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The role of forestry sciences in combating climate change and advancing sustainable development goals

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Introduction: As ecological disasters loom, forests play a crucial role in mitigating climate change and aligning with the United Nations Sustainable Development Goals (SDGs). This study aims to systematically examine the contribution of forestry science research to the SDGs through a multidisciplinary perspective, highlighting its role in advancing global sustainability efforts.

Methods: Utilizing the PRISMA protocol, we conducted a comprehensive analysis of 39,841 publications since 2015, focusing on the intersection of forestry sciences with the SDGs. Network and keyword co-occurrence analyses were performed to identify thematic clusters and interdisciplinary linkages among SDGs.

Results: Our findings indicate a significant focus on SDG 15 (Life on Land) and SDG 13 (Climate Action), emphasizing the forestry sector's contributions to biodiversity conservation, climate change mitigation, and ecosystem services. The analyses revealed thematic clusters centered around ecological sustainability, sustainable energy, and social development, demonstrating the diverse ways in which forestry research supports the SDGs.

Discussion: This study highlights the interdisciplinary nature of forestry sciences and identifies key areas of contribution while pointing to potential research gaps. Future research should explore advanced technologies such as AI-driven analytics and remote sensing, socioeconomic impacts of forest-based livelihoods, and innovative reforestation techniques. Strengthening urban forestry, enhancing interdisciplinary cooperation, and improving governance are recommended to ensure continued contributions of forestry sciences to global sustainability and the SDGs.

KEYWORDS

sustainable development goal, ecology, social development, urban planning, environmental sustainability, circular society

1 Introduction and related work

Forests, encompassing approximately 31% of the Earth's terrestrial surface (UN, 2021), stand at the forefront of addressing global environmental and societal challenges, representing an essential connection between ecological balance, economic development, and social welfare (Basak et al., 2022; Baumgartner, 2019; Fujimori et al., 2020). The critical role of forests in terms of providing oxygen supply and carbon sequestration, enhancing climate resilience, supporting biodiversity, and providing essential livelihoods for millions underscore the urgency of aligning research in the field of forestry sciences with the UN Sustainable Development Goals (SDGs) (Basak et al., 2022; Baumgartner, 2019; Fujimori et al., 2020). This alignment presents a strategic pathway to employ the comprehensive capabilities of forests in tackling pivotal issues such as climate change, biodiversity loss, poverty, and achieving sustainable economic growth (Balvanera et al., 2014; Bose, 2017; Hagenbo et al., 2022). Fulfilling the 'third task', which is about research benefitting society, necessitates forestry science to extend its reach beyond academia, directly influencing policy frameworks and societal practices aligned with the SDGs. By harmonizing forestry research endeavors with the objectives outlined in the SDGs, there is a profound opportunity to harness the inherent potential of forests to contribute to a more sustainable and equitable global future (Baumgartner, 2019; Bennett et al., 2023; Hagenbo et al., 2022).

The SDGs represent a comprehensive framework adopted by all United Nations Member States in 2015, aiming to address a wide array of global challenges and achieve a better, more sustainable future for all by 2030 (Baumgartner, 2019; Ma et al., 2022). These goals underscore the importance of not only targeting regional issues but also aligning them with broader, global sustainability objectives (Baumgartner, 2019; Ma et al., 2022). Forestry sciences play a key role in tackling various environmental challenges, such as preserving biodiversity, restoring ecosystems, reducing climate change through carbon capture, and improving ecosystem services. It is important to keep up with progress and pinpoint areas that need more research in this field (Baumgartner, 2019; Ma et al., 2022).

Forests are vital ecosystems that significantly contribute to the planet's biodiversity, housing over 80% of terrestrial species (UN, 2021). Their role as carbon sinks is crucial in climate change mitigation and climate action priorities (SDG 13) (Basak et al., 2022; Brown, 2020). Additionally, their influence on water cycles is essential for ensuring clean water supplies (SDG 6) (Pavlidis and Tsihrintzis, 2018) and protecting against natural disasters, fostering resilient communities and ecosystems. Moreover, forests are lifelines for countless individuals, especially in rural areas, where dependence on forest resources for food, fuel, and income is prevalent, thereby directly supporting sustainable economic growth (SDG 8), food security (SDG 2), and health and well-being (SDG 3) (Basak et al., 2022; Baumgartner, 2019). It is our collective responsibility to preserve these invaluable resources through sustainable forest management practices, ensuring that the benefits derived from forests are available for present and future generations, in alignment with SDG 15, which calls for the protection, restoration, and sustainable use of terrestrial ecosystems (Ma et al., 2022).

By incorporating a comprehensive approach, research on biodiversity conservation has reinforced the objectives of SDG 15, which aims to manage forests sustainably, combat desertification, halt and reverse land degradation, and enhance biodiversity (Feng et al., 2015; Jandl, 2020; Ma et al., 2022). Insightful studies by Adler et al. (2018), who explored the dynamics of plant competition, and a study by Anderegg et al. (2016), who focused on the hydraulic traits influencing tree mortality under drought, highlight the understanding required to predict biotic and abiotic stresses in forest ecosystems. Barney et al. (2015) standardized methodology for assessing the ecological impacts of invasive species and highlighted the importance of innovative strategies in forest management and conservation. The integration of advanced technologies, as demonstrated by Bubnicki et al. (2023) through the application of image processing and artificial intelligence (AI) in wildlife ecology and exploration of population genomics in conservation (Hohenlohe et al., 2021), signifies the multidisciplinary nature of forestry research toward addressing complex ecological challenges. Hendricks et al. (2018) focused on computational methods and next-generation sequencing in populations and conservation genomics data analysis. Heuertz et al. (2023) stressed the role of genomics in biodiversity and ecosystem service (ES) management, proposing a framework to bridge the gap between applications and benefits.

Recent studies in the field of afforestation and urban forestry have highlighted various ecological and social aspects, emphasizing the protection of biodiversity-rich areas, an effort closely aligned with SDG 15 (Escobedo et al., 2019). Within the sustainability domain, the integration of urban forestry has focused on enhancing resilience and livability (Escobedo et al., 2019), addressing SDG 11 (Sustainable Cities and Communities) by exploring the potential benefits of small-scale forestry initiatives. The development of integrated models for accurately quantifying forest carbon sequestration potential supports SDG 13 (climate action) by improving carbon management in the urban forestry sector. However, as highlighted by Abeli and Di Giulio (2023), a significant limitation is that many large-scale tree-planting initiatives compromise crucial ecological aspects, such as impacts on biodiversity, potentially leading to the planting of nonnative species that limit biodiversity. Additionally, to incentivize future carbon-neutral initiatives aligned with sustainability goals, there is a need for carbon-neutral assessment models that account for high regional variability in urban settings (Dian et al., 2024), further supporting SDG 13 by promoting informed and region-specific climate actions. Addressing research gaps in biodiversity conservation is crucial for enhancing our understanding and effectiveness of conservation strategies. Abas et al. (2022) emphasize the imperative of integrating indigenous knowledge with conservation policies, highlighting the need for research that ensures the inclusion of local wisdom in restoration efforts. Barney et al. (2015) emphasized involving a broader range of study species and ecosystems within the Global Invasive Impacts Network (GIIN) framework. Collectively, these studies call for a broadened research scope to fill critical gaps in our knowledge, facilitating more effective conservation practices and policies.

Recent advancements in restoration ecology have enhanced our understanding of ecosystem restoration dynamics, which is crucial for achieving SDG 15 (Life on Land). Liu and Yu (2023) advocated for a holistic approach to ecosystem restoration through multiple

ecosystem services synergistically. Another study by Lu et al. (2018) stressed the importance of sustainable water management in large-scale afforestation projects. The integration of remote sensing and modeling in forestry, as demonstrated by Abbasi et al. (2023), and the work on modeling the impact of land-use changes on carbon storage (Cao et al., 2022) highlight multidisciplinary research convergence in forest ecosystem research. Similarly, Francini et al. (2023) applied machine learning approaches to analyze dendrometer data, and Luo et al. (2021) utilized machine learning to understand forest diversity, indicating that some research has been conducted through multidisciplinary approaches. However, in alignment with the SDGs, future research trajectories emphasize key areas such as the effective management of invasive species (Segelbacher et al., 2022) and the integration of conservation strategies across countries and regions (Fady et al., 2022; Sun et al., 2019).

The role of forests in mitigating climate change aligns closely with SDG 13 (climate action) through their capacity to reduce greenhouse gas concentrations and act as carbon sinks (Arifanti et al., 2022; Svensson et al., 2021). In terms of urban environments, forests and green spaces contribute to SDG 11 (sustainable cities and communities) by cooling cities, improving air quality, and providing recreational spaces (Chen et al., 2023). Significant progress has included initiatives such as mangrove conservation for carbon sequestration (Arifanti et al., 2022). To address the impacts of climate change on forests, current research employs multidisciplinary approaches that integrate machine learning and robotic platforms for the assessment of forest health (Estrada et al., 2023). Additionally, studies are exploring the interactions between native plants, microbial endophytes, and invasive species under different climatic conditions (Fang et al., 2023) and improving remote sensing for accurate vegetation index assessments (Hilker et al., 2015). Genomic advancements include understanding the genetic responses of tree species to environmental changes and conservation strategies in relation to climate change (Fernández, 2016; McKown et al., 2018). However, research gaps remain. Touchette et al. (2021) noted the necessity of integrating traditional ecological knowledge, particularly with the participation of indigenous communities.

Agroforestry significantly contributes to SDGs 2, 13, and 15 by improving agricultural resilience, food security, biodiversity, and climate action through the integration of trees with crops and/or livestock. Agroforestry enhances soil fertility, crop yields, and climate resilience (Zerssa et al., 2021), promotes carbon sequestration, and introduces sustainable crop production systems (Zerssa et al., 2021). The integration of artificial intelligence (AI) into agroforestry research has significantly advanced the field by increasing the accuracy and efficiency of data analysis, prediction models, and decision-making processes (Eskandari et al., 2020; Silva et al., 2020; Wei and Cheng, 2022). Modeling applications in agroforestry range from integrating artificial intelligence and remote sensing for monitoring plant health and growth and predicting environmental impacts to improving crop yield through optimized resource management (Eskandari et al., 2020; Wei and Cheng, 2022). Despite these advancements, a review revealed that many AI models have limited predictive potential (Araújo et al., 2021).

