

## Contents

### PAPERS

Polycentric forest governance for social equity of Indigenous Peoples? A critical appraisal D. ADHIKARI	1	Unlocking the potential of private forests for carbon storage, biodiversity conservation, and livelihoods in Nepal R. JOSHI, H. ZHANG, T. MARASENI, N. DHAKAL, J. GAUTAM, H. SINGH and H. ADHIKARI	67
The transformation of institutional capacity for social forestry policy in Java, Indonesia M. ADIB, M. SAUD, R. RUSTINSYAH and I. ABDULLAH	16	Youth knowledge, engagement, and challenges in forest management and governance in Africa: a literature review C. WEKESA, A. ROOS, D. GITONGA, L. POPOOLA, D. MUTTA, M-L. AVANA-TIENTCHEU, C. MARK-HERBERT, F. BABALOLA, J. CHEBOIWO and P. MBILE	85
A comparative legal analysis of silvicultural interventions for sustainable forest management Ü. BİRBEN and F. ÇAKIR	29	Empirical analysis of the links between China's forest product imports and tropical forest loss X. SUN, A.L. HAMMETT and R. BUSH	102
An assessment of export-import performances of Nepal's wood sector: market landscape and trade indices analysis R.B. DANGI	42	<b>BOOK REVIEW</b> Resilient Forest Management <i>Philip J. Burton</i>	113
Energy forests on small rural properties in the semi-arid region of Brazil D.C. GAMA, D.A. DEUS, T.A.S. FREITAS, F.F. OLIVEIRA, M.D.S. FONSECA and A.C.P. SANTOS	55		



THE INTERNATIONAL FORESTRY REVIEW

Vol. 28 (1), 2026

# The International Forestry Review



EDITOR: A.J. POTTINGER

International Forestry Review (print) ISSN 1465-5489  
International Forestry Review (online) ISSN 2053-7778

PUBLISHED BY THE COMMONWEALTH FORESTRY ASSOCIATION

Vol.28(1), 2026

www.cfa-international.org

# The International Forestry Review

## Editor

Alan Pottinger  
[alan.pottinger@cfa-international.org](mailto:alan.pottinger@cfa-international.org)

## Editorial Board

Fred Babweteera  
*Budongo Conservation Field Station, Uganda*

Neil Byron  
*Independent, Australia*

José Joaquín Campos  
*CATIE, Costa Rica*

Jim Carle  
*Independent, New Zealand*

Ebby Chagala  
*Kenya Forestry Research Institute (KEFRI), Nairobi, Kenya*

Ben Chikamai  
*Executive Secretary, Network for Natural Gums and Resins in Africa (NGARA)*

Mafa Chipeta  
*Independent, Malawi*

Jonathan Cornelius  
*World Agroforestry Centre (ICRAF), Peru*

Julian Evans  
*Independent, UK*

Lukas Giessen  
*Technical University Dresden, Germany*

Verina Ingram  
*CIFOR, Indonesia and LEI Wageningen UR, The Netherlands*

## Contact

The Editor, International Forestry Review,  
The Crib, Dinchope, Shropshire SY7 9JJ, UK  
Telephone: +44 (0)1588 672868  
Email: [cfa@cfa-international.org](mailto:cfa@cfa-international.org),  
Web: [www.cfa-international.org](http://www.cfa-international.org)

Cover photo: Youth participants explore ideas for home-grown green enterprises during the #AfricanYouth4Forests workshop in Voi, Kenya, 2022, guided by scientific insights from Dr. Doris Mutta of the African Forest Forum (AFF) (*Credit: Felix Odhiambo*).

## Chairman of the Editorial Board

Jeff Sayer  
*University of British Columbia, Canada*  
[jeffrey.sayer@ubc.ca](mailto:jeffrey.sayer@ubc.ca)

John Innes  
*University of British Columbia, Canada*

Peter Kanowski  
*Australian National University, Australia*

Roger Leakey  
*James Cook University, Australia*

John Palmer  
*University of British Columbia, Canada*

Gill Petrokofsky  
*University of Oxford, UK*

Jack Putz  
*University of Florida, USA*

Lee Su See  
*Forestry Research Institute Malaysia, Malaysia*

Changyou Sun  
*Mississippi State University, USA*

Terry Sunderland  
*University of British Columbia, Canada*

Jerome Vanclay  
*Southern Cross University, Australia*

Michael J. Wingfield  
*Forest and Agricultural Biotechnology Institute (FABI), South Africa*

# GUIDELINES FOR AUTHORS

Please send the Summary of the paper to the Editor at [cfa@cfa-international.org](mailto:cfa@cfa-international.org). If it is considered suitable for consideration you will be asked to send the complete manuscript. Manuscripts submitted for consideration must conform to the following points. Any deviation will result in the manuscript being returned to the author.

