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THE ROLE OF FORESTS IN LOW CARBON TRANSITION: A SYSTEMATIC LITERATURE REVIEW

Gabija Stanislovaityte
E-mail: stanislovaityte.gabija@gmail.com
ORCID: https://orcid.org/0000-0002-2379-3088
Affiliation: Kaunas Faculty, Vilnius University, Lithuania
ROR: https://ror.org/03nadee84

Marija Jankovic
E-mail: marija.jankovic.mbs@gmail.com
ORCID: https://orcid.org/0000-0001-8598-072X
Affiliation: Faculty of Economy and Business, University of Mediterranean, Montenegro
ROR: https://ror.org/03tsjvt68

Asta Mikalauskiene
E-mail: asta.mikalauskiene@knf.vu.lt
ORCID: https://orcid.org/0000-0002-4301-2058
Affiliation: Kaunas Faculty, Vilnius University, Lithuania
ROR: https://ror.org/03nadee84

Remigijus Ciegis
E-mail: remigijus.ciegis@knf.vu.lt
ORCID: https://orcid.org/0000-0001-9303-7205
Affiliation: Kaunas Faculty, Vilnius University, Lithuania
ROR: https://ror.org/03nadee84

Agne Lauzadyte-Tutliene
E-mail: agne.tutlyte@gmail.com
ORCID: https://orcid.org/0000-0002-8053-383X
Affiliation: Faculty of Economics and Business Administration, Vilnius University, Lithuania
ROR: https://ror.org/03nadee84

Annotation. The use of a carbon sink mechanism plays an important role in achieving a low-carbon transition. Forest-based carbon sequestration assumes a notable role in the suite of ecosystem services that influence global climate dynamics. The paper aims to conduct a systematic literature review on the role of forests in decarbonising the economy, define the research gap, and develop a future research agenda. The SALSA and PRISMA frameworks and the PSALSAR protocol were used in the systematic literature review. The main findings of the analysis showed that there is a lack of integrated studies addressing the water, land, climate, energy, agriculture, and forests nexus for defining the harmonised climate change mitigation policies targeting specific sectors of the economy linked to natural resources, as decarbonisation can be achieved through various climate change mitigation and carbon sequestration measures in interlinked water-land-climate-food-energy-forests systems.

Keywords: forests, sustainable development, climate change mitigation, sequestration, policies and measures.

JEL classification: Q2, Q28, Q54, Q58.

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Introduction

The paramount objective resides in the deceleration of global warming and the realisation of a low-carbon econonomic paradigm. Among the pivotal avenues for achieving low-carbon development, a salient approach entails the concurrent reduction of carbon dioxide emissions and the augmentations of total factor productivity to bolster carbon productivity, as noted by Chen *et al.* (2021). Effectively addressing the confluence of economic growth and climate change mitigation hinges on the deployment of a carbon sink mechanism. Forest-based carbon sequestration assumes a notable role in the suite of ecosystem servies that govern global climate dynamics. While carbon sequestration does incur associated social costs, it is imperative to underscore that socio-economic co-benefits persist, as explained by Castro-Magnani *et al.* (2021).

It is widely acknowledged that forest resources constitute a pivotal natural asset, functioning as a fundamental material resource that serves as a cornerstone for economic and societal advancement. The quantification of resource abundance is frequently assessed in terms of either aggregate quantities or relative measures, as explicated by Sachs and Warner (1995). Metrics such as per capita or per unit of land area are frequently utilised to assess the abundance of forest resources. It is imperative to discern that the concept of forest resource abundance encapsulates the count of readily available forest resources, indicative of their prevalence within a given context, as elucidated by Adler (1998).

In view of the necessity to address global warming, the imperative of embarking upon a low-carbon development trajectory has become inevitable. The low-carbon economy represents the initial phase of this overarching low-carbon developmental paradigm, as delineated by Yuan *et al.* (2011). Specifically, the concept of economic low-carbon development signifies a sustainable developmental framework that encompasses the reduction of high-carbon energy consumption and the mitigation of atmospheric carbon dioxide emissions through technological innovations and other strategic measures, as articulated by Mulugetta and Urban (2010). It is the responsibility of society as a whole to reduce carbon emissions as a fundamental strategy for mitigating the impacts of climate change. Carbon emissions can be categorised into two distinct types: absolute emissions and relative measures. Absolute emissions refer to the direct release of carbon into the atmosphere, whereas relative measures take into account a country's or region's economic output, using metrics such as emission intensity or emissions per unit of Gross Domestic Product (GDP), as expounded upon by Lee *et al.* (2018). The fundamental premise of low-carbon economic development is, therefore, intrinsically linked to the pursuit of economic progress.

Despite the prevalence of research addressing the low-carbon transition and the establishment of a neutral society, there remains a notable absence of systematic investigation into the role of forests in achieving the decarbonisation of the economy. However, sustainable forest management holds considerable potential in this regard. The present paper aims to provide a systematic literature review on the role of sustainable forest management in decarbonising the economy, to define the research gap, and to develop a future research agenda in this area.

The paper is structured in the following way. Section 2 introduces data and methods. Section 3 describes results of a systematic literature review according to specified thematic areas. Section 4 presents a discussion of the main findings and highlights the reserach gap, with the last part of the paper being the conclusions.