In addition to its contributions to SDG 15 (life on land) and SDG 13 (climate action), this study highlights the direct impact of integrating gender aspects into forestry research, which significantly contributes to SDG 5 (gender equality). Research shows that when women are actively involved in decision-making processes related to forestry, there is a notable improvement in the adoption of sustainable practices and biodiversity conservation efforts (Begum et al., 2022; Maleknia and Salehi, 2024). Studies reveal that the underrepresentation of women in forestry initiatives compromises their effectiveness and outcomes, highlighting the necessity for gender-responsive forestry practices (Samndong and Kjosavik, 2017). Furthermore, there is a significant gap in ensuring the participation of women, local communities, and the application of indigenous knowledge in forest management efforts, which is critical for the inclusivity and sustainability of these initiatives (Kamelamela et al., 2022; Wendiro et al., 2019). These studies highlight serious gaps in gender and community participation, emphasizing the need for more inclusive forestry practices. Moreover, by addressing gender disparities in access to land, resources, and training, forestry research can further empower women, leading to broader socioeconomic benefits that indirectly support SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities) while also enhancing community resilience and promoting sustainable practices within SDG 15.

Although various studies have linked forestry sciences to the SDGs, no comprehensive systematic review has provided a holistic and integrated analysis that directly maps forestry sciences research to all 17 SDGs. Our research is the first to map the forestry sciences via the SDG mapping framework, which uses innovative machine learning algorithms to map publications accurately to the 17 SDGs, thereby enhancing our ability to identify SDG-related research. A unique contribution of this study is that through a systematic review and in-depth analysis, it aims to highlight significant research contributions within the forestry sciences that impact biodiversity, climate resilience, sustainable forest management, urban and agroforestry practices, and more, all of which are interlinked and collectively contribute to the overarching aims of the SDGs. By mapping current research trajectories and future priorities, this work seeks to provide a valuable blueprint for how forestry science can continue to contribute effectively to global well-being and sustainability, ensuring that research efforts are well aligned with the SDGs and equipped to address future challenges.

Accordingly, this study addresses the following research questions:

1. RQ1: Which SDGs receive the most and least attention in forestry science research in terms of publications and citations?
2. RQ2: To what extent is forestry sciences research interdisciplinary, as indicated by the cocitation network analysis of SDG-related publications?
3. RQ3: What are the thematic areas of forestry science research on the basis of keyword co-occurrence? What are the characteristics of the most highly cited papers in each theme, and how are they mapped to specific SDGs?

The paper unfolds systematically, beginning with the methods section that outlines the research design and analytical techniques, followed by the results, where the interdisciplinary connections between forestry sciences and the SDGs are explored through

network analyses and the examination of influential publications in thematic clusters. The discussion interprets these findings within the broader sustainable development context, while the conclusions provide key insights, propose future research directions, and acknowledge study limitations.

2 Methods

Our methodology adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, ensuring a systematic and transparent approach to identifying and selecting relevant publications from a global perspective (Page et al., 2021; Raman et al., 2023; Raman et al., 2024a; Raman et al., 2024b). This includes applying specific inclusion and exclusion criteria to refine our dataset, thereby ensuring that our analysis is both focused and relevant to the study objectives, as seen in the research framework (Figure 1).

2.1 Identification phase

Employing the Dimensions database, which is lauded for its comprehensive journal coverage beyond Web of Science by 82.2% and Scopus by 48.1% (Singh et al., 2021), this study embarks on an exhaustive search of forestry sciences research. The Dimensions database employs the Australian and New Zealand Standard Research Classification (ANZSRC) system, which comprises 22 broad fields of research (FoR) divisions for detailed classification of research activities. Using the ANZSRC system (Raman, 2023), a total of 92,113 publications on forestry sciences (ANZSRC code = 3007) were identified on January 2, 2024. This search captures the breadth of SDG-related literature from the landmark year 2015—marking the United Nations' embrace of the SDGs—up to 2023.

2.2 Screening phase

The preliminary screening eliminated publications lacking complete author details or DOIs, a necessary step to maintain the integrity of the data, thus refining the pool to 92,101 publications.

2.3 Eligibility phase

A focused selection of publications mapped directly to the 17 SDGs was conducted via proprietary algorithms within the Dimensions database, influenced by various SDG mapping initiatives, including the Aurora-Network-Global's SDG-Queries, the University of Auckland's methodology (Auckland SDG mapping, n.d.), and Elsevier's SDG Mapping Initiatives (Elsevier's, n.d.). Notably, the Digital Science SDG Mapping Initiative was selected for its seamless integration with Dimensions, providing preset search queries for each SDG, which were backed by a machine-learning model refined through expert review. A variety of studies have utilized detailed SDG mapping methods to examine the trajectory of new research themes. For example, the area of green hydrogen has been scrutinized by Raman et al. (2022), whereas the subjects of Fake News and the Dark Web have been investigated by Raman et al. (2024c) and Rama et al. (2023), respectively. These studies illustrate the use of SDG mapping as a tool to gauge how academic endeavors align with and influence sustainable development goals in these emerging fields. This phase resulted in 46,257 eligible publications.

2.4 Inclusion phase

The criteria for final inclusion were exacting only English-language research articles, conference papers, and review articles while decisively excluding preprints to ensure the study's data quality and reliability. This resulted in the inclusion of 39,841 publications for final detailed analysis. The structured methodology of this study, delineated with precise publication counts at each juncture, highlights the adherence to the PRISMA protocol, setting the stage for VOSviewer software application (Waltman et al., 2010) to map and interpret the forestry sciences research landscape in the context of SDGs.

2.5 Keywords co-occurrence network

A keyword co-occurrence network aims to understand the knowledge components and structure of a scientific field by analyzing the connections between keywords in the literature. This network is constructed by treating each keyword as a node and each co-occurrence of a pair of keywords as a link between them (Lozano et al., 2019). The nodes represent the keywords, and their sizes indicate the frequencies of these cooccurrences. Both node size and line thickness are positively correlated with keyword connections: larger nodes denote higher keyword frequencies, and thicker lines signify stronger connections between topics. We used VOSviewer software v1.6.20 to visualize the keyword co-occurrence network, with "index keywords" as our unit of analysis.

3 Results

3.1 Forestry sciences research mapped to SDGs (RQ1)

In this context, the distribution of publications and citations reveals noteworthy trends (Table 1). SDG 15, "Life on Land," is the most prominent goal, with the highest number of publications and citations, highlighting the central role of forestry in land management and biodiversity conservation. This is followed by SDG 13, "Climate Action," and SDG 14, "Life Below Water," emphasizing the impact of forestry on climate change mitigation and aquatic ecosystems. SDG 7, "Affordable and Clean Energy," and SDG 2, "Zero Hunger," also receive considerable attention, underscoring the role of forestry in sustainable energy solutions and food security. Interestingly, SDGs 11, "Sustainable Cities and Communities," and 3, "Good Health and Well Being," although not at the top, still receive notable attention, indicating a growing awareness of the role of urban green spaces in promoting community well-being and public health. Conversely, SDG 4,

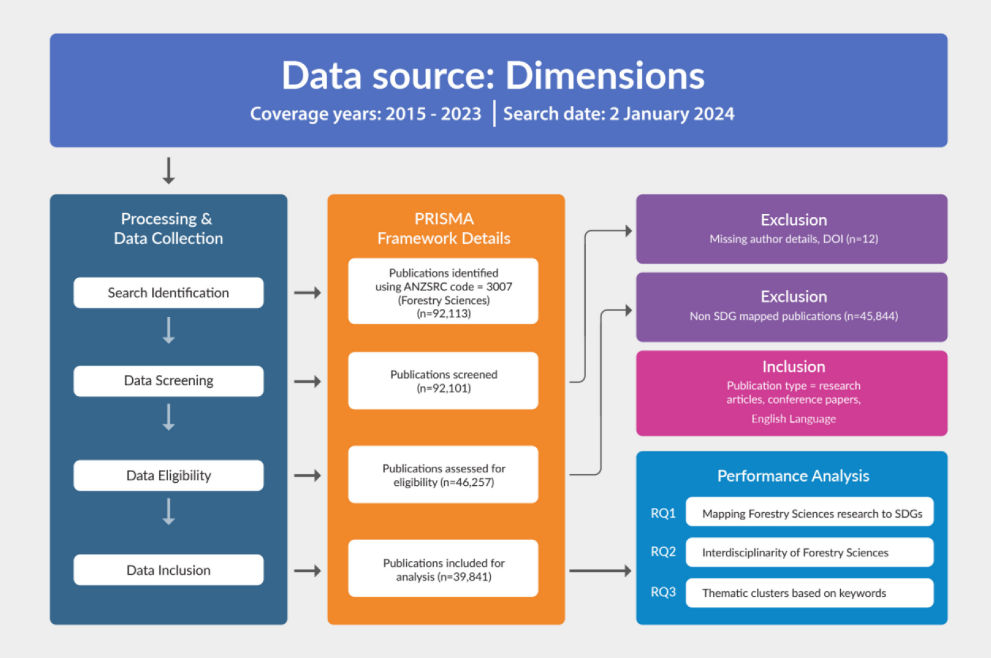

FIGURE 1
Research framework for mapping forestry science publications to SDGs.

"Quality Education," 10, "Reduced Inequalities," and 9, "Industry, Innovation and Infrastructure," are among the least represented in forestry research, suggesting potential areas for further academic exploration. The minimal focus on SDG 5, "Gender Equality," and SDG 17, "Partnerships for the Goals," indicates a need for a more inclusive and collaborative approach in forestry sciences.

