Sustainable Futures 10 (2025) 101467

Contents lists available at ScienceDirect

Sustainable Futures

journal homepage: www.sciencedirect.com/journal/sustainable-futures

Sustainability barriers in nordic forestry: A systematic review

Ayonghe Nebasifu [a,b,*], Luis Andrés Guillén [c], Stefanie Linser [d], Anne Toppinen [a,b]

[a] International Forest Policy team, Department of Forest Sciences, University of Helsinki, Finland
[b] Helsinki Institute of Sustainability Sciences (HELSUS), University of Helsinki, Finland
[c] Swedish Forest Research Center, Swedish University of Agricultural Sciences, Sweden
[d] Department of Economics and Social Sciences, IFER, BOKU University, Vienna, Austria

ARTICLE INFO

Keywords:
Nordic forests
Systematic scoping review
Content analysis
PICO framework
Sustainability challenges
Forest-based bioeconomy
future science

ABSTRACT

Nordic forests are important carbon sinks for climate change mitigation, signaled in forest policies aimed at sustainability transitions to deliver multiple ecosystem services. However, the pressures of transitioning can be challenging to many stakeholders, risking efforts to preserve biodiversity and ensure a competitive forest-based value chain. This study aims to review the sustainability challenges that Nordic forests face and determine future solutions according to recent scientific literature. Using a cross-sectional study, we screened publications scoping the period 2019–2024 that focused on the sustainable use and management of forests in Finland, Sweden, Norway, and Denmark. A total of 8303 studies from Scopus and Web of Science were systematically reviewed using the PICO and ROSES protocols, of which 151 met our inclusion criteria. The results show a majority of articles on environmental barriers focused on biodiversity conservation. Most economic barriers were found in articles discussing economic development, while the social barriers were found mainly in articles on social relations in forestry. Our analysis suggests future opportunities for improving avenues for the use and management of Nordic forests by (a) prioritizing biodiversity conservation under thriving forest management conditions, (b) reinforcing compliance with sustainability standards that limit unsustainable sourcing of biomass, and (c) encouraging knowledge access and exchange between forest owners and service providers.

1. Introduction

Nordic forests are those in the Nordic countries, including Denmark, Finland, Sweden, and Norway [1]. They constitute systems that differ in their ecological characteristics and percentage of forest cover: a mix of ecological zones such as temperate continental and boreal coniferous in Finland (74 %) and Sweden (69 %), temperate oceanic in Denmark (15 %), and boreal mountainous in Norway (40 %) [2,3]. Nordic forests are important sources of timber and provide essential ecosystem services through biodiversity conservation, recreation, and carbon sinks [4]. They also influence international trade significantly, with lumber and paper exports representing 18 % and 15 % of the global trade respectively [5]. Nordic forest systems are crucial to combating climate change and thus are continuously influenced by various sustainability-based policies [6–8]. Measures advancing their sustainable use and management are important. This entails monitoring, reporting, and verifying carbon fluxes and stocks; monitoring and reporting forest biodiversity; sustaining a competitive forest-based value chain; maintaining sources of livelihoods and income for forest-reliant communities, and different stakeholders, and actors whilst adopting best practices in the transition to a forest-based circular bioeconomy [2,7–10]. These processes face a multitude of knowledge gaps but also present opportunities for the bioeconomy transition [11], from the risk of long-term resource price volatility [12] and climate change uncertainties [13] to hopes for more vertical interaction (bottom-up) including local stakeholders in decision-making [11].

For Nordic forests, 'sustainability' is broadly defined with reference to global, international, regional, and national legislative frameworks. For example, the United Nations' Brundtland Report, published in 1987, uses the term 'sustainable development' to mean meeting present needs in society without compromising the ability of future generations to meet their own needs [14]. This was echoed in the Statement of Principles for the Sustainable Management of Forests at the United Nations Conference on Environment and Development (UNCED) in 1992 [15]. In 2015, UN Member States adopted the 2030 Agenda for Sustainable Development, which focuses on 17 Sustainable Development Goals (SDGs) aimed at combating climate change and preserving forests. SDG 13 (Climate Action) and SDG 15 (Life on Land) are expected to influence

* Corresponding author.
E-mail address: akonwi.ayonghe@helsinki.fi (A. Nebasifu).

https://doi.org/10.1016/j.sftr.2025.101467
Received 14 May 2025; Received in revised form 22 October 2025; Accepted 23 October 2025
Available online 10 November 2025

the sustainability transition [16]. At the European level, the Forest Europe ministerial process for monitoring and reporting progress towards sustainable forest management [17], the European Green Deal and its associated EU Forest Strategy for 2030, along with the EU Biodiversity Strategy for 2030, impact the policy framework for Nordic forests in line with the UN 2030 Agenda for Sustainable Development; for instance, by emphasizing the importance of multifunctional forestry in delivering multiple ecosystem services [18].

Between 2019 and 2024, sustainability efforts were challenged by the COVID-19 pandemic, rising global emissions, and escalating climate impacts. Focus areas included forest-based bioeconomy strategies, cross-sectoral collaboration, and sustainability in energy, transport, and urban planning. The Nordic countries reinforced their commitments to EU regulations targeting climate mitigation, bioeconomy, and urban development. The EU Bioeconomy Action Plan promoted a sustainable, circular economy by strengthening bio-based sectors and restoring ecosystems [19], while the Nordic Council of Ministers' Vision 2030 supported cross-sectoral cooperation for a green, competitive, and socially sustainable region [20]. Key EU legislation—the Climate Law (adopted 2021), LULUCF Regulation (adopted 2023), and Nature Restoration Law (adopted 2024)—further advanced climate-wise land management [21]. In Finland, Sweden, Norway, and Denmark forest owners and companies apply PEFC and FSC certification schemes, which ensure sustainable forestry through chain-of-custody tracking and high environmental, social, and economic standards [7]. However, sustainability transitions also pose complex risks. Gawel et al. [22] highlight governance failures in the bioeconomy, including underinvestment due to knowledge spillovers. Justice concerns persist around the exclusion of marginalized groups [23], while scholars call for confronting the "dark side" of transitions [24–26] and addressing the interlinked dimensions of sustainability [27]. A more integrated approach is needed to build resilience and reduce uncertainty in Nordic forestry. Hereafter, 'forest sustainability' and 'sustainable forestry' refer to the sustainable use and management of Nordic forests.

Recent publications highlight key sustainability challenges related to forests and the green transition. Katila et al. [28] identify inequities in Nordic forest research, particularly a lack of focus on gender in decision-making, policy, and politics. Stanitsas et al. [29] note difficulties educators face in selecting suitable sustainability goals, while [30] point to a digital divide hindering social sustainability. High initial costs of the green economy create stakeholder resistance [31], and technological advances often disadvantage those with fewer resources [32]. Standardized monitoring of environmental degradation and of climate change induced disturbances also remain underemphasized [33]. A comprehensive framework is lacking to assess sustainability barriers from multiple perspectives or to evaluate systemic interventions and their impacts. As the Nordic countries advance their sustainability transition, addressing these concerns in forest use and management is vital to shaping future forest-based bioeconomy pathways. Based on these premises, this paper uses a systematic review to address two issues:

a) To investigate the prevailing sustainability challenges facing the use and management of Nordic forests in terms of the social, economic, and environmental dimensions. We compare the concerns observed in publications across the study countries.
b) To determine future avenues for the use and management of Nordic forests. We reflect on ways to bring about the best outcomes for Nordic forestry.

We apply a conceptual framework integrating environmental, economic, and social dimensions of sustainability [34,35], based on the UN Sustainable Development concept which considers nature, society and the economy as elements approached holistically through systems thinking that emphasizes problem-solving, connection and interdependency within a system [36]. In today's context of climate change, geopolitical tensions, economic instability, and social inequality, understanding barriers within each dimension is urgent [37]. Applied to Nordic forests, the framework helps examine system-level challenges. While forests support carbon storage, biodiversity, and livelihoods [38], they also face pressures and conflicts—for instance, Finland's intensive forest management threatens species, calling for all three dimensions to be addressed [39]. This review focuses on Finland, Sweden, Norway, and Denmark—countries with shared multifunctional forest demands and complex, polycentric governance [2].

2. Materials and methods

This section presents the data collection and analysis through a systematic review. We also adopt [40] notion of establishing a systematic map, taking into consideration the background, methods, and results of the systematic review; the range and nature of the evidence base in the scientific articles we analyzed; and some knowledge gaps that may be relevant to sustainability in Nordic forests and forestry.