## COMPOSITION

- Contributions must be original\* and not have been submitted for publication elsewhere. (Note: Plagiarism is evaluated by use of electronic software. For more information on what constitutes plagiarism, and why it is important please click here).
- The text, excluding tables, references and appendices, should not exceed 7000 words, although exceptions may be permitted in special cases.
- A SUMMARY of not more than 150 words must be supplied, together with 5 keywords.
- All spelling must conform to UK/international English.
- The layout of the text and style of table and figure legends and references must conform to that of the International Forestry Review. This means:
  - Main title in Arial, Text in Times New Roman
  - The hierarchy of headings is: CAPITALS, **bold lower case**, *italics lower case*.

## TEXT

- Manuscripts should be produced in Microsoft Word, written in Times New Roman typeface (size 12 pt), with single row spacing, left justification and without hyphenation.
- The manuscript should be written in the passive voice, e.g. 'The experiment was carried out' *is correct*; 'We carried out the experiment' *is incorrect*.
- Manuscripts should be submitted with UK English spellings. Make sure that a spell check with UK English spellings is used prior to submission.
- Paragraphs should not be separated by any additional line spacing. The first paragraph in a section should not be indented. The first line of each subsequent paragraph should be indented to 1.27cm.
- Use quotation marks (" ") *only* around quotations or titles. Do not use them to highlight or emphasise text.
- et al.* *is correct*. *et al* *is incorrect*.
- The document should be saved as a Microsoft Word file with \*.doc file extension.

## TITLE

- The title and author's details should be in the following format

Mutually beneficial company-community partnership in ensuring its long-term viability: emerging lessons from Indonesia

A.A. NAWIR and L. SANTOSO

*Center for International Forestry Research, Jl. CIFOR, Situ Gede, Sindang Barang, Bogor 16680, Indonesia*

Email: [a.nawir@cgiar.org](mailto:a.nawir@cgiar.org) and [l.santoso@cgiar.org](mailto:l.santoso@cgiar.org)

## TABLES

- Tables should clear and simple, with a maximum of 8 columns. (Note that tables have limited space in the final layout and therefore the reduction of font size to a minimum of 8 pt during typesetting should be taken into account when preparing tables).
- Headings and other texts in table cells should to be concise. Tables including captions, legends and footnotes should be written in Microsoft Word (in exceptional cases Microsoft Excel can be used following agreement of the Editor).
- Tables should be saved in a separate file (not as an integral part of manuscript) and the manuscript text should contain the reference to the position of the table (or figure) in brackets.

## NUMBERS

- Numbers greater than 999 should be written with appropriate spaces and without commas, e.g 10 000 is correct, 10,000 and 10000 are incorrect

## FOOTNOTES

- References to footnotes in the main text should be marked with arabic numerals in superscript form.

## GRAPHS AND FIGURES

- Graphs, diagrams and other figures should be prepared in Microsoft Excel or in Microsoft PowerPoint and saved in separate files. Graphs and diagrams should be drawn in 2-D form (not in 3-D spatial form) and single columns or circle sectors (in case of pie diagrams) should be filled with grayscale colours (not with colour filling or by using of automatic hatching). The line weight of axes and other lines and also the size of used letters or numerals should be appropriate to the final size reduction of diagrams during layout of final magazine page (maximum width of finally reduced diagram is either 8 or 18 cm depending on whether it fits one or two columns).
- Complex images such as maps (drawn in line draw or grayscale format) should be prepared in one of the following: CorelDraw, Adobe Illustrator, Adobe Photoshop, Macromedia Freehand or similar in which he finished images can be saved as \*.eps (Encapsulated PostScript) file format. B&W photographs should be submitted as \*.tif image file format with a resolution of at least 300 dpi. Colour

photographs may be submitted only after agreement with the Editor. Colour images should be saved in CMYK colour format, as \*.tif file format and with a resolution of at least 300 dpi.

- Titles should be in the format: TABLE X *Title of table*

## SCIENTIFIC NAMES

- The complete scientific name (genus, species, authority and, where appropriate, cultivar) should be cited at the first occasion of its mention and written in italics (authority in normal type). If vernacular names are used, they must be accompanied by the correct scientific name at first use.