1. Methods and Data

The SALSA framework is the basis for the search for literature and analysis conducted to achieve the goal outlined in the article. By minimising the potential for subjectivity, this technique enables a thorough review of the literature (Amo *et al.*, 2018). It is evident from the scientific literature that the SALSA methodology is regarded as one of the most effective instruments for locating, assessing and organising academic and real-world investigations (Amo *et al.*, 2018). Consequently, it guarantees the methodological correctness and comprehensiveness of the research (Grant and Booth, 2009). The PRISMA declaration is a tool that is employed to ensure that the study conducted in this article is both comprehensive and consistent. As posited by Moher *et al.* (2010), the PRISMA statement encompasses four distinct stages, namely: article recognition, paper screening, paper eligibility, and included papers. These stages are further delineated by a total of 27 checkpoints. In Mengist *et al.* (2020a), the SALSA and PRISMA approaches were combined into a unified methodology, with PRISMA being incorporated within the SALSA framework. This entailed the inclusion of the study procedure and results reporting as two new phases in SALSA. The six key phases of the author's innovative, integrated technique are referred to as C for Protocol, Search, Appraisal, Synthesis, Analysis, and Report. This approach was employed in a comprehensive review of the extant literature on the status quo and areas that require further investigation in the study of ecosystem services in mountainous regions (Mengist *et al.*, 2020b).

In this study, an integrated PSALSAR approach was employed. As illustrated in *Table 1*, the framework for the comprehensive literature search and review has been established in order to examine the role of forests in the decarbonisation of society.

Table 1. Framework of the Systematic Literature Review and Search

	Tasks and methods
1. Protocol	• Study scope: Role of forests in low carbon economy. • Method: The PICOC (Booth, 2016)
2. Search	• Search databases on identified keywords
3. Appraisal	• Selection of studies • Method: Papers identification, screening, eligibility and included papers (Moher, *et al.*, 2010)
4. Synthesis	• Preparation of extracting data • Categorizing the data for further analysis • Method: The PRISMA statement 27-item checklist (Moher, D. *et al.*, 2010)
5. Analysis	• Data collection results analysis • Data organization analysis based on predetermined categories. • Determination of finding and suggestions
6. Report	• Results presentation in the form of an article • Method: The PRISMA statement 27-item checklist (Moher, D. *et al.*, 2010)

Source: created by the authors.

The research procedure is characterised by its commitment to transparency, reproducibility, and a systematic approach to the literature review process. It has been demonstrated that this approach serves to mitigate the degree of bias inherent in the study. The determination of the scope of the research is a crucial endeavour at this stage. The formulation of research questions, and the selection of the most appropriate procedures for achieving the study's objectives, can only be effectively undertaken once the scope of the study has been clearly defined (Booth, 2016; Amo *et al.*, 2016). The present study employs the PICOC framework as a methodological instrument for delineating the research domain. The framework provides a formal structure that facilitates the decomposition of research questions into their constituent ideas, thereby defining the inquiry's scope.

In order to ascertain the response to the following research query: 'What is the role of forests in decarbonising the economy and creating a carbon-neutral society?', the search may be divided into a number of sub-questions:

- What is the role of forests in a low-carbon economy?
- What methods are used to distinguish the role?
- What indicators are most appropriate for the role of forests in decarbonisation and creation of carbon neutral society assessment?

Table 2 illustrates the PICOC framework used in this study:

Table 2. Justification of the PICOC Framework-Based Research Scope

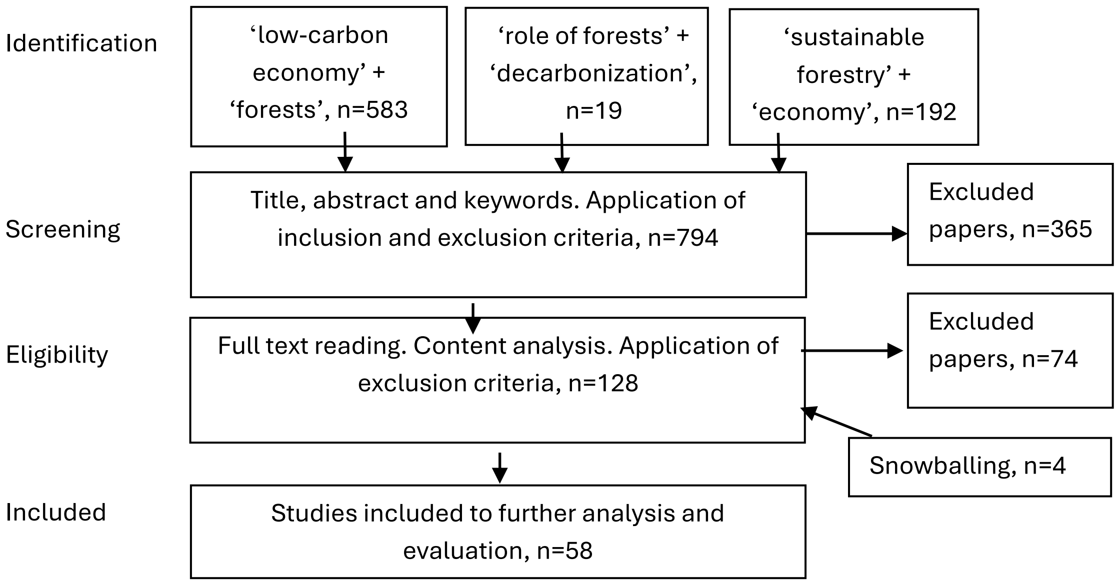
Concept	Description	Use
Population	The research studies about decarbonization or low carbon economy dealing with forests.	Scientific articles that used indicators, systems or other methodologies to evaluate the role of forests.
Intervention	Current methodology utilised to tackle the highlighted question.	Identification of indicators and their systems used to measure the role of forests in decarbonisation.
Comparison	Approaches to contrast the intervention used to measure the role of forests.	Disparity between the methods used to address the primary query
Outcome	Achievements and gaps of role of forests measurement in the analysed studies.	Current metrics, frameworks and methods for evaluating the contribution of forests to a low-carbon economy; constraints pertaining to the creation of an approach and a list of indicators.
Context	Characteristics of analysed information.	Research trends, obstacles, and gaps in the field of forest decarbonisation; knowledge and information dispersed according to certain categories (methodologies, indices, etc.).