2.1. Data collection

In November and December 2024, we applied a cross-sectional study targeted scientific articles in Scopus and Web of Science (WoS) scoping from the period 2019–2024. We targeted both Open and Close Access publications from Finland, Sweden, Norway, and Denmark. The period 2019–2024 presents a major development in sustainability efforts among Nordic countries that experienced persistent challenges and the strengthening of national efforts towards sustainability action [41]. Hence, this time frame enabled us to capture recent sustainability

Table 1
Search results in Scopus and WoS.

	Finland	Sweden	Norway	Denmark	Database
Search strings	**All fields** (sustainability AND challenges*) AND **All fields** (sustainable* AND forest*) AND **Article title, Abstract, keywords** (finland*) OR **Article title, Abstract, Keywords** (finnish*) 528 documents found	**All fields** (sustainability AND challenges*) AND **All fields** (sustainable* AND forest*) AND **Article title, Abstract, keywords** (sweden*) OR **Article title, Abstract, Keywords** (swedish*) 665 documents found	**All fields** (sustainability AND challenges*) AND **All fields** (sustainable* AND forest*) AND **Article title, Abstract, keywords** (norway*) OR **Article title, Abstract, Keywords** (norwegian*) 385 documents found	**All fields** (sustainability AND challenges*) AND **All fields** (sustainable* AND forest*) AND **Article title, Abstract, keywords** (denmark*) OR **Article title, Abstract, Keywords** (denmark*) 216 documents found	Scopus
Filters	Range 2019–2024, limited to English, close and open access				
Search strings	forest (Topic) AND forestry (Topic) AND sustainable forest (Topic) AND forest management (Topic) AND barriers (Topic) AND challenges (Topic) AND Finland (Topic) AND Finnish (Topic) – 2089 – Web of Science Core Collection	forest (Topic) AND forestry (Topic) AND sustainable forest (Topic) AND forest management (Topic) OR barriers (Topic) AND challenges (Topic) AND Sweden (Topic) AND Swedish (Topic) – 1509 – Web of Science Core Collection	forest (Topic) AND forestry (Topic) AND sustainable forest (Topic) AND forest management (Topic) OR barriers (Topic) AND challenges (Topic) AND Norway (Topic) AND Norwegian (Topic) – 1465 – Web of Science Core Collection	forest (Topic) AND forestry (Topic) AND sustainable forest (Topic) AND forest management (Topic) OR barriers (Topic) AND challenges (Topic) AND Denmark_ (Topic) AND Danish_ (Topic) – 1446 – Web of Science Core Collection	Web of Science
Filter	Publication Years: 2019–2024				

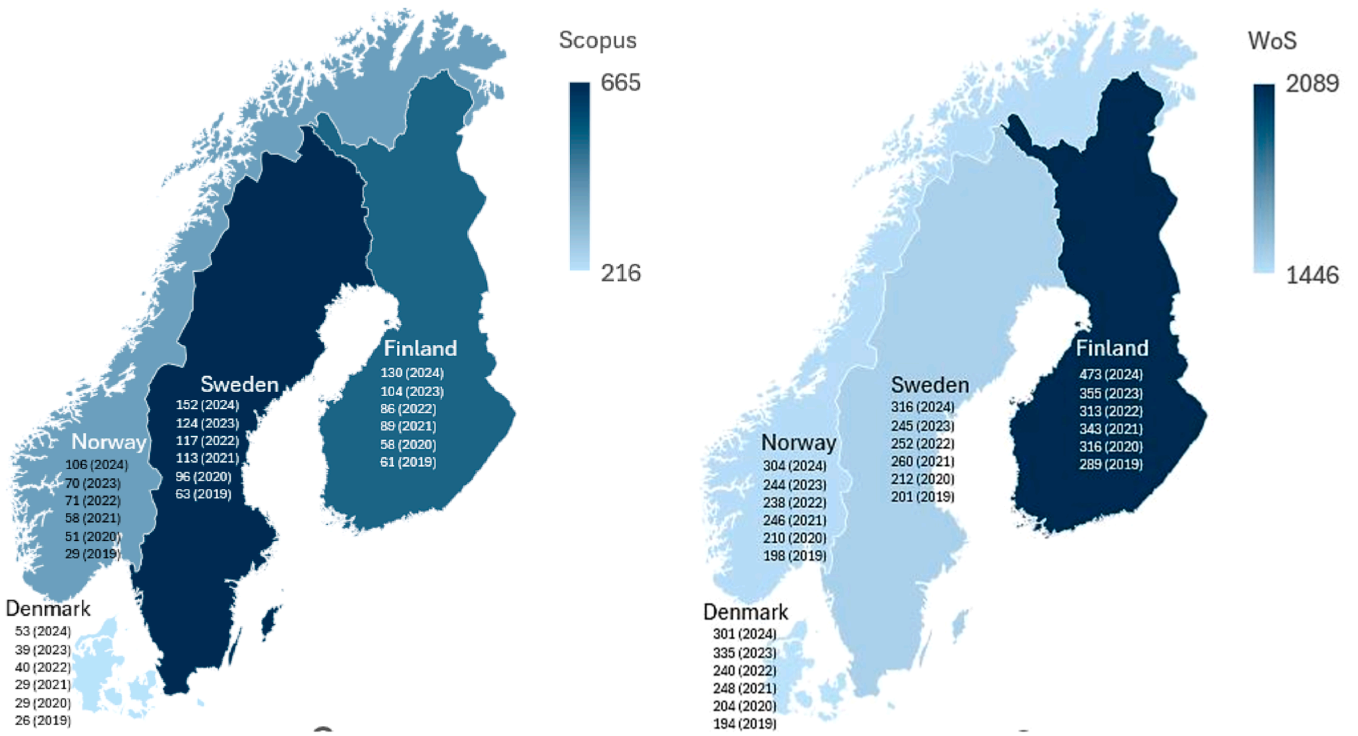

Fig. 1. Cross-country map visualizing the search results by number of scientific publications in each study country retrieved by target year (2019–2024) in Scopus and Web of Science (WoS).

challenges facing Nordic forests and forestry. The search process was applied as part of stage 1 within a ROSES (RepOrting standards for Systematic Evidence Syntheses) protocol (https://www.roses-reporting.com/) that enabled us to target relevant and recent publications, record our findings, and keep track of duplicates. Table 1 presents the search results. See also supplementary materials for search query links.

We used Microsoft Excel (map chart function) to generate a cross-country map chart illustrating the number of articles we gathered for each targeted year in both WoS and Scopus (Fig. 1).

The legend to the right of the country maps shows the maximum (Scopus = 665; WoS= 2089) and minimum (Scopus= 216; WoS= 1446) number of scientific publications retrieved based on summation across the four countries. Moreover, based on the country-specific search results for publications in Scopus, we recorded the highest value of 152 (corresponding to 2024) in Sweden and the lowest of 26 (2019) in Denmark. For WoS, we retrieved the most values 473 (and in 2024) from Finland, with the lowest of 194 from Denmark in 2019. In general, we observed a trend of an increasing number of publications in all the countries from 2019 to 2024, which could be signaling the increased momentum that the topic had from 2018 (after the aforementioned policy events) and the time passed for the publication of studies.

2.2. PICO and ROSES framework for forests and forestry

In this paper, we delved into scientific publications that present a multitude of gaps and gluts with respect to sustainability challenges for forests and forestry within the national boundaries and contexts of the study countries. We adapted a PICO (Population, Intervention, Comparison, Outcome) framework, initially developed for use in the medical field to determine the best intervention for patients [42]. PICO may be less than optimal in seeking evidence when the problem does not relate to determining the best treatment. However, Nishikawa-Pacher et al. [43] argued that PICO can be used universally in any discipline beyond clinical settings, regardless of a preferred study design. Thus, shifting away from medical to environmental research such as forestry necessitates adapting the PICO logic to effectively identify and address sustainability challenges. An example concerns the work of [44] which emphasizes an eligibility criterion for which: (a) Population, includes participant households, and individuals who contribute to significantly different environmental outcomes as compared with forests, ecological trees, and land resources; (b) Intervention, such as an action, policy, or activity undertaken that impacts a population and the environment; (c) Comparator, comparing the before-and-after effect of the intervention,

Table 2
Adapting the PICO framework to studying sustainability barriers in Nordic forest systems.