3.2 Forestry sciences interdisciplinary research as a network of SDGs (RQ2)

Sustainable development goals are designed to be mutually reinforcing, with the advancement of one often reliant on the progress of others (Nilsson et al., 2016). Through network analysis, Le Blanc (2016) reported that the connections between these goals are not evenly distributed. Some SDGs have a web of targets that link them extensively to other goals, whereas some are less connected within the network of SDGs. To illustrate these links, a cocitation map is shown in Figure 2, which maps out how SDGs are contextually related on the basis of how often they are referenced together in the literature. The closeness of the SDGs on this map mirrors their topical relatedness, the size of each node indicates the volume of publications for each SDG, and the width of the lines between them reflects their cocitation frequency.

In the realm of forestry sciences and its alignment with the SDGs, three distinct thematic networks emerge, each highlighting a different aspect of how forestry research intersects with these global goals.

SDG-Network1 (Green-Ecological and Environmental Sustainability): Dominated by SDG 15 (Life on Land), this network integrates SDGs 2 (Zero hunger), 13 (Climate Action), and 14 (Life Below Water), forming a theme centered around ecological and environmental sustainability. The prominence of SDG 15 underscores forestry science's critical role in land management and biodiversity conservation, which is intrinsically linked to combating hunger (SDG 2), addressing climate change (SDG 13), and protecting aquatic ecosystems (SDG 14) with partnerships (SDG 17). This network reflects the fundamental understanding that healthy forest ecosystems are vital for environmental resilience and sustainable food sources.

SDG-Network2 (Blue—Sustainable Energy and Industry): Led by SDG 7 (Affordable and Clean Energy) and encompassing SDGs 12 (Responsible Consumption and Production), 8 (Decent Work and Economic Growth), and 9 (Industry, Innovation, and Infrastructure), this network represents a theme of sustainable energy and industry. This highlights the role of forestry sciences in contributing to sustainable energy solutions, such as bioenergy, and promoting sustainable practices in forest-related industries. This network also addresses the economic aspects of forestry, linking sustainable forest management with economic growth and innovation.

SDG-Network3 (Red—Social Development and Urban Planning): This network is dominated by SDG 11 (Sustainable Cities and Communities) and SDG 3 (Good Health and Well-being), followed by SDGs 1 (No Poverty), 4 (Quality Education), 5 (Gender Equality), and 16 (Peace, Justice and Strong Institutions). This network reflects a theme of social development and urban planning. It emphasizes the role of urban forestry in enhancing the livability of cities, contributing to public health, and addressing issues of poverty and equality. This network underscores how forestry sciences contribute to the creation of sustainable, healthy, and inclusive urban environments.

TABLE 1 Forestry sciences research mapped to SDGs.

Sustainable development goal	Publications	%Publications	Citations
1 No poverty	129	0.32%	2214
2 Zero hunger	1157	2.90%	17595
3 Good health and well being	700	1.76%	10051
4 Quality education	100	0.25%	784
5 Gender equality	36	0.09%	378
6 Clean water and sanitation	177	0.44%	2189
7 Affordable and clean energy	1620	4.07%	18023
8 Decent work and economic growth	177	0.44%	1280
9 Industry, innovation and infrastructure	54	0.14%	450
10 Reduced inequalities	58	0.15%	903
11 Sustainable cities and communities	857	2.15%	14472
12 Responsible consumption and production	250	0.63%	3238
13 Climate action	5960	14.96%	113275
14 Life below water	3688	9.26%	48911
15 Life on land	30643	76.91%	342490
16 Peace, justice and strong institutions	129	0.32%	1337
17 Partnerships for the goals	13	0.03%	85

Each of these networks, green, blue, and red, illustrates a unique perspective through which forestry sciences contribute to the SDGs, highlighting the multifaceted role of forests in ecological balance, sustainable economic development, and societal well-being.

Next, we perform keyword co-occurrence analysis of each of these SDG networks to identify highly cited publications and explore their SDG focus.

3.3 Forestry sciences thematic clusters (RQ3)

3.3.1 SDG network 1: ecological and environmental sustainability

On the basis of keyword cooccurrences, SDG-Network1 results in 3 distinct clusters (Figure 3). Each keyword's importance within its cluster is quantified by its 'total link strength', indicating the strength of its association with other keywords within the cluster.

In cluster 1 (red), the prominent keywords include "forest," "species," "ecosystems," "climate change," "biodiversity," "deforestation," "forest management," and "fire." These terms suggest a focus on forest ecosystems and their management, the species they support, and the threats they face from climate change and human activities. Cluster 2 (green) emphasized soil and carbon-related terms, highlighted by "soil," "carbon," "biomass," "organic carbon," "sequestration," "carbon stocks," "land use," and "agriculture." This cluster seems to concentrate on the role of soil and land use in carbon sequestration, reflecting the importance of agricultural practices and land management in sustainability and carbon cycle dynamics. Finally, cluster 3 (blue) addresses biodiversity and community composition, as indicated by "diversity," "richness," "community," "vegetation," "species richness," "restoration," "plant communities," and "ecosystem functions." This cluster likely addresses the ecological aspects of sustainability, focusing on the conservation and restoration of biodiversity and ecosystem functions. Collectively, these keywords form a complex interrelated schema that underscores the multifaceted nature of ecological and environmental sustainability, incorporating aspects of conservation, management, and the understanding of natural processes critical to maintaining the resilience and functionality of ecosystems.

Next, we look at highly cited publications in this network (Table 2). Exploring the accelerating shifts in species distributions due to climate change and their profound effects on ecosystems and human well-being, the study by Pecl et al. (2017) emphasized the critical need for incorporating species redistribution in climate change mitigation and adaptation strategies. It aligns closely with SDG 15 (Life on Land) by highlighting the importance of conserving biodiversity for ecosystem services and addresses SDG 13 (Climate Action) by focusing on the impacts of climate change on species movements and ecosystem functions. To demonstrate the significant role of anthropogenic climate change in increasing forest fire activity in the western US, Abatzoglou and Williams (2016) underscore the urgent need for climate action (SDG 13). This research is also related to forest management and conservation in the face of changing fire regimes, supporting SDG 15 (Life on Land). These findings indicate that climate change will likely increase disturbances from fire, drought, wind, and insects, especially in coniferous forests and the boreal biome, and the findings of Seidl et al. (2017) support SDG 13 (Climate Action). The study suggests preparedness for future forest management challenges due to these disturbances, also supporting SDG 15 (Life on Land). To protect microbial diversity as a critical component of global sustainability goals, Delgado-Baquerizo et al. (2016) demonstrated a positive relationship between soil microbial diversity and ecosystem multifunctionality. This research emphasizes its importance for climate regulation, soil fertility, and food production, which are related to SDGs 2, 13, and 15. Because a significant portion of global forest loss is due to commodity production, Curtis et al. (2018) emphasized the need for sustainable land use practices (SDG 15). This study calls attention to the ongoing challenge of commodity-driven deforestation, which is directly relevant to SDG 12 (Responsible Consumption and Production).

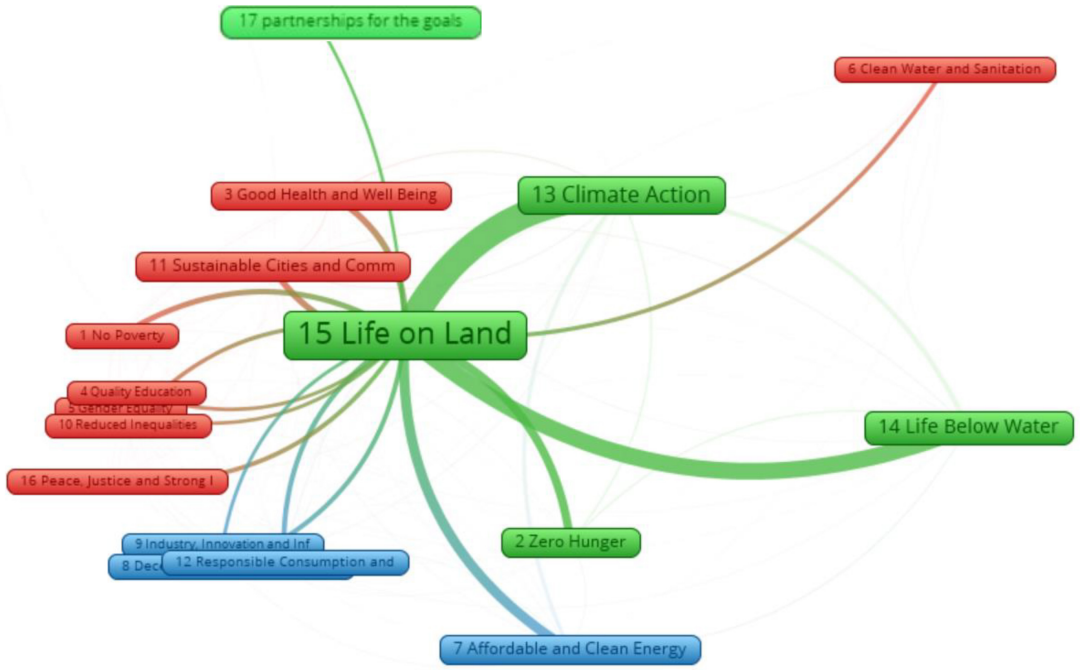

FIGURE 2
Interdisciplinary research in forestry sciences as a network of SDGs.