Source: created by the authors.

The subsequent phase is the development and implementation of a search strategy. In order to ensure that the literature gathered during the search strategy stage is of the highest standard and comprises the majority of papers accessible in the scientific topic under investigation, it is crucial to select the appropriate database.

The PICOC framework is utilised to refine the search terms and the information to be searched in the articles that are discovered. A comprehensive search was conducted on the *Web of Science* (WoS) database, utilising three distinct combinations of themes to identify relevant literature. The following key terms and concepts are to be considered in this study: the 'low carbon economy' and'forests', 'decarbonisation' and 'the role of forests', and 'sustainable forestry' and 'economy'.

In the assessment stage, the articles found through the search are evaluated in accordance with the goals that have been established for this particular task. The present study is concerned exclusively with articles that meet the search parameters. The PRISMA statement guidelines for information search (phases of articles identification, screening, eligibility, and included papers) are adhered to when choosing publications for analysis. As illustrated in *Figure 1*, the information flow for the present study is presented in accordance with the PRISMA statement.



Source: created by the authors.

Figure 1. **The Research's Information Flow (Under the PRISMA Declaration)**

The following inclusion criteria have been established for this review. The search terms are identified in the article's title, keywords section, or abstract; these are publications that have been published in peer-reviewed scientific journals and journals that are pertinent to the sustainable forestry WoS database category. The exclusion criteria for this study encompass study papers, editorial letters, conference proceedings, publications that are not fully available, studies not written in English, studies that are repeated within the search documents, and studies that are not primary research. A comprehensive review of the articles selected for the initial search has been conducted, encompassing the formulation of concise summaries. Subsequent to the initial assessment, in the event that the publication satisfied at least one inclusion criterion but not any exclusion criteria, an examination of the substance of the publication was conducted.

The search for articles was conducted using the categories of the WoS database, with the objective of ensuring that the search results closely reflected the subjects of the study. A search for the terms 'low carbon economy' and 'forests' yielded 583 articles, of which 295 satisfied the inclusion criteria. A search for the terms 'decarbonization' and 'role of forests' yielded a total of 19 articles, of which two satisfied the inclusion criteria. A search for articles containing the keywords 'sustainable forestry' and 'economy' yielded 192 results, of which 68 met the inclusion criteria. The content analysis was conducted on the original data set, which excluded proceedings articles (47), non-English papers (4), and duplicates (164). The content analysis was conducted over the period from 2018 to 2023. The following scientific journals were identified as the primary sources of publications: Energies (28), *Frontiers in Forest and Global Change* (19), *International Symposium on Low-carbon Economics and Forestry Sustainable Management* (12), Business Strategy and the Environment (9), *International Journal of Sustainable Development and World Ecology* (9), *Ecology Economics* (5), and *Journal of Cleaner Production* (9). It is important to note that more than 70% of the research has been published in the previous three years. This underscores the significance of the topic and the necessity for a widely recognised definition, as well as the imperative to examine the role of forests in the transition to a low-carbon economy. In the course of the content analysis process, studies that were not primary research or only tangentially relevant to the research have been excluded (59). In this stage of the research, a snowballing approach was utilised to identify as many roles of forest assessment indicators and indices as was feasible. In the course of the examination of the content of review papers and of the publications discovered during the search, publications that would be useful for the study of this article were also analysed.

A total of 58 relevant papers were identified, encompassing a range of indicator sets and evaluation procedures employed or presented. The TIMES method was one of the indicators employed in numerous articles.

The study data was retrieved and categorised during the synthesis stage in accordance with the established categories, thus enabling the identification of the indicators that are used to evaluate the contribution of forests to a low-carbon economy. Two categories of data extraction can be distinguished: generic data and specialised article data. The general data can be allocated to the year of publication, the regions/countries of case studies, and the type of study. All additional data that contributes to addressing the primary topic of the analysis topic is attributed to the data of individual publications. The following elements are to be included in a checklist for information extraction: the year of publication, the journal, the location of the case study, the application area, the research's aim, the methodology, and the indicators employed.

In the course of the analysis, the categorised data is examined using predetermined criteria in an attempt to ascertain a response to the primary issue of the study. The arrangement and display of the indicators is based on the primary goal (application area) (*Table 3*).