Framework		Target	Eligibility criteria
P	Population	Persons who contribute to various environmental, social, and economic outcomes.	Identifying experts impacted by an intervention, e.g., indigenous and local communities, forest owners, forest managers, environmental and governance professionals.
I	Intervention	An action, policy, or activity taken that impacts the population and the environment.	The focus of intervention emphasized within the research strategy. We explore the environmental, social, and economic dimensions.
C	Comparator	The before-after control-treatment comparison	Comparing interventions and outcomes between the study countries with emphasis on spatial comparator. Also, drawing comparisons with cases elsewhere, i.e., from countries not included in our study.
O	Outcome	Impacts of different interventions on the population and environment. i.e., in the use and management of forests.	Identifying the social, environmental, and economic challenges facing the sustainable use and management of Nordic forests. We broadened our criteria to include outcomes from studies about resilience and adaptation in forestry.

Note. See also the code book we designed illustrating the categories for analysing various scientific publications (Appendix A).

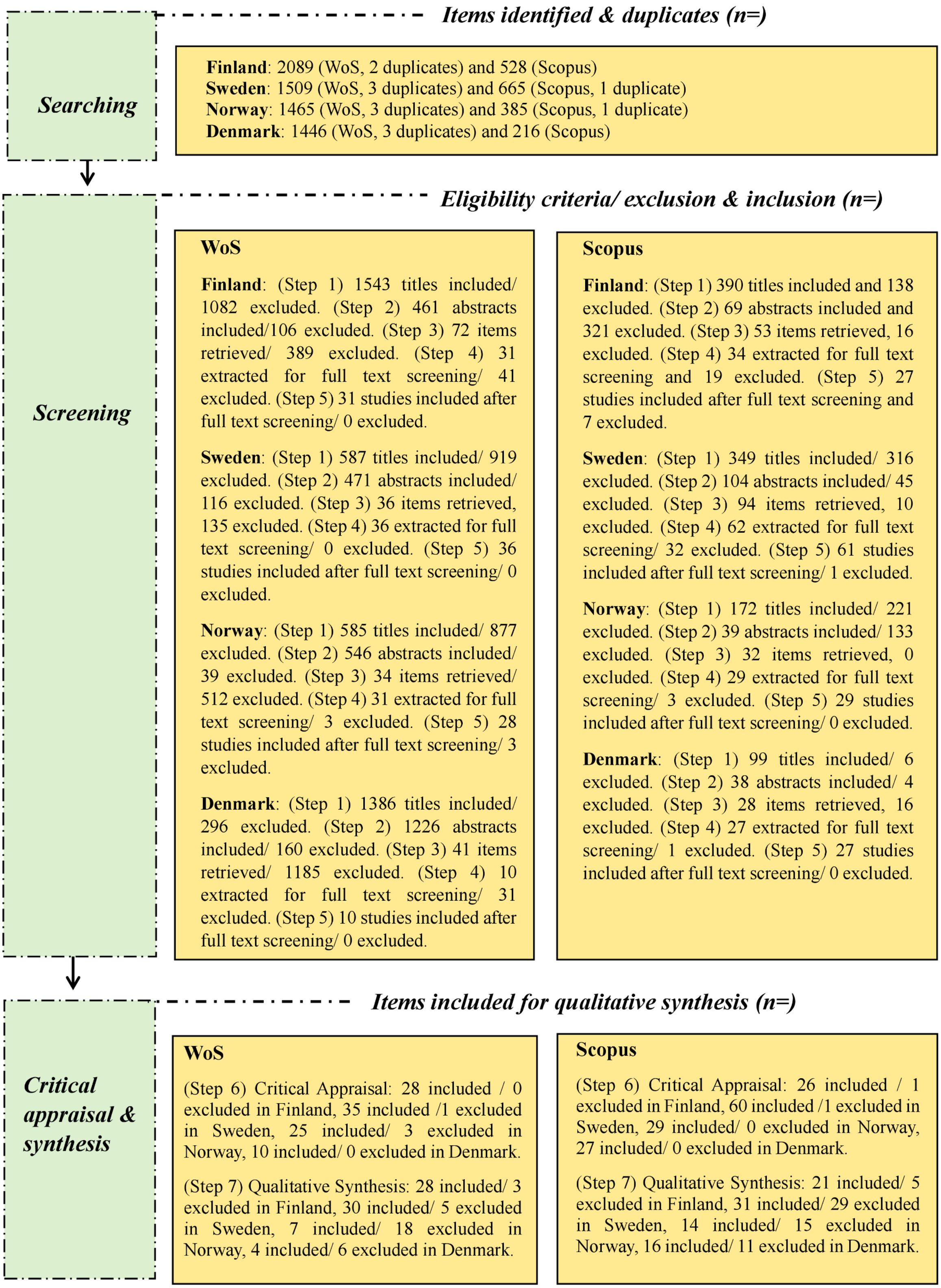

Fig. 2. ROSES map protocol for the systematic review of publications retrieved from Scopus and WoS.

and comparisons with other cases; (d) Environmental outcome, including land-use and forest cover change, tree survival rates, biomass and carbon storage, biodiversity, land access, and social equality.

In environmental research, the study aims, or environmental activity becomes the intervention when it is the focus of investigation, represents the treatment given to the population, and its effects are being measured [45–47]. Oliva [48] refers to this activity as the research strategy and focus of investigation. We thus adapted a PICO—situating existing concepts and categories of inquiry (e.g., see, Appendix A) whilst advancing a form of three-dimensional sustainability that identifies prevailing barriers in Nordic Forest systems from the environmental, economic, and social standpoint (Table 2).

The next step was to screen the data by filtering duplicates and irrelevant publications from the data initially retrieved. We adopted the ROSES framework, which uses a map protocol to facilitate rapid identification of key findings while ensuring proper standards for reporting evidence-based synthesis. ROSES has been designed specifically for systematic reviews and maps in conservation and environmental management studies. It can accommodate diverse methods applied to a variety of review subjects, revealing the heterogeneity and interdisciplinarity of topical issues within a study [49]. We utilized the ROSES map protocol through three stages of the protocol from searching, screening, and critical appraisal and qualitative synthesis (Fig. 2).

Fig. 2 above illustrates the three major phases of screening the scientific publications we retrieved for each study country. An important criterion in the screening phase involved a 7-step process of including titles (step 1) and abstracts (step 2) of studies about 'sustainability', 'forest', 'resilience', and 'adaptation'; retrieving publications that focus on the study country (step 3); keeping track of items extracted for full text screening after retrieval (step 4) and after full text screening (step 5); applying a critical appraisal (step 6) and including studies for a qualitative synthesis (step 7).

For the eligibility criteria in including and excluding publications, we acknowledge that 'sustainability' is broadly defined and may differ by the context of the country. Hence, beyond the concepts of sustainability, forests, resilience, and adaptation, we also included studies addressing agroforestry. We excluded studies that focus on countries elsewhere than the study countries, as well as aspects not associated with forests, such as fisheries, marine transportation, immigration, health care, and housing. We worked concurrently to cross-check for missing publications and their inclusion. Out of 8303 studies extracted from Scopus and WoS, 151 were included for full text screening.

2.3. Content analysis

We adopted content analysis as a step in the process to make sense of the sustainability challenges in the publications following the ROSES map protocol. Content analysis is a useful tool that determines meaningful relationships within a given data set by quantifying and analysing themes or code categories through inductive and/or deductive processes [50]. We followed this method by aligning the PICO framework with a series of code categories synthesized through [50] (p. 117–122) five-step process for content analysis, using the Microsoft Excel 2021 tool (Table 3):

From the deductive stance, we developed the code categories based on the PICO framework. In contrast, the inductive process focused on iteratively developing interpretations of the data set, where we sought to reflect on potential avenues and future implications for the sustainable use and management of Nordic forests. In the following section, we present the results based on the studies included for the qualitative synthesis.

3. Results

We combined the literature found in WoS and Scopus to develop cross-country comparisons of subcategories corresponding to the PICO framework based on their frequency of occurrence. Drawing from the three-dimensional sustainability framework [51,52], we particularly investigate the barriers in line with [53] to further understand the multifaceted sustainability challenges and how to respond to them. Using Table 2, which adapts the PICO framework to environmental research, we highlight four main aspects: (i) the focus of the intervention as viewed through the research inquiry (including an overview of the method types); (ii) the sustainability challenges (Outcome); (iii) stakeholders identified (Population); and (iv) comparisons with countries elsewhere. Appendices C1-C4 highlights references to the examples cited in the results section.

