous studies.

4.1. Dearth of Social and Environmental Focus in Forest Bioeconomy Research

Our findings suggest that there is a dearth of literature on the social and environmental challenges that confront forest bioeconomy supply chains. Past research on the forest sector has identified numerous environmental challenges at the harvesting stage of the value chain. For example, absent well-managed reforestation efforts, harvesting of forest biomass can remove vital carbon sinks and lead to escalating carbon emissions [74]. In locations where reforestation is practiced, monocultures of fast-growing species with economic value can have adverse impacts on biodiversity [75]. Yet, despite these acknowledged challenges to the environmental sustainability of harvesting forest biomass, climate change (SDG 13) is foregrounded in only 8/81 articles in our sample and terrestrial biodiversity (SDG 15) is foregrounded in only 2/81 articles. This suggests that the forest bioeconomy literature has yet to grapple with the environmental challenges associated with value-added forest bioproducts to the same extent that the topic has been addressed in the broader forestry or agriculture literatures. It is telling that several major forestry and interdisciplinary environmental journals were absent from our search results, including *Forest Ecology and Management* and *Ecological Economics*. This suggests that environmental impacts remain associated with the supply chains of conventional forest products like dimensional lumber and pulp or paper but have yet to be connected to things like bio-based pharmaceuticals.

A similar point can be made about social sustainability challenges. Research on forestry more generally has highlighted significant problems with gender equity at the harvesting stage [76] and the potential for forestry to either exacerbate or alleviate income inequality in forest-adjacent communities, depending on how resources are managed [77]. Scholars of land use have highlighted the tension between agriculture and forestry that is increasing under conditions of resource scarcity and rising global demand for commodities [78]. While these challenges are well-documented in other literatures, it would appear that they have failed to permeate scholarly discourse on forest bioeconomy supply chains. None of the articles in our sample foregrounded the challenge of reducing inequality in forest bioeconomy supply chains, and only one primarily focused on gender equity. In total, 6/81 articles focused on peace and justice as challenges arising from the scarcity of biomass supply. Taken together, these figures imply a need for forest bioeconomy scholars to engage more broadly with social sustainability challenges at the harvesting stage.

4.2. Eurocentrism in the Forest Bioeconomy Supply Chain Literature

Our literature review uncovers a significant regional bias in articles related to sustainable supply chains in the forest bioeconomy (see Figure 7 below). Europe is the most widely addressed region, with 42/81 publications in our sample focusing on either the EU as a whole or one or more European countries. South America is the second most represented region, with 12/81 publications focusing on a South American country, although 8/12 of these articles focus solely on Brazil. North America sees scant representation, with three articles focused on Canada and one each for the United States and Mexico. The most underrepresented geographic regions are Africa and Asia. Only 2/81 articles focus on African countries, touching on Malawi [41] and Zambia [42], respectively. Asian countries represent only 4/81 articles in the sample.

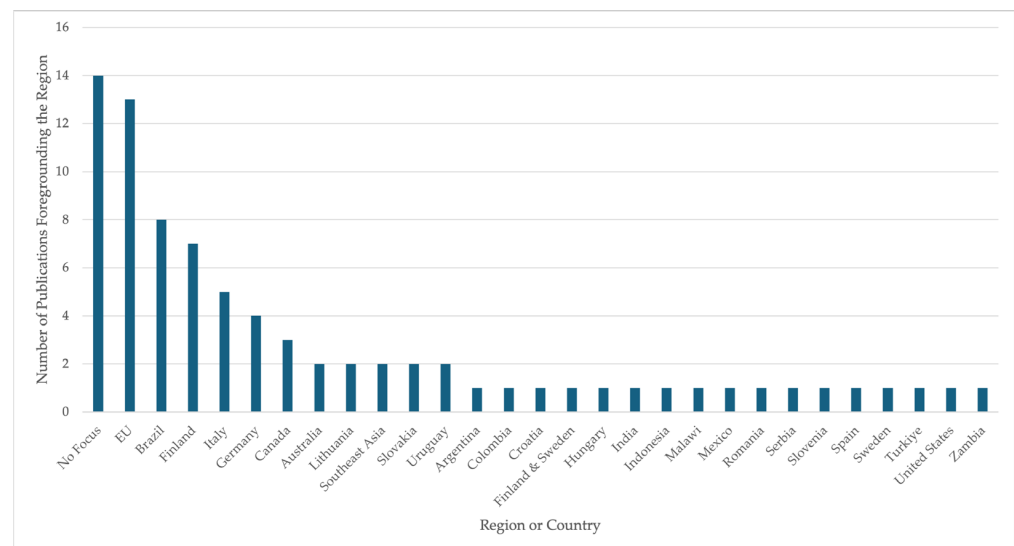


Figure 7. Primary Regional Focus by Number of Publications. Europe is the most widely addressed region, representing over half of all studies in the sample.