It is important to note that research that satisfied the search parameters ‘role of forests’ and ‘decarbonization’ yielded the largest number of indicators and their sets. In the course of the present study, the analysis has been conducted on studies that have replicated ‘sustainable forestry’ and ‘economy’. The search for ‘low carbon economy’ and ‘forests’ has been conducted on the basis of these studies. While the low-carbon economy and decarbonisation share many concepts, the main subjects of research in the scholarly literature on this subject are stakeholder evaluations in the non-household sector and renewable energy sources.

Table 3. Classification of Reviewed Studies

Application areas	Methods applied	Groups of indicators	Locations	Years of publications
• Natural forests • Planted forests. • Biomass potential • Biomass energy • Forested area	• Integrated assessment models • Global Change Analysis Model • Induced Technical Change Hybrid model. • Random forest algorithm • TIMES approach • Integrated Economic Environmental modelling. • Global climate-economic model • Energy efficiency index model • Deep decarbonisation pathways method, • Backcasting method • Carbon budget model	• Reforestation • Afforestation • Cost-effective • Net energy balance • Forest resilience • Biodiversity protection • Sustainable potential • Policies • Social • Green Economic Growth	• Europe: Russia, Finland, Sweden, Italy • Asia: China, Malaysia • South America: Argentina, Colombia, Costa Rica, Ecuador, Mexico, Peru, Brazil • North America: Canada • Australia • Multiple countries: Western Europe, Developing Countries, Global South	• 2018 (4) • 2019 (1) • 2020 (8) • 2021 (12) • 2022 (18) • 2023 (16)

Source: created by the authors.

The report stage of the research process involves the presentation of the study's key findings. The results of the literature review are presented in the following section, using the PRISMA statement 27-item checklist.

2. Systematic Literature Review

2.1 Role of Forests in Climate Change Mitigation

In the context of mitigating global warming and fostering the development of a green economy, the forest industry has emerged as a pivotal sector, a role that is set to persist in the future. The forest sector's key contribution to climate change mitigation is the storage of carbon dioxide through the growth of forest cover and the management of forests. In addition, the manufacture of wood and related goods that can substitute fossil fuels and energy-intensive commodities is a significant contributor. It is evident that this contribution has considerable potential for further development (Nieuwenhuis *et al.*, 2013).

Forests are the second-largest terrestrial carbon sink on the planet after peatlands. Consequently, their usage and management are of pivotal significance in terms of both driving climate change and mitigating and adapting to it. Significant calculations by Pan *et al.* (2011) imply that the absorption of globally established forests may account for the entire terrestrial carbon sink. As a result, non-forest ecosystems are neither a substantial sink nor a major source. Despite the presence of substantial regional variations, and the global nature of the estimates, they underscore the efficacy of the forest sink, even when emissions from deforestation are factored out (Nieuwenhuis *et al.*, 2013).

The optimisation of the energy structure is of paramount importance in the reduction of carbon emissions. The energy structure needs to be replaced quickly and efficiently, which calls for a procedure, significant financial outlays, and technological development. 'Low-carbon' and 'development' are combined to form low-carbon economic development (Zhang *et al.*, 2023). There are two approaches to reducing emissions that are specifically linked to forests. The first involves determining the portion of greenhouse gas emissions termed 'net emissions' that must be subtracted from forest carbon sequestration. The second involves achieving net emissions reduction through a system for sustainable development (Streimikiene, 2024; Dat and Hung, 2023). Mitigating carbon emissions must not compromise economic growth, and carbon dioxide emissions are identified as the primary contributor to the phenomenon of global warming, as evidenced by Meinshausen *et al.* (2009). Consequently, in accordance with previous research (Davis and Caldeira, 2010; Lee *et al.*, 2018; Mulugetta and Urban, 2010), the researchers employed carbon emissions per unit of Gross Domestic Product (GDP) as the dependent variable to assess the advancement towards a low-carbon economy.

The influence of forest resources on the ratio of carbon emissions to Gross Domestic Product (GDP) is primarily exerted through the mediating mechanism of urbanisation. Urbanisation has been shown to engender heightened production efficiency and to capitalise on the agglomeration scale effect (Zhang *et al.*, 2023). This, in turn, has the effect of diminishing the marginal costs associated with public management facets like pollution control. The presence of a forest carbon sink exerts a certain constraint on the trajectory of economic development; nevertheless, it effectively ameliorates atmospheric carbon dioxide concentrations, facilitates the pursuit of a low-carbon economic trajectory, and augments the overall quality of economic advancement. Consequently, the further enhancement of the forest ecological benefit compensation system emerges as a principal avenue for fostering environmentally sustainable economic development, whilst concurrently attaining the objectives of carbon emission reduction and carbon neutrality, as proposed by van den Bremer and van der Ploeg (2021).

2.2 Role of Forests in Transition to Low Carbon Economy

Carbon emissions are categorised into two distinct types: absolute emissions and relative emissions. The latter are proportionately attributed to economic development (Lee *et al.*, 2018). In the context of a developing nation, the pursuit of economic growth, enhanced energy efficiency, and the reduction of emissions are of equal importance (Pan, 2022). The impact of abundant forest resources on low-carbon growth in the economy can be viewed from two perspectives: the source and sinks of carbon.