Table 3
Content analysis process.

Step process of analysis	*Step 1: Read and familiarize*	*Step 2: First-round coding - identify big-picture meaning units*	*Step 3: Second-round coding - developing subcategories and fine-grained codes*	*Step 4: Refining the fine-grained subcategories*	*Step 5: Synthesis and interpretation*
Authors' application	**Qualitative synthesis** Retrieving 64 publications for full text reading and comprehending issues about sustainable forest management and challenges.	**Code book** Designing a code book using a comprehensive list of code categories developed from the PICO framework, particularly: Forest stakeholders; Study inquiry/goal/objective; Comparator type; Sustainability challenge, i.e., economic, social, environmental; and method variables	**Deductive coding** Using Microsoft Excel sheets to extract contents from publications and cluster them based on subcategories and their relevance to the PICO and the research questions.	**Code comparisons** Deductively generating cross-country comparisons of the coded data in line with the PICO framework, i.e., cross-country frequency measures to determine predominant and less-predominant occurrences of the subcategories.	**Inductive coding** Producing an interpretation of the coded data to provide answers to the research question/s.

Note. See Appendix A for details aligning the PICO framework with code categories and subcategories.

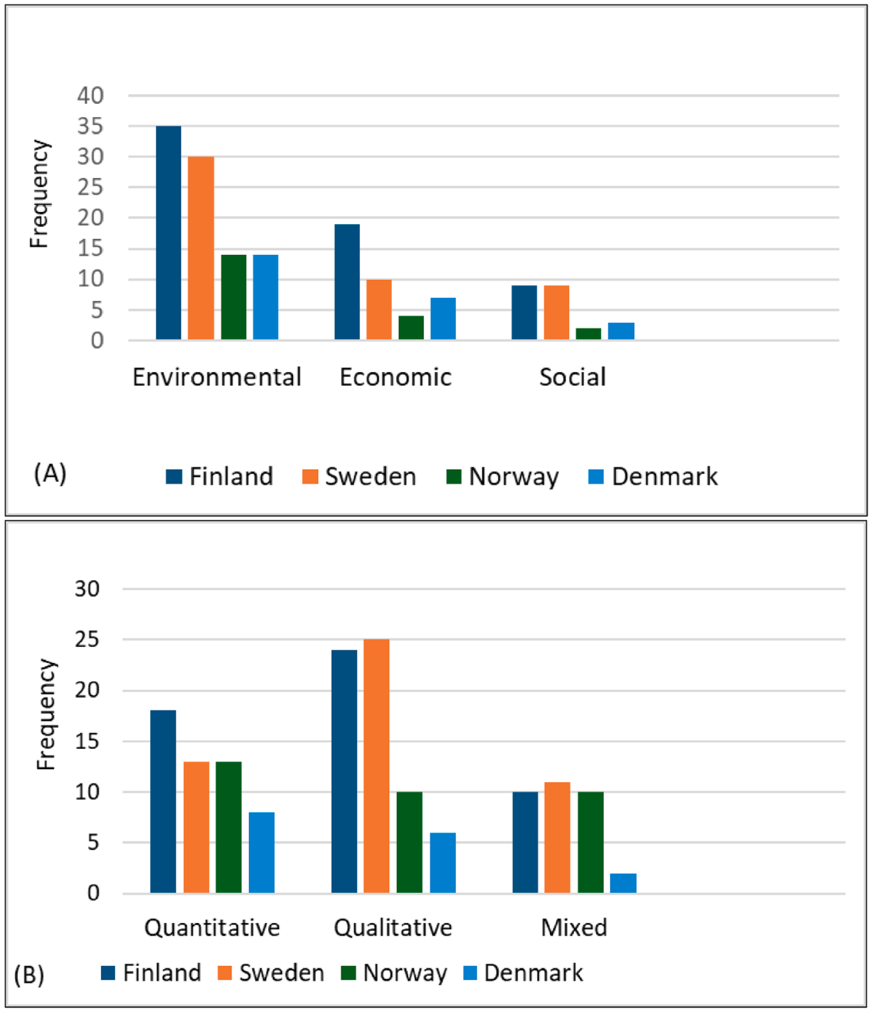

Fig. 3. Frequency of scientific papers on sustainability challenges of forests and forestry across Nordic countries based on A) Focus of intervention and, B) methods applied within the reviewed studies.

3.1. Overview of intervention dimensions and methods in reviews

Based on the three dimensions of sustainability, out of the 151 publications 93 had interventions that focused on the environment across the four countries. Forty focused on the economic aspects of intervention, and 23 on the social. We also examined studies that have an experimental, policy, forecast, and perspective-opinion focus. We observed these focal areas by totaling their frequency occurrence (Fig. 3). Additionally, we considered the types of methods utilized in the publications.

In comparing the methods used across all the studies (Fig. 3), we found that qualitative methods were most prevalent in Sweden (25). Swedish publications also employed many mixed methods (11). Eighteen of the studies in Finland used quantitative approaches. Appendices C1-C4 illustrate the methods specified in the literature in all four countries.

We also observed that some studies contain elements in their inquiry that can be placed in two or more subcategories depending on whether they addressed multiple dimensions regarding the sustainable Nordic forest use and management. For instance, of the publications reviewed, 10 fell into both the environmental and social categories [54–62,109]. Similarly, 10 of the studies covered the economic and environment inquiry [62–70]. Meanwhile, only two studies covered all three dimensions (environmental, economic, and social) [71,72]. We also identified publications centered on policies, perspectives, history, forecasts, and experiments relevant to Nordic forests. These studies also appear in other subcategories.

3.1.1. Environmental inquiry

Most of the Finnish publications had interventions that focused primarily on environmental issues (35), followed by Sweden (30), and Norway (14), and Denmark (14).

For instance, in Sweden, research has focused on several areas: urbanization and monitoring [73,74], agricultural expansion [75], and the pressures affecting connected systems [70]. Other topics include the spread of *Heterobasidion* infection [76] and conflicts over land use in forestry [71,77]. Studies have also explored urban ecosystem services [78], sustainable consumption [55], forest regeneration [79], and multifunctional landscapes [80]. Research related to sustainable forestry research focused on selection systems in Norway spruce (*Picea abies* L.*)* [81], biomass in climate mitigation [82], future sustainability [83], and forest carbon and in ensuring the availability of wood [67]. Practical issues included the effects of thinning on birds [84], forestry industrial farming [85], policy coherence for sustainable resource management [56], and continuous cover forestry (CCF) [86].

Studies also examined climate change impacts on oak forests and historical views on monocultures [87,88], forest degradation, protection, and policy issues [57,65,80,89], as well as agroforestry challenges and forest adaptation to climate change [90,91]. Evaluations included FSC's informed consent, climate-smart forestry, regeneration gaps, and links between wood production, carbon, and biodiversity [66,92–95]. Additional studies covered the Heureka decision system, corporate forest information use, biomass harvesting indicators, and lichen availability in snowy forests [96–99].

In Finland, the publications we found explored forest owners' views on sustainable management [100], and the forest bioeconomy transition discourse [61,63,64,68,101,102]. Publications also focused on the role of biomass in nature conservation, carbon footprint [102,104,105,108] and enhancing wood production and quality in response to climate change [107]. Policy studies examined sustainability framing [108] and the impact of EU and certification policies on what sustainable forest biomass procurement [109,110]. Other publications addressed environmental urbanization impacts on forests [111], the environmental burden of forest trafficability [112], natural disturbances on forests [114], multi-taxa forest management experiments [115], and errors in deadwood modelling [116].

Our reviews identified studies that quantified carbon storage in urban shrubs [117], explored cost-effective management of biodiversity and carbon stocks [118], and highlighted the environmental benefits of urban green spaces [54]. Research assessed boreal forest carbon balance [119] and developed sustainable forest management strategies [120–123]. Other work examined wooden housing's carbon footprint [124] and compared greenhouse gas and nutrient runoff reductions between continuous cover forestry and clear-cutting in boreal peatlands [109]. Prinz et al. [113] analyzed fuel use of harvesting machines on peatlands, while Byholm et al. [125] studied forest loss impacts on Northern Goshawk nesting. The environmental effects of logging residues on nitrogen, carbon leaching, and nitrous oxide emissions post-clearcutting were also investigated [126].