## CITATIONS

- For text citations, papers should be referred to as (Smith 1998) and papers by the same author in the same year should be distinguished by lettering in sequence (1998a, 1998b, etc.). Where papers are written by a single author or two authors their names should be cited. If three or more authors are involved the first name should be listed followed by 'et al.', e.g. (Smith *et al.* 2002).
- Citations should be separated by a comma, not a semi-colon, i.e. (Johnstone 2003, Smith 2002, Smith *et al.* 2002).
- Multiple citations by different authors should be listed alphabetically, e.g. (Brown 2001, Jones 2003 and Smith 2002).
- Multiple citations by the same author should conform to the following format (Brown 2001, 2005, 2009).

## QUOTATIONS

- Direct quotations from papers or books should be referenced in the format (Smith 1998: 23-24).

## REFERENCES

- At the end of the paper, the list of references must be arranged in alphabetical ordering without serial numbering.
- References should be formatted with a 'hanging' indent.
- There should be no additional line spacing between individual references.
- The following standard forms of citation must be used:
  - Author's name, all authors' initials to follow surname, journal and book titles in italics. Volume number in bold. Second and subsequent lines should not be indented. For example:

**Journal paper**  
LÄHDE, E., LAIHO, O., NOROKORPI, Y. and SAKSA, T. 1999. Stand structure as the basis of diversity index. *Forest Ecology and Management* **115** (2/3): 213-220.

**Paper or chapter in proceedings**  
SMITH, W.J. 2001. Selection of tree species for arid environments. In: BLACKBURN, J.W. (ed.) *Multipurpose trees and shrubs for fuelwood and agroforestry*. CNRD Monograph No4. 366 pp.

**Book**  
PHILLIP, M.S. 1994. *Measuring trees and forests*. 2nd edition, CAB International, Wallingford, England. 310 pp.

- Unnecessary use of capitals should be avoided. For example HOLMGREN, J., JOYCE, S., NILSSON, M. and OLSSON. H. 2000. Estimating Stem Volume and Basal Area in Forest Compartments by Combining Satellite Image Data with Field Data. *Scandinavian Journal of Forest Research* 15: 103–111. *Is incorrect*.
- HOLMGREN, J., JOYCE, S., NILSSON, M. and OLSSON. H. 2000. Estimating stem volume and basal area in forest compartments by combining satellite image data with field data. *Scandinavian Journal of Forest Research* 15: 103–111. *Is correct*.
- Websites should only be quoted in isolation where hard copies are not available.

## ACKNOWLEDGEMENT

- It is necessary for authors to acknowledge suggestions made by referees with a simple statement such as 'The valuable suggestions made by anonymous referees is gratefully acknowledged'.

## SUBMISSION

- Manuscripts offered for publication should be submitted by email to [cfa@cfa-international.org](mailto:cfa@cfa-international.org)

## REFEREEING

- Contributions will be referred to at least two expert referees. Authors will be consulted if the paper is considered suitable but alterations are thought desirable. After alterations have been agreed and incorporated, the paper will be considered final.

## ASSISTANCE WITH PUBLICATION

- For assistance with preparing manuscripts visit our **Online guide to scientific writing** at <http://www.cfa-international.org/ONGSWintro.html>

\* Original means that the paper, or any close derivative of it, has not been published previously in any form, including on the internet.

# Contents

## PAPERS

Polycentric forest governance for social equity of Indigenous Peoples? A critical appraisal D. ADHIKARI	1	Unlocking the potential of private forests for carbon storage, biodiversity conservation, and livelihoods in Nepal R. JOSHI, H. ZHANG, T. MARASENI, N. DHAKAL, J. GAUTAM, H. SINGH and H. ADHIKARI	67
The transformation of institutional capacity for social forestry policy in Java, Indonesia M. ADIB, M. SAUD, R. RUSTINSYAH and I. ABDULLAH	16	Youth knowledge, engagement, and challenges in forest management and governance in Africa: a literature review C. WEKESA, A. ROOS, D. GITONGA, L. POPOOLA, D. MUTTA, M-L. AVANA-TIENTCHEU, C. MARK-HERBERT, F. BABALOLA, J. CHEBOIWO and P. MBILE	85
A comparative legal analysis of silvicultural interventions for sustainable forest management Ü. BİRBEN and F. ÇAKIR	29	Empirical analysis of the links between China's forest product imports and tropical forest loss X. SUN, A.L. HAMMETT and R. BUSH	102
An assessment of export-import performances of Nepal's wood sector: market landscape and trade indices analysis R.B. DANGI	42		
Energy forests on small rural properties in the semi-arid region of Brazil D.C. GAMA, D.A. DEUS, T.A.S. FREITAS, F.F. OLIVEIRA, M.D.S. FONSECA and A.C.P. SANTOS	55		
		<b>BOOK REVIEW</b> Resilient Forest Management <i>Philip J. Burton</i>	113