In the context of a low-carbon economy, the mitigation of carbon emissions is contingent on two primary strategies: source control and enhanced carbon sequestration within ecosystems, as expounded upon by Yang *et al.* (2019). Forest ecosystems, being robust repositories of carbon sequestration, play a pivotal role in this regard. The advancement of forestry has been demonstrated to contribute to sustainable forest management, as well as augmenting the intrinsic value of forests. Consequently, the development of forestry practices has been identified as a catalyst for the eventual reduction of carbon emissions originating from forested regions, in accordance with the insights presented by Swingland *et al.* (2002). At present, reforestation is regarded as one of the most efficacious methodologies for climate change mitigation, as emphasised by Bastin *et al.* (2019). Nevertheless, while the utilisation of forest biomass for bioenergy purposes holds the potential to curtail greenhouse gas emissions, alternative applications of forest biomass bear the risk of escalating greenhouse gas emissions over the long term, as documented by Luyssaert *et al.* (2008) and Ter-Mikaelian *et al.* (2015).

The realisation of carbon sequestration (CCS) is identified as a significant means for achieving low-carbon economic progress. The function of forest carbon sinks is to absorb carbon dioxide via forest vegetation and sequester it within plants and soil, thereby mitigating atmospheric carbon dioxide concentrations. Consequently, forests are the preeminent carbon reservoir within terrestrial ecosystems, aligning with the findings advanced by Zhang *et al.* (2023). However, it is important to acknowledge the social costs associated with carbon sequestration, as discussed by Welsby *et al.* (2021). The rapid expansion of urban areas exerts a direct influence on the provisioning and utilisation of ecosystem services, resulting in significant ramifications for land use, as discussed by Zhang *et al.* (2023). Moreover, the objective of curtailing carbon dioxide emissions should not be regarded as being in opposition to economic development. In order to achieve a symbiotic relationship between economic advancement and carbon emissions mitigation, structural adjustments are imperative. The replacement of conventional fossil fuels with renewable energy sources is identified as a pivotal method in this context, as emphasised by Gustavsson *et al.* (2021).

2.3 Forests and Green Economic Growth

In their study, researchers Tan and Wang (2023) explored the role of forests in green economic growth (GEG). Green Economic Growth (GEG) is a contemporary concept in the field of economic development. It emphasises the integration of ecological sustainability and the judicious use of natural resources in achieving and fostering economic growth (Soundarrajan, Vivek, 2016). The fundamental notion of attaining and engaging with GEG is predicated on the premise that social development should concurrently consider the advantages to the environment and the economy. However, research conducted by other academics indicates that, within the context of actual provincial or regional economic growth, rural regions or those abundant in forest resources frequently exhibit slower economic growth rates (Davis and Tilton, 2005). It is therefore vital to address issues of medium- to long-term sustainable and green development if the ongoing impact of green economic growth (GEG) is to be maintained. It can be hypothesised that there are several plausible reasons for the varying attainment of sustainable development at differing degrees of forest endowment. Initially, an abundance of forest resources has the potential to result in oversight with regard to their efficient utilisation. Evidence suggests that this might result in a rudimentary exploitation of resources, which is not conducive to achieving green economic growth (Haseeb *et al.*, 2021). Secondly, in instances where forest resources are developed to an excessive degree, there is a risk of impeding investment in other industries. This, in turn, has the potential to hinder the growth of high-tech and tertiary industries, thereby leading to a paucity of innovation in other domains (Lee and He, 2022). These circumstances impede the transition to green economic growth (GEG), particularly in provinces or regions with a high abundance of forest resources, as they are not conducive to the promotion of green growth (Porfiryjev, 2018). It is imperative to leverage the advantages of being endowed with forest resources to promote their efficient utilisation and accelerate the economic advancement of areas rich in these resources.

Auty (2022) posits that the possession of abundant natural resources has the potential to impede, rather than facilitate, economic growth. This assertion is supported by the concept of the ‘Dutch Disease Effect’, which suggests that an excessive concentration on resource-based industries can dilute a region’s economic prowess, fostering instability and delayed progress that might culminate in resource exhaustion and subsequent econominc downturns. Similarly, Sachs and Warner (1995) found that, even when accounting for variables such as initial investment rates, government efficiency, trade policies, and income per capita, countries with greater natural resource reserves experienced slower economic growth. Apergis and Katsaiti (2018) further confirmed the negative correlation between the abundance of natural resources and economic expansion. As Davis and Tilton (2005) demonstrate, commodities originating from the natural resource sector are susceptible to considerable price volatility due to their inelastic nature. This has a detrimental effect on external trade, domestic consumption, government revenues and the planning of economic development over time. Concurring with this perspective, Kim and Lin (2017) posit that economies abundant in natural resources frequently exhibit a substantial reliance on the extraction and commercialisation of these resources, a practice that has the potential to adversely impact their overall economic well-being. These sectors are frequently distinguished by their constrained capacity for innovation, minimal demands for skilled labour, and negligible effects on technological advancement. This scenario may result in the undervaluation of human skills development and technological investments by both governments and corporations. Guo *et al.* (2021) posit that the presence of abundant resources has impeded the evolution and diversification of the economy in the West. Furthermore, Qiu and Tao's (2020) research identified that the abundance of resources influences decisions regarding corporate innovation and the adoption of environmental practices.