While in Norway, we reviewed studies growth responses of suppressed Norway spruce in peatlands after selection harvesting [127] and thinning effects on spruce growth [128], alongside studies on bird communities in planted spruce forests [129] and drivers of forest ecosystem service changes [130]. Other work focused on ecological condition indicators [77] and silvicultural adaptations to climate change [131]. Socio-environmental challenges included reindeer herders' adaptation to forest encroachment [132] and projected land-use impacts from agroforestry and the bioeconomy [133,134]. Urban sustainability governance was studied by Tomprou [62], while wildfire risk reduction in Coastal Norway was addressed by Log and Gjedrem [135]. Additional research applied the Index-Based Ecological Condition Assessment (IBECA) [77], compared effects of continuous cover and clear-felling on soil fungi and chemistry [136], and assessed surface waters' role in climate mitigation [137]. Our reviews also found studies that focused on training needs for prescribed heathland burning [138] and the analysis of integrated knowledge systems for adaptive reindeer management [139].

In Denmark, interventions focused on analysing the impact of multiple ecosystem services on habitat quality [6], woody biomass sourcing among Danish energy companies and their compliance with voluntary sustainability standards [60], and the effectiveness of perennial plants in landscapes in mitigating wind and water erosion [169]. We identified studies addressing forest regeneration, land cover change, legislative shifts, and supporting decisions on sustainable forestry [73,140,141]. Harrison et al. [142] assessed climate change impacts across sectors, including forestry, at the regional level, while other scholars [143] have examined the feasibility of urban greening targets in Denmark. Other studies investigated the role of ecosystem services in Nordic countries [6], how farmer communication in collaborative processes reduces nitrogen emissions [58], the effectiveness of slurry storage acidification [144], and knowledge about the life cycle of groundwater [145].

3.1.2. Economic inquiry

The publications that addressed economic issues relevant to the sustainable management of forests came from Finland (19), Sweden (10), Denmark (7) and Norway (4). In Finland, studies examined the impact of foreign investment on forest-based product diversification [62], how forest-based sector firms adapt their business models towards a bioeconomy [68,69], implementing a circular bioeconomy in small and medium-sized enterprises (SMEs) [63], and identifying drivers of the forest-based bioeconomy [64]. Other research has focused on enhancing digital tools for sustainable agroforestry [146], mapping wood ecosystem services supply and demand for sustainable forestry [147], and the effects of CCF on harvesting costs [109]. Studies clarified key terms in the forest-based bioeconomy and examined how the UN SDGs are integrated into national bioeconomy strategies and monitoring [148]. Other interventions addressed the EU's influence on planning practices [149], the cost-effectiveness of converting boreal forests to multi-use landscapes [150], the impact of recent disruptions on tourism in protected areas [151], the role of strategic forest planning [152], and the effects of forest certification as an economic tool on national biodiversity [127].

In Sweden, researchers explored how interconnected systems (water-energy-food-land-climate) impact forest-ecosystem services [70], the challenges faced by multi-actor design teams in creating sustainable solutions [62]. Other studies investigated increasing carbon stock while generating wood-based materials [153] and tested whether the benefits of forest ecosystem services can be measured by monetary valuation [62]. Studies also compared expert views on bioeconomy impacts on farming and forestry [133].

In Norway, Climent et al. [107] focused on improving wood production and quality, as well as ensuring tree species adaptability to changing environmental conditions. Other focus areas included the implementation of forest management plans among non-industrial private forest owners in Norway [154], and the role of co-governance in managing productive urban spaces for sustainable urban transformation [62]. In Denmark, [155], examined how activities such as tourism, renewable energy use, economic growth, and human capital can forecast life expectancy.

3.1.3. Social inquiry

Based on the review criteria, we identified nine publications on the social aspects in both Sweden and Finland, with two in Norway and three in Denmark. Research in Sweden explored key dimensions of sustainable development and environmental protection, including cooperative values among forest-owner associations [72], the integration of policies across water, energy, food, land, and climate sectors [56], and the effectiveness of international frameworks like the 1972 World Heritage Convention in safeguarding natural heritage [156]. Studies also highlighted land use conflicts in Northern Sweden [71] and the challenges local governments face in promoting sustainable consumption and identity [55]. Studies have examined conflicts as perceived by private forest owners and their implications for sustainable forest management [77], and conflicts involving stakeholders from forestry, mining, tourism, energy, and reindeer husbandry [71]. Studies explored the Swedish debate on historical forest degradation [57], and the management behaviour of small-scale private forest owners in relation to EU bioeconomy strategies [157]. Other research has addressed how people's engagement in protected areas in Sweden improve their health and well-being [89], land use conflicts in Northern Sweden [71], and the role of Free, Prior, and Informed Consent (FPIC) in FSC processes [92], and collaborative planning challenges [158].

In Finland, studies focused on various aspects of sustainable forest management, including forest owners' and professionals' perceptions of sustainable use [159], institutional changes and forest data governance [160], and the role of forest-owner associations [72]. Research also investigated interest in and willingness to pay for vegetatively propagated Norway spruce materials among forest plant producers and end users [161], and the integration of social and technical knowledge systems in managing privately owned forests [162]. Additional work explored the emotional dimensions of forest conflicts from a rural perspective [163], socio-economic disparities and their mitigation in

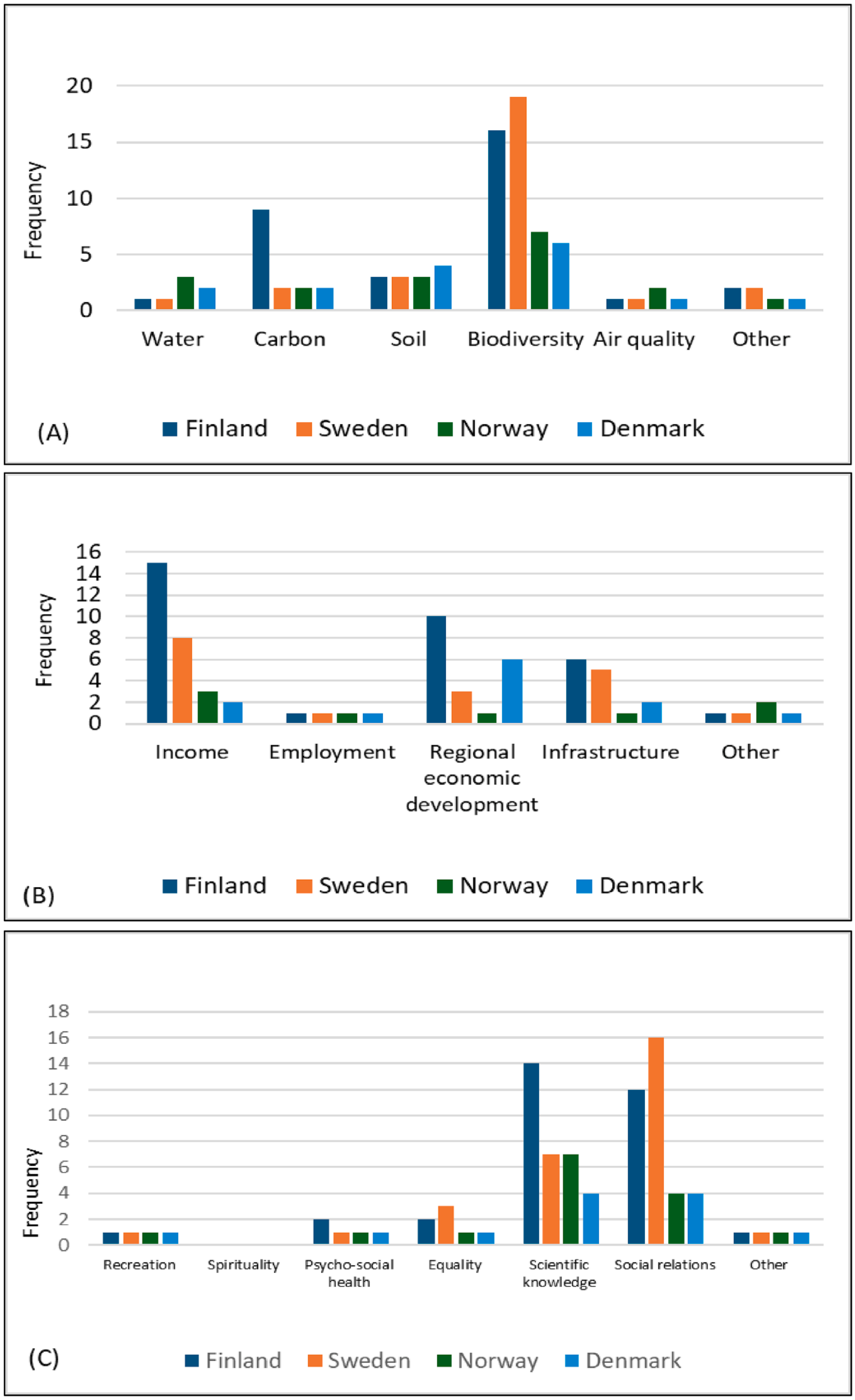

Fig. 4. Comparing sustainability challenges of forests and forestry across Nordic countries based on the A) Environmental, B) Economic and C) Social attributes.

urban green spaces [54], and university students' views on using forest-based biomass for energy [164].