This regional bias is both surprising and unsurprising. On one hand, it stands to reason that Europe is disproportionately represented given that it is the region where the forest bioeconomy has existed longest and where value-added forest bioproducts have seen the greatest amount of uptake. Without the same abundance of biomass, European forest product businesses have been compelled to extract the most value from each tree since long before their counterparts in North or South America [79]. On the other hand, the dearth of research focused on emerging forest bioeconomy markets elsewhere is surprising

given the primacy being placed on forest bioproducts as a means of addressing climate change and revitalizing economies elsewhere. For example, Canada has made the forest bioeconomy a central pillar of its efforts to transition to a net-zero economy and revitalize a struggling forest sector [80]. Notwithstanding the attention that the sector receives from policymakers, it would appear that academic research focused on Canada has yet to catch up. The same can be said for the burgeoning forest bioenergy industry in Asia and Africa.

4.3. Overreliance on Stakeholder Engagement as a Solution to Supply Chain Challenges

The literature reviewed in our sample demonstrated a tendency to view stakeholder engagement as a solution to most sustainable supply chain challenges. Albeit, the nature of stakeholder engagement varied widely, with some articles focusing on collaboration between research, industry, and government and others stressing the importance of meaningful engagement with forest-adjacent communities, especially indigenous communities. The reliance on stakeholder engagement raises some key questions about which sustainability challenges it is equipped to address. While meaningful stakeholder engagement can certainly address some of the economic challenges that confront forest bioeconomy supply chains, principally creating supportive economic conditions, awarding social license to operate, and improving financial viability, it is less clear that it can address others. Past research has found that stakeholder engagement can actually exert downward pressure on social and environmental standards for businesses [81,82]. Thus, there is a need for a more balanced assessment on what stakeholder engagement can reasonably achieve.

4.4. Lack of Research on Supply Chain Challenges for Multistory Wood Buildings

In terms of sectoral coverage, we were surprised to find only two articles focused on multistory wood buildings [50,52]. This is a surprising dearth of research given the importance being placed on engineered wood by scholars and policymakers as a solution to the twin challenges of housing supply and climate change. As the global population continues to grow, emissions from concrete and steel production for the building sector are expected to soar. Multistory wood buildings have been touted as a means to mitigate emissions from production and provide a long-term storage solution for carbon [83]. Notwithstanding the promise of mass timber construction, there is a lack of research examining the logistical challenges confronting the industry. The two articles that address this topic in our sample focus on Finland and Sweden, thereby leaving important contextual factors in other regions unaddressed.

5. Conclusions

The forest bioeconomy holds the potential to significantly advance many of the objectives outlined in the United Nations Sustainability Goals. Forest bioproducts can simultaneously reduce carbon emissions, provide new sources of employment for forest-dependent communities, and be an engine of global economic growth. However, the sector confronts a myriad of supply chain challenges ranging from the economic feasibility of substituting bioproducts for petrochemical-based products to significant GHG emissions associated with the production and transportation of bioproducts and to social issues associated with harvesting biomass. In this paper, we systematically reviewed the scholarly literature addressing sustainable supply chain challenges in the forest bioeconomy. Our findings suggest that the extant literature is narrowly focused on economic sustainability issues, regionally biased towards Europe, and predominantly focused on stakeholder engagement as a panacea to all sustainability challenges.

We therefore make five recommendations for future research directions in this field. First, forest bioeconomy scholars need to pay more attention to the social and environmental challenges associated with the supply chains of value-added forest products. These

include, but are not limited to, GHG emissions resulting from the harvesting, production, and transport of forest bioproducts, impacts of the industry on poverty and inequality at different points in the supply chain, and consequences for peace and stability under conditions of finite supply. Second, the literature should consider a broader array of solutions to sustainability challenges than stakeholder engagement and government subsidies. In particular, the forest bioeconomy literature would benefit from deeper engagement with research on how voluntary sustainability standards have been used in tandem with public policy to improve supply chain sustainability [84,85]. Third, the forest bioeconomy literature needs greater regional diversity. Currently, too much of the research effort is directed at Europe to the detriment of emerging forest bioeconomies in North America, Asia, and Africa. Fourth, further research is needed on promising sectors within the forest bioeconomy. We identify multistory wood buildings and mass timber construction as particular areas of interest; however, we also echo calls in other research to expand research connecting different supply chain categories [86,87].

Fifth, we acknowledge that the results of this study are conditioned to some extent by the search strategy used here and the inclusion of terms like “bioeconomy” and “supply chain.” Future researchers might try broadening the search terms used to encompass a larger array of keywords like ‘forest byproduct’ or ‘valorization.’ Doing so may yield different types of sustainability challenges and attendant solutions, such as a greater focus on green extraction technologies as a solution to environmental sustainability challenges like energy consumption and fresh water usage. Nonetheless, we argue that the results presented here are indicative of the narrow scope of research that would be presented to any policymaker, practitioner, or non-forest expert conducting a routine literature review of the forest bioeconomy. As such, the findings suggest significant blindspots in the way supply chain challenges are perceived amongst lay observers.

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