Conversely, some scholars argue against the notion that resource wealth inherently limits economic progress. For instance, research highlighting the south-central United States demonstrates how abundant natural gas production has spurred job creation in related sectors, fueled by the growth of the mineral resource industry (Wang and Chen, 2020). Brunnschweiler and Bulte (2008) posit the hypothesis that the growth potential of developing countries is not constrained by their natural resource base. A study of data from 95 cities by Tan and Wang (2023) suggests that there is no direct correlation between resource wealth and economic deceleration. Yan (2014) conducted an empirical study using provincial area data. The study found that while natural resource endowments have a direct impact on economic growth, the indirect effects present a more complex picture. This challenges the notion that resource richness invariably undermines regional economic prosperity. In addition, Sun and Sin's (2014) study, as cited by Tan and Wang (2023), concluded that there is an absence of compelling evidence to suggest that resource wealth exerts a deterrent effect on economic expansion (Tan and Wang, 2023).

The literature on mineral resources is abundant both domestically and internationally, but it is rare and mostly concentrates on domestic research when it comes to the forest sector. As demonstrated in Wang and Xie's (2020) research, the forest resource endowment areas in China that impede economic expansion are predominantly situated in the country's north and west, exhibiting minimal inhibitory influence in the country's east and south. Liu *et al.* (2015) distinguished between the endowment and reliance of forest resources. The percentage of forestry system personnel to total employees in the society was utilised to indicate forest resource endowment, while the regional per capita forest stock was employed to reflect forest resource endowment. In order to ascertain whether there had been a detrimental impact, the dependency of forest resources was empirically evaluated. Hou and Wang's (2011) conclusion was that the forestry resources of Heilongjiang province had no inhibitive impact. Tao (2012) provided actual evidence demonstrating the many ways in which shifts in forest resources and economic expansion are related. As posited by Razafindratsima *et al.* (2021), the objective of a sustainable income rise may be advanced by fully leveraging and regulating the ecological services provided by forests.

2.4 The Influence of Forest Resources on the Development of Low-Carbon Economies

The absorption of carbon by trees as they grow plays a crucial role in the carbon capture capabilities of both natural and man-made forests. As Hemingway *et al.* (2019) observe, the carbon stored in the biomass of trees can be transferred to the soil through processes such asrhizodeposition and the decay of fallen leaves and branches, potentially remaining there for centuries. It is important to note that soil carbon reserves exceed the combined carbon content of the atmosphere and vegetation. Consequently, even minor alterations in soil carbon levels can substantially influence a forest's capacity for carbon storage. The capacity of forests to function as carbon sinks exhibits a high degree of sensitivity to these alterations, given the significant quantity of carbon stored within soil profiles. In the context of a decadal timescale, activities such as afforestation and reforestation have been shown to contribute to an increase in soil carbon stocks (Nave *et al.*, 2018). However, the process of tree planting can, on occasion, result in a depletion of carbon, particularly in regions where the soil is inherently carbon-rich, such as peatlands and specific types of grasslands (Waring *et al.*, 2020).

Recent studies have led to a shift in our understanding of forest carbon sequestration over extended periods. The prevailing hypothesis in the field was that the permanence of soil carbon was contingent on the chemical nature and properties of the carbon compounds introduced into the soil. However, the findings of Schmidt *et al.* (2011) suggest that the stability of biomolecules such as lignin in soil organic matter is more intricate than previously believed. The fate of carbon derived from plants in soil is greatly influenced by the activities of decomposer microorganisms and their interaction with soil minerals (Dungait *et al.*, 2012; Cotrufo *et al.*, 2013), underscoring the importance of understanding soil properties to enhance carbon sequestration efforts (Hemingway *et al.*, 2019). The cycling and stability of soil carbon can also be significantly affected by forest management practices. In some situations, high levels of nitrogen are required to boost productivity, especially in sandy or tropical soils (Adams and Pfautsch, 2018). This has a considerable effect on the dynamics of soil organic matter (Averill and Waring, 2018).

The fate of wood harvested from plantations serves as a significant indicator and key element. Leskinen *et al.* (2018) advocate for the substitution of wood products in place of materials with higher carbon footprints, such as steel and cement, in the construction industry to lessen its notable impact on global greenhouse gas emissions, a concern noted by Lucon *et al.* (2014). The utilisation of wood as a substitute for conventional construction materials has the capacity to transform edifices into urban carbon sinks, with the potential to offset one to three tons of carbon emissions for each ton of wood employed (Churkina *et al.*, 2020). Moreover, the substitution of fossil fuels with biomass energy derived from wood could further contribute to the mitigation of climate change. However, it is imperative to exercise caution to avert counterproductive land use changes or the disregard of long-term management strategies. The utilisation of wood waste for the purpose of bioenergy production has been identified as a more environmentally sustainable approach when compared with the cultivation of bioenergy crops. This is due to the fact that the former does not necessitate the extensive use of land, a factor which could potentially compromise efforts to preserve biodiversity (Groom *et al.*, 2008). Finally, the application of in-depth knowledge of forest growth and structure, such as through selective thinning, has been demonstrated to optimise wood production for both immediate economic benefits and the enhancement of long-lived wood products, thereby supporting both economic and environmental goals in forested regions (Braun *et al.*, 2016). This holistic approach has been demonstrated to engender revenue for local communities, frequently situated in rural areas, whilst concomitantly facilitating the augmentation of forest cover.