In Norway, authors have examined conditions supporting social acceptance of bioeconomy transitions [165], and synergies for landscape management-tourism [166]; while in Denmark, research has focused on the influence of tourism, renewable energy use, economic growth, and human capital on predicting life expectancy [154], and how communication in collaborative processes to reduce nitrogen emissions can be improved by understanding farmers' negotiation of collective solutions [58].

3.1.4. Other focal areas in the reviews

Among the publications, we found 18 (11 in Finland and 7 in Sweden) of an experimental nature, i.e., where researchers introduce an intervention and then study the outcomes by testing a hypothesis. In Sweden for instance [86,87,84], and [75] were experimental in their inquiry. While in Finland, we identified [104,160], and [166] as experimental studies relevant to forest sustainability, with [103] being policy-based. In Norway, all four studies [77,128–130] were classified as experimental.

We also identified studies whose areas of inquiry focused on historical events, forest policies, forecasting, and perspective viewpoints. For instance, Kumar et al. [82] focuses on forecasting, Stjernquist et al. [83]

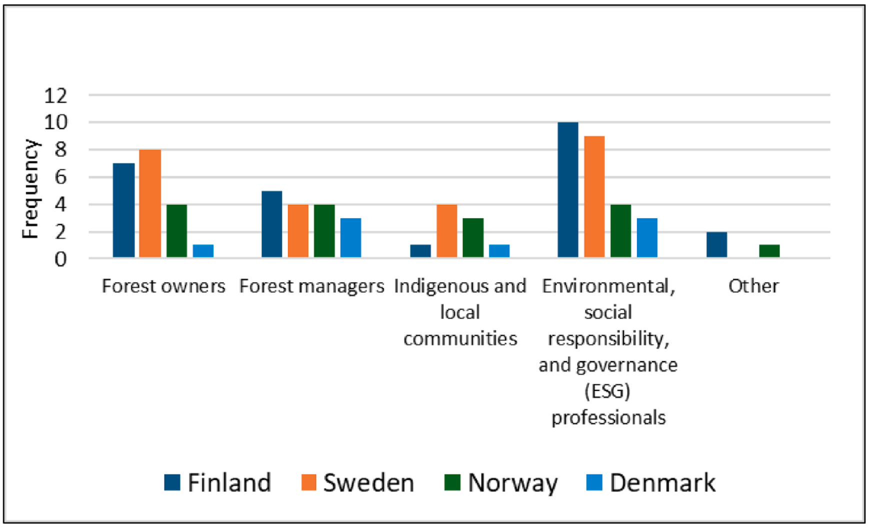

Fig. 5. Cross-country comparisons calculated based on stakeholder frequency across Nordic countries.

is perspective-driven, [155] and [85] are policy-oriented, and Jönsson [167] mainly historical.

3.2. Sustainability challenges and stakeholder frequency

We adopted various attributes (Appendix A) to identify the barriers facing the sustainable use and management of Nordic forests. Fig. 4 visualizes our analysis of sustainability barriers. In the economic dimension, we recorded the highest values with 15 studies on Finland with barriers relating to income. For the social dimension, 16 studies in Sweden revealed social relations challenges. The environmental dimension included 17 studies in Sweden highlighting challenges facing biodiversity preservation. The analysis accounted for the type of forest stakeholders identified in the studies with sustainability challenges across the study countries (Appendices C1-C4). Based on the frequency measures for the highest values, 10 studies had challenges on environmental, social responsibility, and Governance (ESG) professionals (e.g., NGOs, State Officials, Management Personnel, Decision-makers) in Finland, with 8 on forest owners in Sweden, 4 on indigenous and local communities in Sweden, 5 on forest managers in Finland, and 8 studies on forest owners in Sweden (Fig. 5).

The following paragraphs present examples of challenges aligned with the three-dimensional framework for sustainability [34,35].

3.2.1. Environmental barriers

The publications assessed which refer to Sweden highlight system constraints linked to land use and climate change pressures [64,70,73,75,100,168]. For instance, Furberg et al. [73] reported a 16 % increase in urban areas within a 200 m buffer zone around nature reserves, which has led to diminishing air purification and degraded forest proximity. Zhou et al. [75] found a 13,008 km2 (−4 %) decrease in forest areas, mainly due to agricultural expansion (9211 km2, 29 %). In Northern Sweden, land use conflicts arising from competing claims over land access, conversion of forests traditionally used by the Sámi to industrial uses, and divergent stakeholder priorities present significant challenges to forests [71]. Protected landscapes with oak forests were found not to increase species richness for all flora or fauna species [88].

Other studies addressed challenges in promoting multifunctional landscapes and maintaining selection systems in forests [80–82]. For example, [81] found that mono-species Norway spruce (P. abies) forests in Central Sweden face increasing risks from windthrow and bark beetle infestations. Concerns over fast-growing spruce monocultures include environmental impacts such as declines in bird populations following conventional thinning—about 20 % of species are negatively affected, especially under climate change influences [84]. Danley et al. [86] noted forest owners' reluctance to adopt conservation measures, favoring production-oriented practices that prioritize economic gains. Also, Stjernquist and Schlyter [83] highlighted how fast-growing spruce monocultures cause negative soil nutrient feedback, worsened by climate change and increased nitrogen deposition.

The Finnish studies highlight several challenges posed by climate change and the transition to a forest-based circular bioeconomy, and the limits of CCF [102,112,114]. For instance, studies [106] indicate that current wood construction methods cannot fully preserve the carbon storage of an area in buildings, and thus cannot be extrapolated to all Finnish regions, comparative to places of greater accessibility to sustainable forest management practices with high carbon storage wood elements such as cross laminated timber (CLT). Other challenges arose from various forest land use disturbances through urbanization, driven by industrial and service demands that increase land use pressures on forests [111]. It has been shown that natural regeneration is not always successful in continuous-cover forestry [117], because, for instance, light demanding species require open canopy spaces.

Based on the reviews, it can be said that Norway faces challenges in applying forest management techniques and addressing drivers of negative changes in forest ecosystem services, with some studies including experiments from other regions [109,127,130,137,153]. For example, a study [130] found that between 1950 and 2020, Norwegian forest management prioritized provisioning services while neglecting cultural and regulatory services. Climent et al. [107] identified gaps in understanding tree species' adaptability to changing biotic and abiotic conditions, noting limited knowledge on trait interactions crucial for production, climate resilience, and biotic threat resistance. Furthermore, trends in key functional traits related to tree size remain poorly understood and often confounded with age effects.

Studies in Denmark point to the challenges of sourcing woody biomass from local to global scales, agroforestry dialogue, terrestrial ecotoxicity, weak incentives, uncertainties surrounding biomass governance, and difficulty meeting certification systems [60,169]. For instance, Jakobsson et al. [60] revealed that the lack of sustainability requirements for wood sourced from outside forests, such as hedgerows, landscaping trees, horticultural wood waste, and short rotation coppice crops from agriculture. Furthermore, with a lack of detailed statistics on the origins and sustainability of the woody biomass used outside the medium- to large-scale energy sector, there is a risk of the market becoming an outlet for unsustainably produced woody biomass. Studies [169] identified the high environmental impacts of nitrogen emissions and pollution triggered by intensive livestock farming in hilly areas, regardless of the establishment of perennial plants.

3.2.2. Economic barriers

Studies in Finland show shortcomings of the bioeconomy transition, deepened by tourism and mining disruptions affecting forest governance [61,68,109,170]. Luhas et al. [61] showed that the physical distance between firms and their customers weakens regional clusters in the forest-based bioeconomy. Meanwhile, financial uncertainties, including declining demand for pulp and paper, threaten companies' ability to invest in sustainability efforts [68]. Moreover, increased selection cutting during late spring and summer in continuous-cover forests leads to higher wood procurement costs due to operational pauses for nesting protection and soil conservation [109].