# Polycentric forest governance for social equity of Indigenous Peoples? A critical appraisal

D. ADHIKARI

*Crawford School of Public Policy, The Australian National University, JG Crawford Building, 132 Lennox Crossing, Canberra ACT 2600, Australia*

Email: dipika.adhikari@anu.edu.au

## HIGHLIGHTS

- Polycentric forest governance literature lacks empirical studies on social equity outcomes for Indigenous Peoples.
- Existing studies highlight issues of hierarchical institutional nestedness, lack of political decentralisation and social heterogeneity that stifle social equity for Indigenous peoples in polycentric forest governance.
- Polycentric systems studies miss theoretical depth and contextual nuances of socio-economic, cultural and political dynamics across scales and levels that underpin polycentric interactions (such as shared autonomy, coordination, conflict resolution) vis-à-vis social equity for Indigenous Peoples.
- Critical and in-depth research on polycentric forest governance aimed at advancing just and inclusive performance of polycentric institutions for social equity of Indigenous Peoples is warranted.
- This review offers a research agenda to strengthen the theoretical and empirical scope of polycentric governance by building stronger bridges with scholarship on environmental justice.

## SUMMARY

Polycentric governance systems are considered to have higher capacity to respond to emerging socio-ecological challenges. However, it remains unclear how these systems improve institutions' ability to solve problems of social inequity for Indigenous Peoples (IPs). This critical appraisal identifies and critically engages with existing research on polycentric forest governance to understand how polycentric institutional arrangements and governance mechanisms influence social equity for IPs, and how objectives related to IPs social equity are presented in empirical studies on polycentric forest governance. A systematic review of literature reveals that studies examining polycentric forest governance vis-à-vis IPs social equity are extremely rare. The literature also exhibits inconsistency in examining complex polycentric governance interactions – such as shared autonomy, coordination, conflict resolution mechanism – in relation to IPs social equity, including distributive benefits, participatory rights and tenurial or cultural recognition in forest. Existing empirical studies show that polycentric interactions can negatively affect IPs' social equity through hierarchical institutional nestedness, lack of political decentralisation, and entrenched social heterogeneity. However, rich empirical insights are missing that critically delve into these connections in-depth across diverse contexts in polycentric forest governance. This review offers a research agenda to strengthen the theoretical and empirical scope of polycentric governance scholarship, particularly by building stronger bridges with the scholarship on environmental justice.

Keywords: polycentric governance, Indigenous Peoples (IPs), social equity, environmental justice, forests

## INTRODUCTION

Polycentric governance systems are considered to have higher capacity to respond to emerging socio-ecological challenges, especially within increasingly interconnected and multi-level governance arrangements (Pahl-Wostl and Knieper 2014). Polycentric governance involves multiple institutions from interdependent domains – including governments, communities, civil society organisations, businesses and others – operating at different scales (ranging from local to global) and exercising varying degrees of autonomy in governance processes (Carlisle and Gruby 2019, Morrison *et al.* 2019, Ostrom *et al.* 1961). This notion of polycentric governance raises the question as to whether multiple independent

institutions or actors are able to cooperate to resolve complex socio-ecological problems. In normative sense, polycentric governance is advocated to have the potential to (1) mitigate the risk of institutional redundancy by allowing other institutions to take over regulatory measures when one fails to deliver the desired goal, thereby maintaining viability of the resource or outcomes, while (2) enhancing adaptive capacity (i.e., the ability to adapt or adopt effective governance practices through learning, experience and partnerships) and (3) institutional fit (ensuring that institutions have the capability to effectively address the desired goal) (Carlisle and Gruby 2019). Polycentric systems are also considered advantageous in promoting cooperation, collaboration, mutual adjustment, and conflict resolution for effective collective action to

deliver environmental or public good outcomes (Ostrom *et al.* 1961, Ostrom 2010).