In a related observation, Lin and Ge (2021a) verified the U-shaped correlation between forest carbon sinks and economic growth, illustrating the presence of the environmental Kuznets curve through their analysis of the link between institutional freedom and forest carbon sinks. This was achieved using a panel threshold model across 139 countries. On the other hand, the favourable effect will be increasingly apparent with the threshold increase when economic development is steady. Research by Lin and Ge (2019b) has indicated that the carbon sink trade can serve as a representation of the value of forest carbon sinks, while simultaneously reducing the financial burden associated with emission mitigation. The establishment of a national carbon trading market with a carbon sink function would facilitate the efficient reduction of the cost of curtailing carbon emissions, while ensuring China's economy maintains low-to-medium growth and transitions towards a low-carbon model.

Cao (2020) posits that forestry should have a substantial impact on climate change. The Faustmann-Hartman model was utilised in the calculation of the economic value of afforestation carbon sink initiatives. Ren *et al.* (2020) assert that the implementation of carbon trading has the potential to enhance the financial performance of heavily polluting businesses, foster enterprise innovation, and continually advance the development of China's carbon market. As Mo *et al.* (2018) demonstrate, the financial outlay required to achieve carbon neutrality can be reduced by combining non-fossil energy subsidies with carbon pricing. Furthermore, Wang *et al.* (2023b) found that rent, natural resources, human capital, and degree of openness to the outside world all affect carbon emissions. Moreover, it is asserted that enhancing trade openness is instrumental in curbing carbon emissions and fostering low-carbon economic development, provided that the structural breakpoint is effectively addressed. However, the findings of Wang *et al.* (2023a) demonstrate that trade openness and natural resource rents exacerbate environmental pressure.

2.5 Climate Change Mitigation Policies inForest Systems

The United Nations Climate Change Conference, held in Glasgow (COP26), represents a pivotal event in the context of climate summits. It is the first occasion on which nations have convened to deliberate on their carbon reduction commitments following the adoption of the Paris Agreement. It is imperative to emphasise that the primary driver of global warming is the emission of greenhouse gases, a fact substantiated by Kweku *et al.* (2018).

A thorough examination of the climate pledges presented by various nations during the COP26 underscores the necessity of prompt policy interventions to ensure that the global warming remains within the threshold of a 2°C increase by the year 2100, as highlighted by Hausfather and Moore (2022). However, it should be noted that the probability of limiting global warming to within this 2°C threshold is less than 50%. It is only through the full and timely implementation of both conditional and unconditional commitments that global warming can potentially be restrained to a margin slightly below the range of 1.9–2.0°C. In order to achieve this outcome, the formulation and enactment of pertinent policies and concerted actions become indispensable, as articulated by Meinshausen *et al.* (2022).

A key consensus achieved at COP26 pertains to the commitment of nations to restrict carbon dioxide emissions and other greenhouse gas discharges in pursuit of the objectives delineated by the conference. Concurrently, they have pledged to halt and reverse the depletion of forests and land degradation by the year 2030, while bolstering measures aimed at safeguarding forested regions, as acknowledged in the work of Haenssgen *et al.* (2022).

A key consensus achieved at COP26 pertains to the commitment of nations to restrict carbon dioxide emissions and other greenhouse gas discharges in pursuit of the objectives delineated by the conference. Concurrently, they have committed to halting and reversing the depletion of forests and land degradation by the year 2030, while fortifying measures aimed at safeguarding forested regions, as acknowledged in the work of Haenssgen *et al.* (2022).

Achieving carbon neutrality within the context of climate policy necessitates a substantial increase in demand for forest biomass, which is projected to exceed anticipated future yields. Forests have been identified as playing a pivotal role in the mitigation of climate change, as asserted by Mitchard (2018). The decline in carbon sequestration in forests poses a considerable challenge to achieving carbon neutrality, as emphasised by Majava *et al.* (2022). As Silva Junior *et al.* (2021) note, curbing deforestation is among the most efficient strategies for climate change mitigation. This is due to the fact that it serves to mitigate emissions originating from land use alterations and land management practices. Moreover, the process of urbanisation is recognised as a principal driver of forest resource depletion, as expounded upon in the work of Curtis *et al.* (2018).

The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 2007) provides a theoretical model for considering the contribution of the forestry sector to mitigating climate change. Sequestration, replacement and substitution are three such mechanisms:

- the replacement of fossil fuel with biomass from forests and other materials (providing the wood comes from forests that are responsibly managed and ideally from forests throughout the international finance system);
- the use of wood products for construction and other end uses;
- the net storage or uptake of atmospheric carbon; the extension of forest cover;
- the enhancement of carbon absorption in existing forests;
- and other related measures (IPCC, 2007).

3. Discussion

The main findings of the systematic literature review showed that the main research areas in disclosing the role of forests in low carbon transition are:

- Natural and planted forests, carbon capture;
- Forest systems in decarbonising economy;
- Biomass and bioenergy potential;
- Economic growth, renewable energy use, carbon emission interplay at forested areas;
- Costs and benefits of decarbonising the economy;
- Energy stability and decarbonisation, approach of forests.

The reviewed studies demonstrate the significance of integrating diverse approaches to address common issues, considering discrepancies in policy considerations and economic strategies to achieve a carbon-neutral society. The promotion of renewable energy adoption and the assurance of sustainable forest management are pivotal in enabling society to derive maximum benefit from the concurrent utilisation of forested areas.

The primary research gaps pertain to the absence of integrated studies that address the interconnectedness of water, land, climate, energy, agriculture, and forests. This research is crucial for formulating harmonised climate change mitigation policies targeting specific sectors of the economy that are linked to natural resources. The decarbonisation process can be achieved through various climate change mitigation and carbon sequestration technologies.