Meanwhile, in Sweden, there are significant challenges from land use conflicts and external pressures like mining [71,88,168,171], especially where forestry interests overlap with reindeer husbandry in the north [71,169]. Industrial forestry, mining, and tourism-driven urbanization further fragment habitats and disrupt reindeer migration routes [171]. Promoting woody biomass as a renewable carbon resource is also difficult, as transport challenges in remote areas reduce economic incentives for forest management, limiting global wood supply [67]. Furthermore, since 2000, the Swedish pulp and paper industry has declined due to rising competition and reduced newspaper demand [82]. In Norway, studies reveal that supplementary feeding to counter crowberry encroachment in reindeer husbandry is costlier and less profitable than direct crowberry control in forest pastures [132].

3.2.3. Social barriers

Our reviews also identified social barriers. For instance, a Swedish study [72] highlights challenges faced by forest-owner associations in engaging other stakeholders, leading to miscommunication rooted in reliance on cooperative identity for sustainable development. Resistance exists against wood-based industrial projects on heritage forest sites like the Laponian area of the Swedish Sámi, protected under the 1972 World Heritage Convention. In February 2022, UN human rights experts supported Sámi opposition to an open-pit mine in Gállok threatening ecosystems and reindeer migration [155]. Swedish municipalities also struggle to promote sustainable consumption due to limited political support and resources [55]. Moreover, gaps persist in addressing forestry conflicts; despite valuing education and dialogue, private forest owners often feel excluded from political decision-making [77].

In Finland, [158] also identified resistance among forest owners due to their focus on wood production hindering recognition of the need for a sustainability transition as a challenge. There is limited access to substantial information on biodiversity hotspots and archeological sites stored in the databases of authorities because of privacy regulations, which further complicates decision-making. Forest service providers lack digital access to this information, leading to biodiversity knowledge having a low perceived importance compared to timber production knowledge [161]. Another social challenge concerns the sense of losing social status among forest sector entrepreneurs, many of whom feel misunderstood, unfairly blamed, and unappreciated for their work. They believe their pride and contributions are overlooked in favour of political and ideological goals [162].

In Norway, among the studies we reviewed, social challenges in forest management include lagging cultural and regulating services [130] and scientific barriers in predicting tree breeding outcomes under changing conditions [107]. Bashir et al. [153] reported that only 37 % of Norwegian non-industrial private forest owners have a forest management plan, with limited understanding and implementation. In Denmark, agroforestry faces social barriers such as farmer frustrations over regulations and doubts about nitrogen's environmental effects, impeding dialogue on agri-environmental issues [58]. As well, there is a lack of sustainability standards and insufficient data on woody biomass sources outside large energy sectors increase Denmark's vulnerability to unsustainable biomass from domestic non-forest areas and imports [60].

3.3. Spatial comparisons from reviews

We focused on the 'comparator in space' which involves comparing the negative impact of a purely regional intervention exposed to an intervention across the four countries. For instance, we identified 6 comparative studies in Finland, such as [64], comparing Finland with bioeconomy transitions in North Rhine-Westphalia, Germany, and the Basque Country in Spain (Fig. 6).

North Rhine-Westphalia faces a shortage of private capital for its forest-based bioeconomy, while the Basque Country struggles with low consumer awareness of bio-based products. Aszalós et al. [114] examined natural disturbances and forest management across boreal (Sweden, Finland, Latvia) and temperate European forests, revealing a widespread preference for even-aged silviculture. Complementing this, Tinya et al. [115] identified research gaps in boreal forests and limited attention to soil organisms through multi-taxa experiments across 14 countries. Huber et al. [172] compared six cases across Mediterranean, alpine, continental, and boreal zones in Spain, Portugal, Finland, Austria, and Romania, showing that diverse socio-economic and legal property rights restrictions hinder a unified EU forest policy.

Poturalska et al. [104] compared the rise in supply and demand of

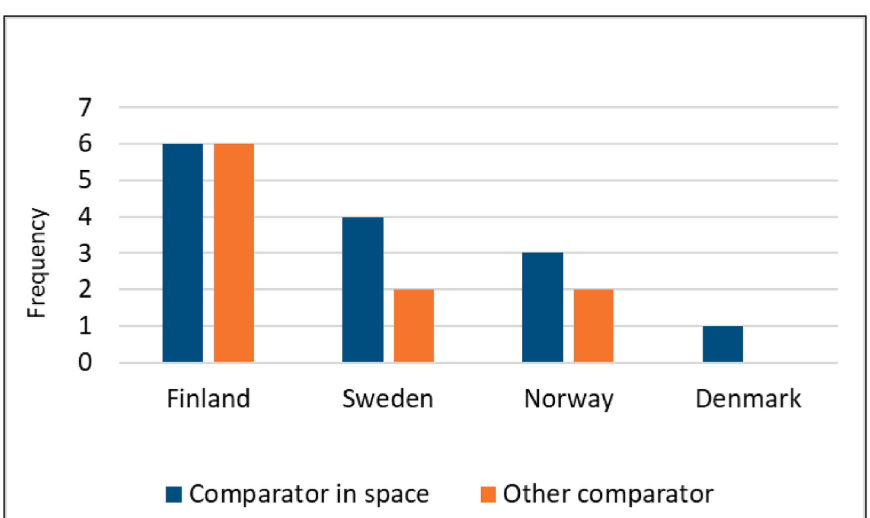

Fig. 6. Frequency of scientific publications using comparators in space and other comparator across Nordic countries.

wood ecosystem services, noting higher demand in southern and southeastern Finland and Sweden from 2014 onwards, as well as in Germany, Poland, the Czech Republic, and cities like Paris, Lisbon, and Riga. They report increased climate change-related pressures in recent decades, which have impacted the quality and condition of European forests, affecting sustainable forest management, forest biodiversity conservation, and trade-offs between different ecosystem services at both continental and regional levels. Tange et al. [110] review articles from Finland, Canada, and Sweden, revealing that 18 % of the studies show weak species abundance in scenarios with increased retention.

In Sweden, Furberg et al. [73] found that northern Stockholm County's higher urbanization has led to fewer and smaller nature reserves compared to southern areas. Zhou et al. [75] compared land cover changes across Sweden, Norway, Finland, and Denmark, attributing Sweden's forest loss mainly to agricultural expansion, while other countries faced soil erosion, wetland decreases, or settlement growth from agricultural land conversion. Angelstam et al. [80] analyzed forest management cultural trajectories across central and eastern Europe, Russia, and Sweden, finding similar patterns. Svensson et al. [173] compared forest fragmentation in the Scandinavian Mountains Green Belt, noting more intact forests in the north and greater fragmentation in the south.

In Norway, Bhati and Epstein [155] compared the Laponian area of the Swedish Sámi with Kenya's Lake System, noting that the 1972 World Heritage Convention and UNESCO have yet to fully recognize the intangible cultural heritage of the Endorois people, crucial for preserving regional biological and cultural diversity. Both sites remain vulnerable to development pressures. Studies also found fewer bird species and pairs in planted Norway spruce stands compared to naturally regenerated forests [129]. Research in Austria's mountainous beech forests showed that relying on imported Norway spruce timber undermines climate goals and negatively impacts forest owners' incomes [174].

In Denmark, Hu et al. [6] compared ecosystem services in Denmark with those of Finland, Sweden, and Norway. They found a negative relationship between carbon sequestration and crop production at high latitudes and in southeastern Sweden. In Norway, they observed increased water yield and sediment retention due to higher precipitation.

4. Discussion

Sustainable management of Nordic forests faces complex challenges. Gawel et al. [22] highlight fragile societal benefits from the bioeconomy transition, market failures related to fossil resource use, and innovation spillovers. Equity concerns arise from exclusion and marginalization in the green transition [23] prompting calls to address the "dark side" of sustainability transitions that challenge the prevailing win-win narrative [24,26]. Using systematic reviews and an adapted PICO framework for environmental research [44–47], alongside a holistic three-dimensional sustainability framework [27,35,36,51], we find increasing research output from 2019 to 2024, which was predominately conducted in Finland and Sweden, reflecting their greater forest cover [2,3]. Environmental concerns prevail across countries. Finland faces economic pressures in forestry, Sweden contends with land-use conflicts, Norway balances cultural and economic needs, and Denmark struggles with nitrogen pollution from livestock farming [71,81,175]. Common challenges include climate-induced droughts, invasive species, bark beetles, storms, fires, and browsing damage.