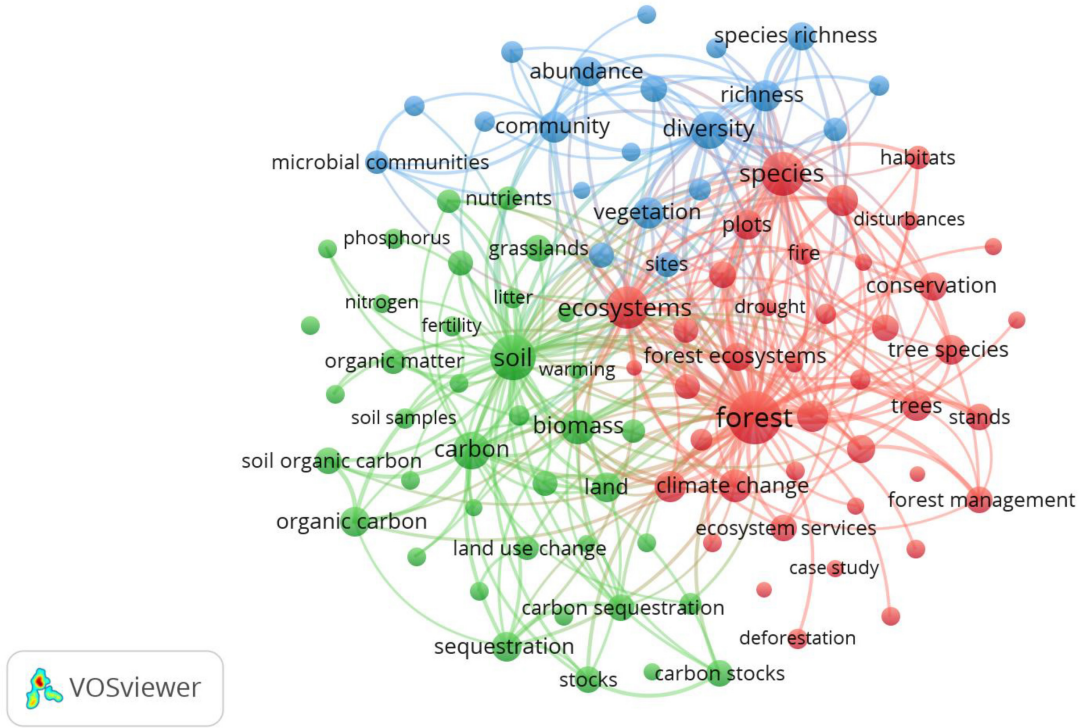

FIGURE 3
Keyword cooccurrences analysis–Ecological and environmental sustainability.

The publications in this network collectively highlight the intricate relationships among climate change, biodiversity, and ecosystem services. These findings underscore the urgent need for integrated approaches to climate action (SDG 13) and land conservation (SDG 15) to mitigate the adverse effects of species redistribution, forest fires, and other disturbances exacerbated by anthropogenic climate change. Furthermore, research on the role of microbial diversity in ecosystem multifunctionality emphasizes

TABLE 2 Ecological and environmental sustainability—highly cited publications.

Title	References	Citations	Year	SDG focus
"Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being"	Pecl et al. (2017)	2077	2017	15 Life on Land; 13 Climate Action
"Impact of anthropogenic climate change on wildfire across western US forests"	Abatzoglou and Williams (2016)	1687	2016	13 Climate Action
"Forest disturbances under climate change"	Seidl et al. (2017)	1527	2017	13 Climate Action
"Microbial diversity drives multifunctionality in terrestrial ecosystems"	Delgado-Baquerizo et al. (2016)	1268	2016	13 Climate Action
"Classifying drivers of global forest loss"	Curtis et al. (2018)	1242	2018	15 Life on Land

the importance of preserving biodiversity across all life forms, including microorganisms, to sustain the Earth's capacity to support human well-being and biodiversity (SDGs 2, 12, and 15). Together, these studies provide a compelling scientific basis for policy and action toward achieving the Sustainable Development Goals through the conservation and sustainable management of terrestrial ecosystems.

3.3.2 SDG-network2: sustainable energy and industry

The network visualization results in four interlinked thematic clusters (Figure 4).

In the red cluster, substantial nodes such as "forest management," "forest plantations," and "forest biomass" suggest a central focus on the sustainable management of forest resources for energy production. Keywords such as "wood," "timber," and "harvesting" point to the utilization of forest products, whereas "fossil fuels" and "gas emissions" imply a contrast or transition from nonrenewable to renewable energy sources within this domain. The green cluster is characterized by keywords such as "biomass," "carbon," and "carbon sequestration," with "biomass" being a particularly prominent node. This implies a strong emphasis on the role of biomass in carbon capture and sustainable energy production. The presence of terms such as "soil," "organic matter," and "microbial communities" suggests the importance of soil health and ecosystems in supporting biomass as a renewable energy source. The blue cluster, with prominent nodes such as "energy crops," "biomass production," and "energy production," indicates a focus on the agricultural production of biomass and its conversion into energy. "Yield" and "use efficiency" are also significant, denoting the importance of optimizing crop productivity and the efficiency of energy conversion processes. The yellow cluster, which had been previously overlooked, contains keywords such as "forest ecosystems," "carbon stocks," "carbon cycle," and "carbon sink," with "forest ecosystems" being a central node. This suggests an emphasis on the broader ecological functions of forests in the context of sustainable energy, highlighting how forest ecosystems contribute to the global carbon cycle and act as carbon sinks, which are crucial for mitigating climate change.

Collectively, these clusters offer a comprehensive perspective on sustainable energy and industry, highlighting the multifaceted approach that encompasses forest resource management, the ecological processes underpinning biomass production, agricultural practices for energy crop cultivation, and the role of forest ecosystems in global carbon dynamics. The network suggests a systemic approach to sustainable energy, where industry practices are closely integrated with ecological health and resource management to advance energy sustainability goals.

Next, we look at highly cited publications in this network (Table 3).

The paper by Ellison et al. (2017) argues for prioritizing the hydrologic and cooling functions of forests for climate adaptation and mitigation, emphasizing the vital role forests play in the water, energy, and carbon cycles. In alignment with SDG 13 (climate action) and SDG 15 (life on land), this approach highlights the need for integrated climate strategies that recognize forest functions. Nobre et al. (2016) discussed agricultural expansion in the Amazon, which has led to biodiversity loss and increased deforestation risk. Advocating for a new development model, this study supports sustainable land-use practices that preserve biodiversity and forest cover, thereby supporting SDG 13 (climate action) and SDG 15 (life on land). In the review by Kawamoto (2017), the pyrolysis of lignin was presented as a sustainable approach to converting lignin into valuable biochemicals, biomaterials, and biofuels. This aligns with SDG 7 (Affordable and Clean Energy) and promotes carbon-neutral energy solutions, contributing to SDG 13 (Climate Action). Investigating the impact of land-use intensification on soil pH and microbial ecophysiological traits critical for soil carbon cycling, the study by Malik et al. (2018) supports SDG 15 (Life on Land). It emphasizes soil health and its link to land management practices, highlighting the role of soil in carbon storage and sequestration for SDG 13 (climate action). Ma et al. (2017) examined the effects of climate warming on the stability of plant community biomass on the Tibetan Plateau. Given that warming reduces stability by decreasing species asynchrony, this study connects to SDG 13 (climate action) and SDG 15 (life on land) by showing how changes in community biomass stability can affect ecosystem services and biodiversity.

The articles in this network collectively address the critical intersections between forest management, land use, and climate change mitigation strategies. They highlight innovative approaches to leveraging forest and land resources for sustainable energy production, climate regulation, and conservation efforts. By emphasizing the importance of forests in water and energy cycles, sustainable land-use practices in the Amazon, the potential of lignin pyrolysis for renewable energy, the impact of soil management on carbon cycling, and the effects of climate change on ecosystem stability, these studies provide valuable insights into achieving multiple SDGs, particularly SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 15 (Life on Land). These

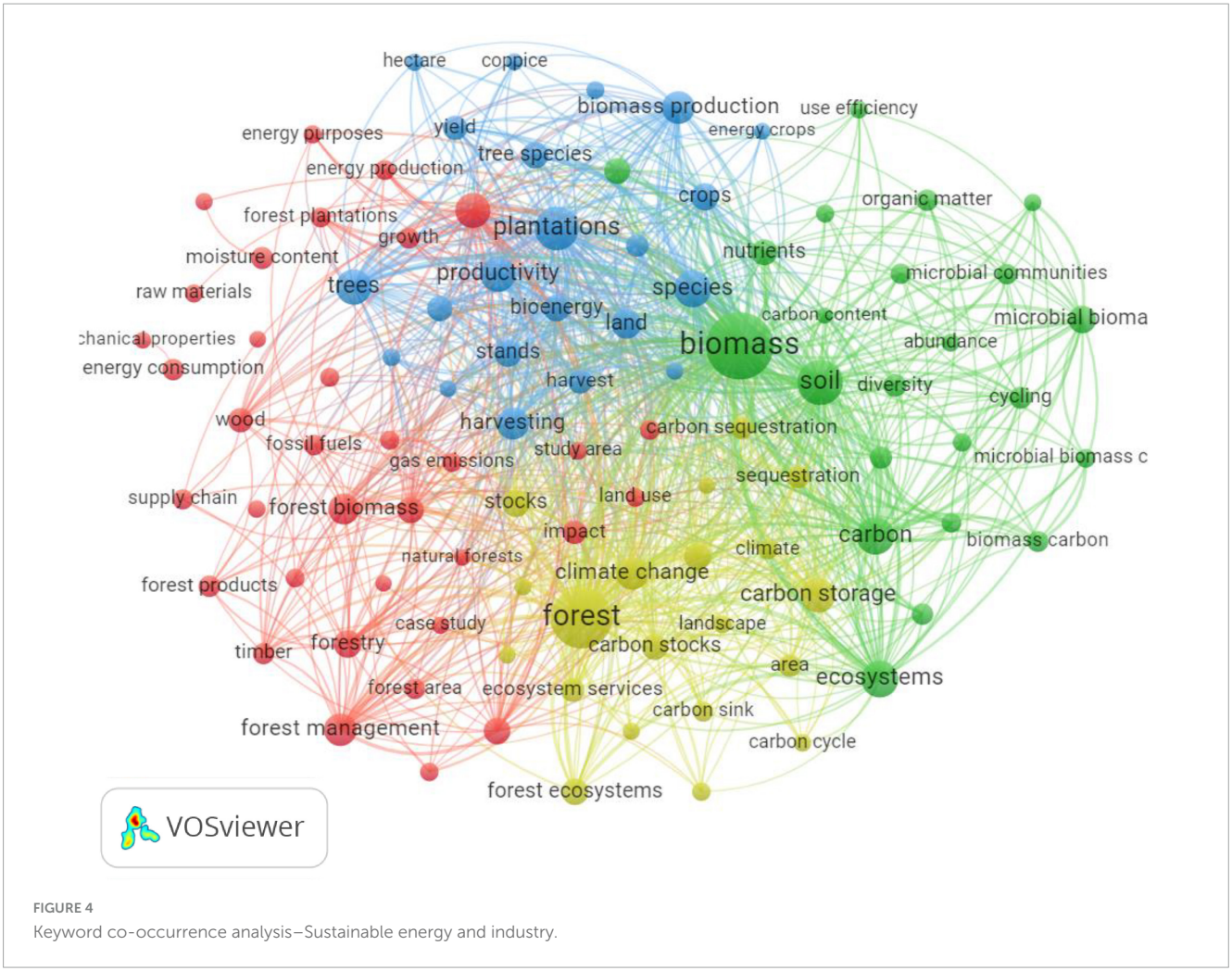

FIGURE 4
Keyword co-occurrence analysis–Sustainable energy and industry.