Achieving a net zero carbon emissions target necessitates a comprehensive understanding of the intricate interconnections between forest systems and their role in water, land, energy, food, and biodiversity. These systems are intricately linked and play a pivotal role in ensuring food and nutrition security, maintaining reliable energy supplies, and sustaining rural livelihoods.

It is imperative to underscore the significance of recognising the inherent interconnectedness between the utilisation of natural resources and the secure provision of water, energy, and food. For instance, the production of biofuels necessitates the utilisation of substantial quantities of water and land, which could otherwise be allocated to food cultivation. Furthermore, the implementation of intensive agricultural practices within the upper regions of river basins has been demonstrated to result in increased soil erosion, thereby exerting a detrimental effect on electricity production at hydroelectric facilities. In addition, it is imperative to acknowledge that both climate change and the policies implemented to mitigate its effects have the potential to exert further pressure on water, land, and forest resources. The Water-Land-Climate-Energy-Food-Forests Nexus is a concept that has been developed to address the cross-sectoral linkages that are becoming increasingly recognised in this field. It is a significant area for future research. Therefore, in order to achieve net zero carbon emissions and unlock progress on multiple SDGs, it is necessary to coordinate action to manage the complex interplay between land, water, climate, food, energy, and forest systems.

The conducted systematic literature review enabled the development of implications for future research. It is recommended that future studies adopt a more comprehensive approach to integrated modelling, encompassing the multifaceted interactions between economic, environmental, and technological factors. Additionally, it is imperative to integrate the Water-Land-Climate-Energy-Food-Forests Nexus to ascertain the pivotal role of forests in decarbonisation processes on a global scale. As previously outlined, comparative studies across a range of countries worldwide (whether grouped or ungrouped) offer significant insights. Future research could expand upon these comparisons to identify similar and common challenges and successful strategies for implementing the policies drawn upon. The concept of policy effectiveness is becoming increasingly prominent. Consequently, the evaluation of the effectiveness of forest-related policies in various domains could provide policymakers with valuable insights to inform the development of strategies that align with global climate and sustainability objectives.

Conclusions

A systematic review of the literature on the role of forests in the low-carbon transition was conducted, which enabled the identification of the main research gaps and the development of future research guidelines. The primary research gaps pertain to the absence of integrated studies that address the interconnectedness of water, land, climate, energy, agriculture, and forests. This absence hinders the formulation of harmonised climate change mitigation policies targeting specific sectors of the economy that are linked to natural resources. The decarbonisation process can be achieved through various climate change mitigation and carbon sequestration technologies.

The establishment of connections across the domains of land, water, climate, food, energy, and forests has the potential to drive advancements in numerous Sustainable Development Goals (SDGs), paving the way for a carbon-neutral society and fostering a more robust environment for the coming generations. While the concept of a 'nexus' connecting diverse facets of natural resource management has garnered increasing attention from the academic community, empirical research on implementing this framework in policy evaluation remains somewhat limited. It is recommended that future research efforts concentrate on elucidating the role of forests in facilitating the transition towards a low-carbon economy. This involves broadening the scope of research through a nexus-based approach and leveraging integrated modelling techniques to explore the intricate interplay within the Water-Land-Climate-Energy-Food-Forests Nexus. A critical examination of the synergies and tensions among different policy objectives is crucial for gaining a deeper insight into the potential benefits and hurdles associated with such interconnectedness. It is imperative, therefore, to swiftly comprehend the dynamics of policy interplay and to incorporate policy coherence analysis into assessments of the resource nexus.

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MIŠKŲ VAIDMUO PEREINANT Į MAŽAANGLĘ EKONOMIKĄ: SISTEMINĖ LITERATŪROS APŽVALGA

Gabija Stanislovaitytė, Asta Mikalauskienė, Remigijus Čiegis, Agnė Lauzadytė-Tutlienė

Santrauka. Siekiant pereiti prie mažai anglies dioksido į aplinką išskiriančių technologijų svarbus anglies absorbcijos mechanizmo įdiegimas. Ekosistemų paslaugų rinkinyje, kuris lemia pasaulinę klimato dinamiką, reikšminga miško anglies sekvestracija. Straipsnyje pateikiama sisteminga literatūros apžvalga, skirta apibrėžti miškų vaidmenį dekarbonizuojant ekonomiką, nustatyti tyrimų spragą ir parengti būsimą tyrimų darbotvarkę. Sisteminei literatūros apžvalgai buvo pritaikytos sistemos SALSA, PRISMA ir protokolas PSALSAR. Pagrindinės analizės išvados atskleidė, kad trūksta integruotų tyrimų, skirtų vandens, žemės, klimato, energijos, žemės ūkio ir miškų sąsajoms spręsti, siekiant apibrėžti suderintą klimato kaitos švelninimo politiką, nukreiptą į konkrečius ekonomikos sektorius, susijusius su gamtos ištekliais. Teigtina, kad dekarbonizaciją galima pasiekti taikant įvairias klimato kaitos švelninimo ir anglies sekvestracijos priemones tarpusavyje susijusiose vandens, žemės, klimato, maisto, energijos ir miškų sistemose.

Reikšminiai žodžiai: miškai; darnus vystymasis; klimato kaitos švelninimas; sekvestracija; politika ir priemonės.