Spatially, barriers are mainly environmental and social, complicated by socio-economic and legal differences within Europe [172]. Key obstacles include climate change [104], industrial development in cultural heritage sites [155], and agricultural expansion [75]. Nordic boreal forests experience fewer fires than Canada, Alaska, and Russia, where large-scale fires reduce carbon sequestration [168,176–178]. The digital divide and unequal access to technological innovation hinder sustainability transitions for resource-limited stakeholders [30,32]. Forest service providers undervalue biodiversity knowledge relative to timber production [161], and Finnish small and medium enterprises face financial constraints in bioeconomy innovation [63]. Limitations include the study's cross-sectional design and exclusion of grey literature, suggesting future longitudinal and broader database studies. The combined PICO and ROSES Map protocols enabled precise evidence synthesis. The literature reflects a growing transition toward a forest-based bioeconomy aligned with the EU Bioeconomy Strategy [19] and UN 2030 Agenda, supported by legislation such as the 2024 EU Nature Restoration Law aiming to restore degraded ecosystems by 2030 and 2050 [179].

Drawing on the three-dimensional conceptual framework, which integrates the environmental, economic, and social dimensions of sustainability from a systems thinking perspective [35,36,51], we identify three means of promoting the best outcomes in the sustainable use and management of Nordic forests: biodiversity conservation, regional economic development, and social relations in the forest sector.

4.1. Optimizing biodiversity conservation and forests where management scenarios thrive

Within sustainable forest management, key practices include setting aside areas for biodiversity protection, ensuring growth continuity through CCF, and maintaining ecosystem health, as emphasized in PEFC and FSC standards in the Nordic countries [7]. At the same time, sustainable forest management requires securing timber harvests, which can conflict with biodiversity goals [2]. Reviews from Finland show that voluntary use of CCF has had limited success in enhancing biodiversity, since many forest owners prioritize production and income [86], while Swedish studies suggest that protecting oak forests does not necessarily increase species diversity [87]. Some approaches, however, appear promising: combining distinct forest types in northern Sweden (e.g., nemoral, boreo-nemoral, and Taiga forests at latitude 60° N) increased arthropod and plant richness [87], and close-to-nature silviculture using CCF raised short-term variability in deadwood volumes in Finland [116]. Profitability concerns, especially among small forest owners, continue to constrain biodiversity outcomes, but existing management standards may help balance environmental, social, and economic sustainability by encouraging models that move beyond profit maximization [85].

4.2. Towards more sustainably-sourced products amid the bioeconomy transition

The transition from fossil fuels to a forest-based bioeconomy is a central ambition for Nordic countries and is emphasized in the EU Bioeconomy Action Plan to restore ecosystems and strengthen bio-based sectors [19]. Renewable biomass sources for energy are increasingly common in Finland, Sweden, and Denmark, given their role in carbon storage and climate change mitigation [82,103]. However, a major challenge revealed from our reviews is the risk that markets become outlets for unsustainably produced woody biomass, particularly where data on the origins of biomass beyond the medium- to large-scale energy sector are lacking. Additional risks arise because some woody products from agriculture fall outside sustainability requirements, as seen in the Danish industry agreement on sustainably managed biomass production approved in 2014 [60]. In this context, certification standards such as FSC and PEFC are pivotal for ensuring traceability and compliance through chain-of-custody systems. Moreover, with wood-based construction expected to play a key role in climate mitigation, using sustainably sourced materials such as cross-laminated timber (CLT) could significantly enhance carbon storage. For example, Talvitie et al. [106] project that by 2050 the use of CLT in Finland could exceed the carbon storage potential of forests by nearly 47 tC ha^{-1}.

4.3. Inclusivity for knowledge access and natural heritage protection

The sustainable use and management of forests can be strengthened through knowledge exchange between forest owners and service providers, which increases awareness of economic and environmental principles for improving ecosystem quality and health. However, significant challenges remain. In Finland, for example, reviews show that access to key information—such as biodiversity hotspots—is restricted in inventory databases by privacy regulations, limiting availability to other authorities [161]. This reduces the effectiveness of decision-making for privately owned forests and lowers the perceived importance of biodiversity knowledge among forest owners. Addressing this gap requires organizational structures and inclusive practices that promote knowledge exchange and learning through co-construction events, enabling the integration of diverse forms of knowledge essential for forest and biodiversity health.

Our review of studies in Sweden also highlights knowledge constraints arising from land use conflicts, where industrial development overlaps with natural heritage sites of cultural importance to indigenous peoples. Risks linked to the sustainability transition are evident in Norrbotten County, where intensive extractive activities clash with traditional Sámi reindeer husbandry (Elomina & Živojinović, 2024). In the Laponian area, designated as a mixed heritage site, the Sámi resisted a proposed open-pit mine in Gállok, citing threats to the protected ecosystem and reindeer migration routes [71]. These cases underscore the need to preserve biocultural heritage and to strengthen indigenous rights to self-determination, cultural continuity, and traditional land use practices. As the Nordic countries continue to attract extractive industries in the pursuit of economic growth, it is crucial to align development with the needs of indigenous and local communities by encouraging multi-actor participation to mitigate the impact of industry [180]. In this regard, the legal provisions of the World Heritage Convention (adopted 1972) and the Akwé: Kon Voluntary Guidelines of the Convention on Biological Diversity (adopted 2004) could be crucial in fostering knowledge inclusivity and dialogue where conservation projects overlap with sites of traditional value to indigenous groups, if they are integrated into sustainable forest management standards.

5. Conclusion

This paper investigates challenges facing the sustainable use and management of Nordic forests in four Nordic countries and determines what future considerations exist for the region's forests based on recent scientific literature. Situating the findings within the environmental, economic, and social contexts of forest and forestry sustainability, we observed that most of the environmental barriers were mentioned in Swedish publications in connection with challenges in preserving biodiversity. Most of the economic challenges were identified in publications in Finland pertaining to economic development in the face of the bioeconomy transition. Publications in Sweden predominantly highlight social challenges, reflected in adverse social relations in land use conflicts, the lack of political support for sustainable consumption, and knowledge exclusion, where industrial developments undermine the value of preserving sites of traditional value to indigenous people. Although recent Danish publications feature less in all three dimensions of sustainability, the risk of the market being vulnerable to unsustainably sourced woody biomass and the pollution problem from livestock grazing for agro-forestry were highlighted.

However, when considering the future, the Nordic Forest sector remains a complex landscape with ambitions for the forest-based bioeconomy that produces demands, with challenges for stakeholders, actors, and local communities that cannot be easily addressed with simplistic solutions. However, tapping the three predominant issues emerging from the reviews–biodiversity conservation, regional economic development, and social relations - the best possible outcomes for Nordic forests can be leveraged through stronger priorities for biodiversity conservation, creating conditions that allow forest management to thrive and strengthening sustainability standards. This will boost data, reporting, and appropriate sourcing of those biomass products that are currently considered 'unsustainable', while also encouraging cooperative events that propels knowledge access and exchange between forest stakeholders.

Ethics statement

We declare that this manuscript adheres to the principles of research conduct as outlined in the Guide for Authors and in the ethical guidelines.

Funding

This work was supported by funding from the Helsinki Institute of Sustainability Science (HELSUS), University of Helsinki through a HELSUS Postdoctoral Fellowship 2024–2026.

CRediT authorship contribution statement

Ayonghe Nebasifu: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Luis Andrés Guillén:** Writing – original draft. **Stefanie Linser:** Writing – original draft. **Anne Toppinen:** Writing – original draft.

Declaration of competing interest

We declare that there are no competing interests among the authors.

Acknowledgments

We are grateful to the HELSUS team for funding this research through the Postdoctoral Fellowship project "*Future 'Ecotopias' of Sustainability in Nordic Forests Systems*". We acknowledge the support of colleagues in the GreenPole project team from which we got inspired to apply the review protocol and code book to studying sustainability issues relevant to Nordic Forestry. Special thanks to the International Forest Policy team for their peer support. We sincerely thank the editorial team and the two anonymous reviewers for their valuable comments and constructive feedback, which have significantly contributed to improve this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.101467.

Data availability

Data will be made available on request.

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