TABLE 3 Sustainable energy and industry cluster—highly cited publications.

Title	References	Citations	Year	SDG focus
"Trees, forests and water: Cool insights for a hot world"	Ellison et al. (2017)	634	2017	15 Life on Land; 13 Climate Action; 7 Affordable and Clean Energy
"Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm"	Nobre et al. (2016)	533	2016	15 Life on Land; 7 Affordable and Clean Energy
"Lignin pyrolysis reactions"	Kawamoto (2017)	392	2017	7 Affordable and Clean Energy; 13 Climate Action
"Land use driven change in soil pH affects microbial carbon cycling processes"	Malik et al. (2018)	369	2018	15 Life on Land; 7 Affordable and Clean Energy
"Climate warming reduces the temporal stability of plant community biomass production"	Ma et al. (2017)	321	2017	13 Climate Action; 7 Affordable and Clean Energy

insights are crucial for developing policies and practices that enhance sustainability, promote energy efficiency, and mitigate climate change impacts.

3.3.3 SDG-network3: social development and urban planning

This network is distributed across three clusters (Figure 5). Cluster 1 (red) is dominated by keywords such as "green spaces," "ecosystem services," "city," "urban green spaces," "urban forests," "urban areas," "climate change," and "urban planning." These terms collectively emphasize the integration of natural elements within urban settings, underscoring the role of urban forestry and green infrastructure in enhancing the quality of urban environments. This cluster illustrates the intersection of urban design and sustainability, with a specific focus on mitigating the impacts of climate change through urban planning. The second cluster (green) features "forest management," "community," "conservation," "forest products," "livelihoods," "forestry," "sustainable development,"

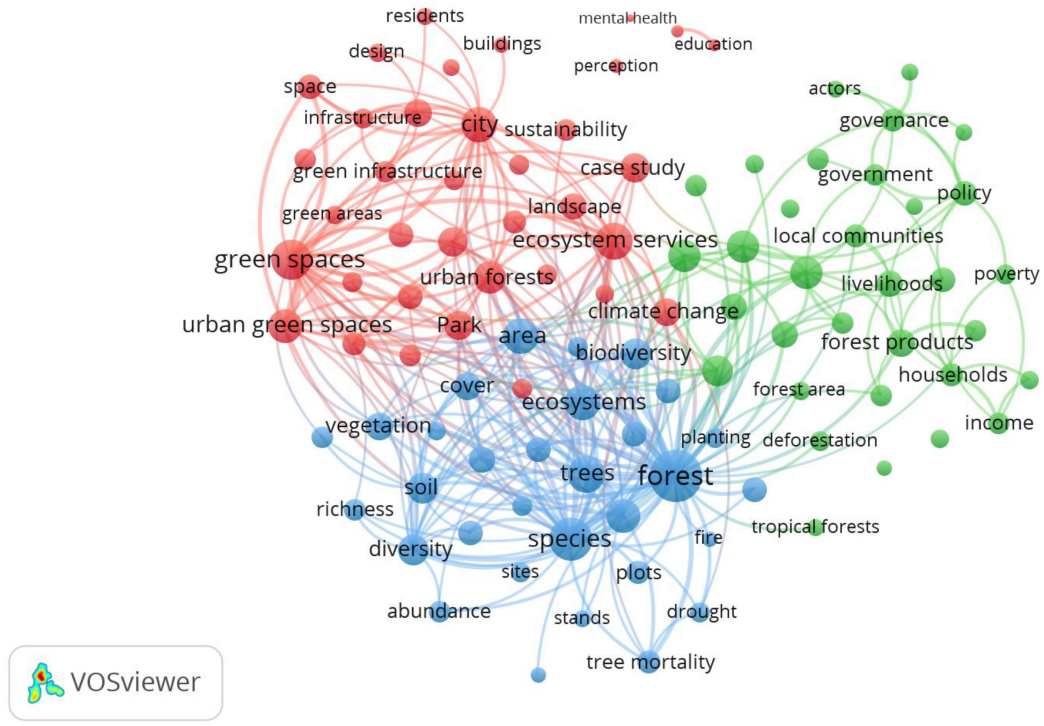

FIGURE 5
Keyword co-occurrence analysis–social development and urban planning.

TABLE 4 Social development and urban planning–highly cited publications.

Title	Reference	Citations	Year	SDG focus
"Temperate forest health in an era of emerging mega disturbance"	Millar and Stephenson (2015)	657	2015	3 Good Health and Well Being
"Assessing street-level urban greenery using Google Street View and a modified green view index"	Li et al. (2015)	528	2015	11 Sustainable Cities and Communities
"Health benefits of green spaces in the living environment: A systematic review of epidemiological studies"	Van den Berg et al. (2015)	518	2015	3 Good Health and Well Being
"Soil health and carbon management"	Lal (2016)	417	2016	15 Life on Land; 1 No Poverty
"Impacts of COVID-19 pandemic on urban park visitation: a global analysis"	Geng et al. (2021)	302	2020	3 Good Health and Well Being; 11 Sustainable Cities and Communities

and "poverty alleviation." This cluster appears to focus on the socioeconomic dimensions of sustainability, particularly the interface between community management of forest resources and the pursuit of sustainable livelihoods. This reflects an understanding of urban planning as a socioecological endeavor that extends into the management of natural resources with the aim of reducing poverty. In cluster 3 (blue), terms such as "forest," "species," "trees," "biodiversity," "soil," "pollution," "forest ecosystems," "plantations," and "air pollution" emerged. These terms suggest a more ecological perspective, indicating the importance of biodiversity and ecosystem health in the context of urban areas. This cluster may be related to broader environmental considerations that need to be incorporated into urban and social development planning to ensure sustainable outcomes.

Overall, these keywords form a comprehensive framework that stresses the importance of ecological considerations in urban spaces, the socioeconomic implications of environmental management, and the role of policy and governance in fostering sustainable urban development. The emphasis across clusters on green spaces, sustainability, and community engagement reflects a holistic approach to urban planning that seeks to balance environmental health with social development goals.

Table 4 shows the highly cited publications in this network.

Millar and Stephenson (2015) emphasized the critical role of forest management in mitigating the impacts of extreme droughts and disturbances exacerbated by climate change. This work aligns with SDG 15 (Life on Land) by underscoring biodiversity conservation and land management and supports SDG 13 (Climate Action) through its focus on mitigating climate change impacts on forests. By introducing a novel method for assessing urban greenery at the street level, Li et al. (2015) enhanced urban landscape planning and management. This research directly supports SDG

11 (sustainable cities and communities) by contributing to the development of sustainable urban spaces and indirectly benefits SDG 3 (good health and well-being) through the health benefits of urban green spaces. In presenting strong evidence of the positive association between green space and mental health outcomes, Van den Berg et al. (2015) support SDG 3 (good health and well-being). This review also underlines the importance of green space for SDG 11 (sustainable cities and communities) by emphasizing the role of urban greenery in improving quality of life. Highlighting the critical role of soil health in carbon management and its impact on global food security, Lal (2016) aligns with SDG 2 (zero hunger) and SDG 13 (climate action). This paper also addresses SDG 15 (Life on Land) by discussing the role of soil in terms of ecosystem services and biodiversity. Analyzing the increase in park visitation during the COVID-19 pandemic, Geng et al. (2021) underscore the importance of urban parks for mental and physical health. This study supports SDG 3 (good health and well-being) and SDG 11 (sustainable cities and communities), highlighting the role of green spaces in fostering community resilience and social cohesion during crises.

The articles in this network collectively emphasize the integral role of forestry and green spaces in addressing several SDGs, particularly SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land). They illustrate a multifaceted approach to sustainable urban planning, the health benefits of greenery, soil health for carbon management, and the resilience of urban parks during global health crises, underscoring the interconnectedness of environmental sustainability and social well-being.

4 Discussion

The analysis across three SDG networks reveals a multifaceted perspective on the role of forestry sciences in advancing the SDGs amidst the challenges of climate change, biodiversity loss, and the need for sustainable urban development. The implications of these findings are significant, as they highlight where forestry sciences are making the greatest impact in terms of SDG contributions and where there may be opportunities to broaden the scope of research to address other critical dimensions of sustainable development.

The analysis of the highly cited papers indicates that SDG 15 and SDG 13 receive the most attention in forestry science research. This is evident from the frequent focus on topics related to biodiversity conservation, forest management, climate change impacts on forests, and carbon sequestration. On the other hand, SDGs such as SDG 4, SDG 10 (reduced inequalities), and SDG 9 (industry, innovation, and infrastructure) appear to receive less attention, as these areas are less directly related to the core subjects of forestry science research. The implementation of the SDGs presents new challenges for forestry practitioners, such as the need for sustainable forest management and addressing the impacts of climate change. However, it also provides opportunities for capacity building and valuable synergy effects through cooperation in teaching and research (Baumgartner, 2019). Forests are vital for human wellbeing and sustainable development, and their contributions to the SDGs need to be systematically assessed to understand potential synergies and trade-offs between goals (Aguayo Lopes da Silva et al., 2023). Forestry plays a crucial role in achieving several SDGs, such as SDG 4 (quality education), SDG 7 (affordable and clean energy), SDG 13 (climate action), and SDG 15 (life on land) (Ma et al., 2022; Walentowski et al., 2020).

Ecological and environmental sustainability underscore the critical impacts of climate change on biodiversity, ecosystem functions, and species distributions. This highlights the necessity for integrated conservation and adaptation strategies to mitigate anthropogenic effects, such as increased forest fires and disturbances, while emphasizing the importance of soil microbial diversity for ecosystem multifunctionality and climate regulation. This cluster is closely aligned with SDG 13 and SDG 15, which focus on biodiversity conservation and the preservation of ecosystem services.

Sustainable energy and industry explore innovative approaches to utilizing forest resources for sustainable energy production and climate mitigation. This study highlights the importance of forests in the water, energy, and carbon cycles, advocating for sustainable land use and the development of carbon-neutral energy solutions through practices such as lignin pyrolysis. The research within this cluster supports SDGs 7, 13 and 15, offering insights into policy development for sustainability and climate change mitigation. Higher education institutions are integrating the SDGs into forestry and wood industry educational programs and research, which is seen as an important step toward achieving the SDGs (Uhan et al., 2024).

Social development and urban planning emphasize the social dimensions of forestry sciences, illustrating how urban greenery and forest management contribute to public health, well-being, and sustainable cities. It addresses the resilience of urban parks during health crises, the role of soil health in carbon management, and the benefits of green spaces for mental health. This cluster aligns with SDGs 3 (Good Health and Well-being), 11 (Sustainable Cities and Communities), 13 and 15, highlighting the interconnectedness of environmental sustainability with urban planning and social welfare. A recent study by Boshoff et al. (2024) highlighted geographical inequalities in the global forestry sciences; revealed persistent disparities in scientific, collaboration, and funding capital; and underscored the mismatch between research focus and regional needs, emphasizing the importance of place and context. The development of a research model of the role of forestry in the national economy, which is based on the example of the development of forestry in Kazakhstan, can provide insights into the role and importance of forestry in the economy and the assessment of trends and prospects for sector development within the country (Abayeva et al., 2024). A methodological framework for quantifying impacts on climate change, biodiversity, and social and economic values in forestry scenarios is needed, emphasizing the importance of tailored assessments and long-term evaluations (Mattsson et al., 2024).

5 Conclusion

The interdisciplinary nature of the forestry sciences demonstrates its pivotal role in addressing global sustainability challenges. The findings advocate for integrated approaches that bridge conservation, sustainable energy production, and urban

development, ensuring the alignment of forestry research with the broader objectives of the Sustainable Development Goals. By highlighting the connections between forestry science and the SDGs—particularly SDG 3, SDG 7, SDG 11, SDG 13, and SDG 15—these studies emphasize the critical need for integrated approaches that prioritize ecological integrity, social well-being, and sustainable economic development.

Research in forestry contributes to SDG 15 by advancing the knowledge of sustainable forest management practices, conservation strategies, and the role of forests in maintaining biodiversity and providing ecosystem services. Highly cited papers within the clusters explored topics such as biodiversity redistribution under climate change, the impacts of anthropogenic activities on wildfires, and the importance of forests in water and climate regulation. These contributions emphasize the necessity of integrating ecological knowledge into land management practices to conserve biodiversity, manage forests sustainably, and mitigate the impacts of climate change, thereby directly supporting the objectives of SDG 15.

The most highly cited papers in forestry sciences share characteristics such as a focus on pressing environmental issues (e.g., climate change, biodiversity loss), innovative methodologies (e.g., large-scale data analysis, modeling studies), and relevance to policy and practice. These papers are mapped to specific SDGs by addressing topics directly related to these goals, such as SDG 13, through studies on the impacts of climate change on forests, and SDG 15, through research on biodiversity conservation and sustainable land management. Mapping to the SDGs highlights the critical role of forestry sciences in addressing global environmental challenges and underscores the multidisciplinary nature of the research.

5.1 Future directions for research with programmatic activities

Future research should explore the integration of advanced remote sensing technologies and AI-driven analytics to monitor forest health, biodiversity, and carbon sequestration on a global scale, providing real-time data to inform sustainable management practices. Investigating the socioeconomic impacts of forest-based livelihoods, with a focus on enhancing gender equality and empowering marginalized communities, will also be crucial. Additionally, research should delve into the restoration of degraded forest ecosystems, examining innovative reforestation techniques and the role of native species in enhancing ecosystem resilience.

Furthermore, the exploration of forest carbon markets and their potential to incentivize sustainable forestry practices could provide new economic avenues for forest conservation. Understanding the long-term effects of climate change on forest ecosystems, particularly in relation to species migration and the shifting of ecological zones, is another critical area of study. Research should also focus on the role of forests in urban environments, explore how urban forests can mitigate the urban heat island effect and contribute to improved air quality. Finally, investigating the integration of traditional ecological knowledge with modern forestry practices can offer new insights into sustainable forest management, ensuring that conservation efforts are culturally appropriate and locally supported.

1. Strengthening urban forestry initiatives

- **Promote urban green spaces:** Encourage the development and maintenance of urban forests and green spaces to enhance public health (SDG 3), support biodiversity (SDG 15), and improve the quality of urban life (SDG 11). Urban planning should integrate green infrastructure as a fundamental component to address climate change and enhance urban resilience.

2. Prioritizing ecological and environmental sustainability

- **Implementing sustainable forest management (SFM):** SFM practices are adopted and promoted to conserve biodiversity (SDG 15), mitigate climate change (SDG 13), and ensure that forests continue to provide essential ecosystem services. This includes managing forests for multiple purposes, such as carbon sequestration, water regulation, and habitat protection.
- **Advance climate change adaptation and mitigation strategies:** Utilize forestry sciences to develop and implement strategies that reduce the vulnerability of forests and communities to climate change impacts, with a focus on preserving ecosystem services and enhancing carbon storage capabilities.

3. Leveraging forests for sustainable energy and industry

- **Promote renewable energy from forest biomass:** Encouraging the use of forest biomass for renewable energy production (SDG 7) in a sustainable way that does not compromise forest health or biodiversity. This includes supporting research and development in lignin pyrolysis and other technologies for converting forest residues into bioenergy and bioproducts.
- **Foster innovation in the bioeconomy:** Support the development of a sustainable bioeconomy that utilizes forest resources to create high-value products and services, thereby promoting economic development (SDG 8) and contributing to climate action (SDG 13) through reduced reliance on fossil fuels.

4. Increasing interdisciplinary and transboundary cooperation

- **Foster interdisciplinary research:** Encouraging collaboration across disciplines to address complex challenges at the intersection of forestry, sustainability, and urban planning. This includes integrating knowledge from ecology, social sciences, economics, and technology to develop holistic solutions.
- **Strengthening transboundary and regional governance:** Promotion of cooperation among countries and regions to manage transboundary forest resources effectively, address shared environmental challenges, and achieve the SDGs through collaborative initiatives and policies.

5. Engaging communities and strengthening governance

- **Community engagement and inclusivity:** Ensure that local communities, including indigenous peoples, are actively involved in decision-making processes related to forest management and land use. Recognizing and safeguarding their rights, knowledge, and contributions to forest conservation and sustainability.
- **Improving policy and legislation:** Update and harmonize policies, legislation, and governance frameworks at all levels to reflect the multifunctional role of forests in sustainable development, water and climate regulation, and biodiversity conservation.

6. Climate change

- **Slowing climate change:** Climate change is a multifaceted issue that demands interdisciplinary research efforts to address its complexities. The concept of "climate justice" is pivotal in this discourse, as it aims to link development and human rights with climate change mitigation and adaptation strategies.
- **Managing climate change:** Addressing climate change requires interdisciplinary research approaches that prioritize climate justice, social equity, and environmental sustainability. Future research directions should focus on understanding the complex interconnections between climate change, social justice, and human development to inform transformative policy and practice.

7. Deforestation (clearing forests)

- **Stopping drastic deforestation:** Deforestation is a global challenge with far-reaching environmental, social, and economic implications. The alarming rate of deforestation highlights the urgent need for research and action to conserve forests and mitigate the impacts of deforestation.
- **Accelerating scientific research:** Future research on deforestation should focus on understanding the drivers, impacts, and potential solutions to deforestation, with an emphasis on interdisciplinary approaches and global cooperation to promote sustainable forest management and conservation.

The study's adherence to the PRISMA protocol, while methodologically robust, introduces limitations characteristic of bibliometric analyses. The exclusion of non-English publications and preprints may omit relevant findings and emergent trends not yet available in peer-reviewed formats, potentially skewing the research landscape's portrayal. Reliance on the Dimensions database, despite its extensive coverage, may overlook relevant publications indexed elsewhere or those not classified under the ANZSRC Field of Research of Forestry Sciences. The use of proprietary algorithms for SDG mapping, even though refined by machine learning and expert review, carries an inherent risk of bias, as the algorithm's internal criteria and weighting may not capture the full spectrum of SDG-relevant research (Raman et al., 2023). The bibliometric approach also inherently limits the analysis to quantifiable data, potentially overlooking qualitative subtleties within the research corpus. Despite these constraints, the methodological rigor of this study ensures a robust and comprehensive analysis, significantly contributing to the understanding of forestry sciences in the context of the SDGs.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RR: Writing – review and editing, Writing – original draft, Project administration, Methodology, Data curation, Conceptualization. SM: Writing – review and editing, Writing – original draft. DD: Writing – review and editing, Writing – original draft, Methodology. PN: Writing – review and editing, Writing – original draft, Visualization, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abas, A., Aziz, A., and Awang, A. (2022). A systematic review on the local wisdom of indigenous people in nature conservation. *Sustainability* 14:3415. doi: 10.3390/su14063415

Abatzoglou, J. T., and Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proc. Natl. Acad. Sci. U.S.A.* 113, 11770–11775. doi: 10.1073/pnas.1607171113

Abayeva, K. T., Igembayeva, A. K., Shynybekov, M. K., Rakymbekov, Z. K., and Rakhimzhanova, G. M. (2024). The basic aspects of the forestry system's functioning in the general economic system of the Republic of Kazakhstan. *Environ. Dev. Sustain.* 26, 7815–7826.

Abbasi, A. O., Tang, X. L., Harris, N. L., Goldman, E. D., Gamarra, J. G. P., Herold, M., et al. (2023). Spatial database of planted forests in East Asia. *Sci. Data* 10:480. doi: 10.1038/s41597-023-02383-w

Abeli, T., and Di Giulio, A. (2023). Risks of massive tree planting in Europe should be considered by the EU Forestry Strategy 2030. *Restor. Ecol.* 31:834. doi: 10.1111/rec.13834

Adler, P. B., Smull, D., Beard, K. H., Choi, R. T., Furniss, T., Kulmatiski, A., et al. (2018). Competition and coexistence in plant communities: Intraspecific competition is stronger than interspecific competition. *Ecol. Lett.* 21, 1319–1329. doi: 10.1111/ele.13098

Aguayo Lopes da Silva, R., Cesar Gonçalves Robert, R., and Purfürst, T. (2023). How is the forest sector's contribution to the sustainable development goals (SDGs) being Addressed? A systematic review of the methods. *Sustainability* 15:8988.

Anderegg, W. R. L., Klein, T., Bartlett, M., Sack, L., Pellegrini, A. F. A., Choat, B., et al. (2016). Meta-analysis reveals that hydraulic traits explain cross-species patterns of drought-induced tree mortality across the globe. *Proc. Natl. Acad. Sci. U.S.A.* 113, 5024–5029. doi: 10.1073/pnas.1525678113

Araújo, H. C. D., Martins, F. S., Cortese, T. T. P., and Locosselli, G. M. (2021). Artificial intelligence in urban forestry-A systematic review. *Urban For. Urban Green.* 66:7410. doi: 10.1016/j.ufug.2021.127410

Arifanti, V. B., Kauffman, J. B., Subarno, Ilman, M., Tosiani, A., and Novita, N. (2022). Contributions of mangrove conservation and restoration to climate change mitigation in Indonesia. *Glob. Change Biol.* 28, 4523–4538. doi: 10.1111/gcb.16216

Balvanera, P., Siddique, I., Dee, L., Paquette, A., Isbell, F., Gonzalez, A., et al. (2014). linking biodiversity and ecosystem services: Current uncertainties and the necessary next steps. *Bioscience* 64, 49–57. doi: 10.1093/biosci/bit003

Barney, J. N., Tekiela, D. R., Barrios-Garcia, M. N., Dimarco, R. D., Hufbauer, R. A., Leipzig-Scott, P., et al. (2015). Global invader impact network (GIIN): Toward standardized evaluation of the ecological impacts of invasive plants. *Ecol. Evol.* 5, 2878–2889. doi: 10.1002/ece3.1551

Basak, E., Cetin, N. I., Vatandaslar, C., Pamukcu-Albers, P., Karabulut, A. A., Caglayan, S. D., et al. (2022). Ecosystem services studies in Turkey: A national-scale review. *Sci. Total Environ.* 844:68. doi: 10.1016/j.scitotenv.2022.157068

Baumgartner, R. J. (2019). Sustainable development goals and the forest sector A complex relationship. *Forests* 10:152. doi: 10.3390/f10020152

Begum, F., de Bruyn, L. L., Kristiansen, P., and Islam, M. A. (2022). Forest comanagement in the Sundarban mangrove forest: Impacts of women's participation on their livelihoods and sustainable forest resource conservation. *Environ. Dev.* 43:100731.

Bennett, A. C., de Sousa, T. R., Monteagudo-Mendoza, A., Esquivel-Muelbert, A., Morandi, P. S., de Souza, F. C., et al. (2023). Sensitivity of South American tropical forests to an extreme climate anomaly. *Nat. Clim. Change* 13, 967–974. doi: 10.1038/s41558-023-01776-4

Bose, P. (2017). Climate adaptation: Marginal populations in the vulnerable regions. *Clim. Dev.* 9, 575–578. doi: 10.1080/17565529.2017.1318747

Boshoff, N., Ngwenya, S., Koch, S., Dudek, J., Strelnyk, O., Costas, R., et al. (2024). Geographical inequalities in global forest science: A bibliometric perspective. *Forest Policy Econ.* 165:103250.

Brown, I. (2020). Challenges in delivering climate change policy through land use targets for afforestation and peatland restoration. *Environ. Sci. Policy* 107, 36–45. doi: 10.1016/j.envsci.2020.02.013

Bubnicki, J. W., Norton, B., Baskauf, S. J., Bruce, T., Cagnacci, F., Casaer, J., et al. (2023). Camtrap DP: An open standard for the FAIR exchange and archiving of camera trap data. *Remote Sens. Ecol. Conserv.* 10, 283–295. doi: 10.1002/rse2.374

Cao, L. D., Kong, F. B., and Xu, C. Y. (2022). Exploring ecosystem carbon storage change and scenario simulation in the Qiantang River source region of China. *Sci. Prog.* 105:3186. doi: 10.1177/00368504221113186

Chen, Y. J., Young, D., de Koff, J., and Britwum, K. (2023). Extension agents' perceptions, practices, and needs of urban forestry: A case study from Tennessee, United States. *Sustainability* 15:5328. doi: 10.3390/su15215328

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., and Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science* 361, 1108–1111. doi: 10.1126/science.aau3445

Delgado-Baquerizo, M., Maestre, F. T., Reich, P. B., Jeffries, T. C., Gaitan, J. J., Encinar, D., et al. (2016). Microbial diversity drives multifunctionality in terrestrial ecosystems. *Nat. Commun.* 7:10541.

Dian, Y., Guo, Z. Q., Liu, H. C., Lin, H. R., Huang, L. Y., Han, Z. M., et al. (2024). A new index integrating forestry and ecology models for quantitatively characterizing forest carbon sequestration potential ability in a subtropical region. *Ecol. Indicat.* 158:1358. doi: 10.1016/j.ecolind.2023.111358

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., et al. (2017). Trees, forests and water: Cool insights for a hot world. *Glob. Environ. Change* 43:51.

Escobedo, F. J., Giannico, V., Jim, C. Y., Sanesi, G., and Lafortezza, R. (2019). Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors. *Urban For. Urban Green.* 37, 3–12. doi: 10.1016/j.ufug.2018.02.011

Eskandari, R., Mahdianpari, M., Mohammadimanesh, F., Salehi, B., Brisco, B., and Homayouni, S. (2020). Meta-analysis of unmanned aerial vehicle (UAV) imagery for agro-environmental monitoring using machine learning and statistical models. *Remote Sens.* 12:3511. doi: 10.3390/rs12213511

Estrada, J. S., Fuentes, A., Reszka, P., and Cheein, F. A. (2023). Machine learning assisted remote forestry health assessment: A comprehensive state of the art review. *Front. Plant Sci.* 14:1139232. doi: 10.3389/fpls.2023.1139232

Fady, B., Esposito, E., Abulaila, K., Aleksic, J. M., Alia, R., Alizoti, P., et al. (2022). Forest genetics research in the Mediterranean Basin: Bibliometric analysis, knowledge gaps, and perspectives. *Curr. For. Rep.* 8, 277–298.

Fang, K., Yang, A. L., Li, Y. X., Zeng, Z. Y., Wang, R. F., Li, T., et al. (2023). Native plants change the endophyte assembly and growth of an invasive plant in response to climatic factors. *Appl. Environ. Microbiol.* 89:e001093–23. doi: 10.1128/aem.01093-23

Feng, Q., Ma, H., Jiang, X. M., Wang, X., and Cao, S. X. (2015). What Has Caused Desertification in China? *Sci. Rep.* 5:98. doi: 10.1038/srep15998

Fernández, R. J. (2016). How to be a more effective environmental scientist in management and policy contexts. *Environ. Sci. Policy* 64, 171–176. doi: 10.1016/j.envsci.2016.07.006

Francini, S., Cocozza, C., Hölttä, T., Lintunen, A., Paljakka, T., Chirici, G., et al. (2023). A temporal segmentation approach for dendrometers signal-to-noise discrimination. *Comput. Electron. Agric.* 210:7925. doi: 10.1016/j.compag.2023.107925

Fujimori, S., Hasegawa, T., Takahashi, K., Dai, H. C., Liu, J. Y., Ohashi, H., et al. (2020). Measuring the sustainable development implications of climate change mitigation. *Environ. Res. Lett.* 15:ab9966. doi: 10.1088/1748-9326/ab9966

Geng, D., Innes, J., Wu, W., and Wang, G. (2021). Impacts of COVID-19 pandemic on urban park visitation: A global analysis. *J. For. Res.* 32, 553–567. doi: 10.1007/s11676-020-01249-w

Hagenbo, A., Antón-Fernández, C., Bright, R. M., Rasse, D., and Astrup, R. (2022). Climate change mitigation potential of biochar from forestry residues under boreal condition. *Sci. Total Environ.* 807:1044. doi: 10.1016/j.scitotenv.2021.151044

Hendricks, S., Anderson, E. C., Antao, T., Bernatchez, L., Forester, B. R., Garner, B., et al. (2018). Recent advances in conservation and population genomics data analysis. *Evol. Appl.* 11, 1197–1211. doi: 10.1111/eva.12659

Heuertz, M., Carvalho, S. B., Galindo, J., Rinkevich, B., Robakowski, P., Aavik, T., et al. (2023). The application gap: Genomics for biodiversity and ecosystem service management. *Biol. Conserv.* 278:9883. doi: 10.1016/j.biocon.2022.109883

Hilker, T., Lyapustin, A. I., Hall, F. G., Myneni, R., Knyazikhin, Y., Wang, Y. J., et al. (2015). On the measurability of change in Amazon vegetation from MODIS. *Remote Sens. Environ.* 166, 233–242. doi: 10.1016/j.rse.2015.05.020

Hohenlohe, P. A., Funk, W. C., and Rajora, O. P. (2021). Population genomics for wildlife conservation and management. *Mol. Ecol.* 30, 62–82. doi: 10.1111/mec.15720

Jandl, R. (2020). Climate-induced challenges of Norway spruce in Northern Austria. *Trees Forests People* 1:100008. doi: 10.1016/j.tfp.2020.100008

Kamelamela, K. L., Springer, H. K., Keakealani, R. K., Ching, M. U., Ticktin, T., Ohara, R. D., et al. (2022). Ko over bar kua aku, Ko over bar kua mai: An indigenous consensus-driven and place-based approach to community led dryland restoration and stewardship. *Forest Ecol. Manag.* 506:9949. doi: 10.1016/j.foreco.2021.119949

Kawamoto, H. (2017). Lignin pyrolysis reactions. *J. Wood Sci.* 63, 117–132. doi: 10.1007/s10086-016-1606-z

Lal, R. (2016). Soil health and carbon management. *Food Energy Secur.* 5, 212–222.

Le Blanc, D. (2016). Toward Integration at Last? The Sustainable Development Goals as a Network of Targets. *Sustain. Dev.* 23, 176–187. doi: 10.1002/SD.1582

Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., and Zhang, W. (2015). Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban For. Urban Green.* 14, 675–685.

Liu, W. P., and Yu, P. M. (2023). Quantifying synergistic effects of multitemporal ecosystem service bundles for degraded ecosystem restoration: A case study in Hubei Province, China. *Environ. Res. Lett.* 18, acea37. doi: 10.1088/1748-9326/acea37

Lozano, S., Calzada-Infante, L., Adenso-Díaz, B., and García, S. (2019). Complex network analysis of keywords co-occurrence in the recent efficiency analysis literature. *Scientometrics* 120, 609–629.

Lu, C. X., Zhao, T. Y., Shi, X. L., and Cao, S. X. (2018). Ecological restoration by afforestation may increase groundwater depth and create potentially large ecological and water opportunity costs in arid and semiarid China. *J. Clean. Prod.* 176, 1213–1222. doi: 10.1016/j.jclepro.2016.03.046

Luo, W. X., Zhang, C. Y., Zhao, X. H., and Liang, J. J. (2021). Understanding patterns and potential drivers of forest diversity in northeastern China using machine-learning algorithms. *J. Veg. Sci.* 32:22. doi: 10.1111/jvs.13022

Ma, Z. Y., Hu, C., Huang, J. L., Li, T., and Lei, J. P. (2022). Forests and forestry in support of sustainable development goals (SDGs): A bibliometric analysis. *Forests* 13:1960. doi: 10.3390/f13111960

Ma, Z., Liu, H., Mi, Z., Zhang, Z., Wang, Y., Xu, W., et al. (2017). Climate warming reduces the temporal stability of plant community biomass production. *Nat. Commun.* 8:15378.

Maleknia, R., and Salehi, T. (2024). Exploring the drivers behind women's intentions toward climate change mitigation through urban forest conservation. *Urban For. Urban Green.* 97:128395.

Malik, A. A., Puissant, J., Buckeridge, K. M., Goodall, T., Jehmlich, N., Chowdhury, S., et al. (2018). Land use driven change in soil pH affects microbial carbon cycling processes. *Nat. Commun.* 9:3591.

Mattsson, E., Karlsson, P. E., Erlandsson, M., Nilsson, A., and Holmstrom, H. (2024). Indicators of sustainable forestry: Methodological approaches for impact assessments across swedish forestry. *Sustainability* 16:3331.

McKown, A. D., Klápste, J., Guy, R. D., El-Kassaby, Y. A., and Mansfield, S. D. (2018). Ecological genomics of variation in bud-break phenology and mechanisms of response to climate warming in Populus trichocarpa. *New Phytol.* 220, 300–316. doi: 10.1111/nph.15273

Millar, C. I., and Stephenson, N. L. (2015). Temperate forest health in an era of emerging megadisturbance. *Science* 349, 823–826.

Nilsson, M., Griggs, D., and Visbeck, M. (2016). Policy: Map the interactions between Sustainable development goals. *Nature* 534, 320–322.

Nobre, C. A., Sampaio, G., Borma, L. S., Castilla-Rubio, J. C., Silva, J. S., and Cardoso, M. (2016). Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. *Proc. Natl. Acad. Sci. U.S.A.* 113, 10759–10768. doi: 10.1073/pnas.1605516113

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Syst. Rev.* 10:89.

Pavlidis, G., and Tsihrintzis, V. A. (2018). Environmental benefits and control of pollution to surface water and groundwater by agroforestry systems: A review. *Water Resourc. Manag.* 32, 1–29. doi: 10.1007/s11269-017-1805-4

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I. C., et al. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* 355:eaai9214.

Rama, R., Nair, V. K., Nedungadi, P., Ray, I., and Achuthan, K. (2023). Darkweb research: Past, present, and future trends and mapping to sustainable development goals. *Heliyon* 9:e22269.

Raman, R. (2023). Transparency in research: An analysis of ChatGPT usage acknowledgment by authors across disciplines and geographies. *Accountabil. Res.* 28, 1–22.

Raman, R., Nair, V. K., and Nedungadi, P. (2023). Discrepancies in mapping sustainable development goal 3 (good health and well-being) research: A comparative analysis of scopus and dimensions databases. *Sustainability* 15:16413.

Raman, R., Nair, V. K., Prakash, V., Patwardhan, A., and Nedungadi, P. (2022). Green-hydrogen research: What have we achieved, and where are we going? Bibliometrics analysis. *Energy Rep.* 8, 9242–9260.

Raman, R., Gunasekar, S., Dávid, L. D., and Nedungadi, P. (2024a). Aligning sustainable aviation fuel research with sustainable development goals: Trends and thematic analysis. *Energy Rep.* 12, 2642–2652.

Raman, R., Sreenivasan, A., Suresh, M., and Nedungadi, P. (2024b). Mapping biomimicry research to sustainable development goals. *Sci. Rep.* 14:18613.

Raman, R., Nair, V. K., Nedungadi, P., Sahu, A. K., Kowalski, R., Ramanathan, S., et al. (2024c). Fake news research trends, linkages to generative artificial intelligence and sustainable development goals. *Heliyon* 10:e24727.

Samndong, R. A., and Kjosavik, D. J. (2017). Gendered forests: Exploring gender dimensions in forest governance and REDD plus in Equateur Province, Democratic Republic of Congo (DRC). *Ecol. Soc.* 22:434. doi: 10.5751/es-09753-220434

Segelbacher, G., Bosse, M., Burger, P., Galbusera, P., Godoy, J. A., Helsen, P., et al. (2022). New developments in the field of genomic technologies and their relevance to conservation management. *Conserv. Genet.* 23, 217–242. doi: 10.1007/s10592-021-01415-5

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., et al. (2017). Forest disturbances under climate change. *Nat. Clim. Change* 7, 395–402.

Silva, S., Neto, S. N. D., Leite, H. G., de Alcântara, A. E. M., Neto, R. R. D., and de Souza, G. S. A. (2020). Productivity estimate using regression and artificial neural networks in small familiar areas with agrosilvopastoral systems. *Agrofor. Syst.* 94, 2081–2097. doi: 10.1007/s10457-020-00526-1

Singh, V. K., Singh, P., Karmakar, M., Leta, J., and Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics* 126, 5113–5142.

Sun, S. Y., Sun, H., Zhang, D. S., Zhang, J. F., Cai, Z. Y., Qin, G. H., et al. (2019). Response of soil microbes to vegetation restoration in coal mining subsidence areas at Huaibei Coal Mine, China. *Int. J. Environ. Res. Public Health* 16:1757. doi: 10.3390/ijerph16101757

Svensson, J., Waisman, H., Vogt-Schilb, A., Bataille, C., Aubert, P. M., Jaramilo-Gil, M., et al. (2021). A low GHG development pathway design framework for agriculture, forestry and land use. *Energy Strategy Rev.* 37:683. doi: 10.1016/j.esr.2021.100683

Touchette, L., Beaudoin, J. M., Isabel, N., Gélinas, N., and Porth, I. (2021). How can forestry and conservation genomics be used to benefit indigenous communities? *For. Chron.* 97, 233–249.

Uhan, Z., Pezdevšek Malovrh, S., Jošt, M., and Remic, K. (2024). Integration of sustainable development goals in higher education and research processes related to forestry and wood science. *Drvna Ind.* 75, 87–98.

UN (2021). *The global forest goals report 2021. United Nations department of economic and social affairs*. New York, NY: United Nations, 10017.

Van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., and Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban For. Urban Green.* 14, 806–816.

Walentowski, H., Kietz, B., Horsch, J., Linkugel, T., and Viöl, W. (2020). Development of an interdisciplinary master of forestry program focused on forest management in a changing climate. *Forests* 11:632.

Waltman, L., Van Eck, N. J., and Noyons, E. C. (2010). A unified approach to mapping and clustering of bibliometric networks. *J. Inform.* 4, 629–635.

Wei, S., and Cheng, S. T. (2022). An artificial intelligence approach for identifying efficient urban forest indicators on ecosystem service assessment. *Front. Environ. Sci.* 10:1389. doi: 10.3389/fenvs.2022.994389

Wendiro, D., Wacoo, A. P., and Wise, G. (2019). Identifying indigenous practices for cultivation of wild saprophytic mushrooms: Responding to the need for sustainable utilization of natural resources. *J. Ethnobiol. Ethnomed.* 15:64. doi: 10.1186/s13002-019-0342-z

Zerssa, G., Feyssa, D., Kim, D. G., and Eichler-Löbermann, B. (2021). Challenges of smallholder farming in ethiopia and opportunities by adopting climate-smart agriculture. *Agric. Basel* 11:192. doi: 10.3390/agriculture11030192