However, it remains unclear how polycentric governance could improve actors' ability to solve problems of justice and liberty – one of the fundamental aspirations upon which polycentric governance was originally conceptualised (Aligica and Tarko 2012). An issue ever more important amid growing uncertainties and precarity in the world. Thus far, there is limited attention to address social equity issues in commons and the underlying context that shape process-related performance of polycentric governance for social equity outcomes (Baldwin *et al.* 2023, Jordan *et al.* 2015, Nagendra and Ostrom 2012, Thiel 2017). This concern is even more pronounced when considering how polycentric systems affect social equity for Indigenous peoples (hereinafter IPs social equity).

The debate on social inequities has remained central to critical forest commons<sup>1</sup> studies over the past three decades. An extensive body of critical literature addresses questions of social inequities and injustices, including critical decentralised forest governance, critical property, resource entitlement, political ecology and economy, feminist environmentalism, and decolonization (Agrawal 2001, 2005, Beck and Nesmith 2001, Bijoy 2021, Blaikie and Brookfield 1987, Jodha 1998, Ribot 1998, Robbins 2017, Sen and Pattanaik 2019, Sengupta 2021). Scholars argue that exclusionary approaches in the appropriation and provision of common-pool resources<sup>2</sup> disproportionately impact the livelihoods and traditional practices of marginalised social groups, especially Indigenous minorities (Beck and Nesmith 2001, Bose *et al.* 2012, Johnson 2001, Li 2007, Loughlin and Milne 2020). Social inequities – including unequal distribution of resources, its associated benefits, IPs exclusion from decision-making processes, disregard for free, prior and informed consent and non-recognition of customary rights, values and knowledge systems – further displace and push marginalised Indigenous groups into endless cycle of poverty, landlessness and poor well-being (Beck and Nesmith 2001, Bose 2012, Kashwan 2013, Loughlin and Milne 2020). Schlosberg's (2007) environmental justice framework offers a comprehensive set of principles of justice to mitigate such social inequities, encompassing distribution, procedural and recognition justice. Distributional justice focuses on equal distribution of resources and associated benefits, including rights over land and forest tenure. Procedural or participatory justice comprises active and engaged participation necessary for individuals to attain and transform distributional rights or governance functions. It includes effective free, prior and informed consent mechanisms, decision-making authority in and capacity building for forest governance processes. Lastly, recognition justice refers to rights that acknowledge individuals' or communities'

cultural significance of resources, their rights of self-determination and their practise of traditional knowledge systems, and skills in natural landscapes. Environmental justice principles offer a comprehensive framework to address social inequities in socio-ecological systems.

Even though IPs social equity is considered crucial for sustainable development and effective environmental outcomes (Dawson *et al.* 2021, Kaur *et al.* 2023, Parsons *et al.* 2022, Pedersen 2016, RRI 2020), accumulated knowledge remains limited regarding how complex interconnected independent governance systems interact through cooperation or conflict resolution mechanisms across decision-making arenas, especially for IPs social equity. Thus far, there is lack of critical in-depth understanding on whether and how polycentric forest governance systems work (or not) for IPs social equity – i.e., to ensure equitable distribution of resources, participation in decision-making, effective free, prior and informed consent mechanism, decision-making authority and capacity building and recognition of socio-cultural rights, self-determination, knowledge systems, and skills.

To address this gap, this review identifies and critically engages with existing research on polycentric forest governance to understand how polycentric institutional arrangements and governance mechanisms influence IPs social equity, and how objectives related to IPs social equity are presented in empirical studies on polycentric forest governance. While the purpose of the review is to synthesise current knowledge on how polycentric forest governance may (or may not) work for IPs social equity, it also draws insights from research on social equity outcomes in other resource systems, such as fisheries, marine and climate governance. Through a systematic appraisal of the literature, empirical studies were examined using Carlisle and Gruby's (2019) theoretical assertions on polycentric governance, with special emphasis on shared autonomy, coordination and conflict resolution mechanism. This critical appraisal highlights lack of depth and nuances in existing polycentric forest governance research in relation to IPs social equity. While polycentric governance systems offer promising alternatives to resolve multi-scalar collective action problems, there is a lack of critical, in-depth, empirical research that warrant such claims. This review stresses the need to rethink polycentric governance by placing autonomy at the centre of analysis, debate and discussion, as it is the only aspect that systematically distinguishes polycentric governance from other governance systems such as multi-level or collaborative governance. This rethinking will steer polycentric research toward analysing complexity in shared autonomy and interlinked cooperative and conflict resolution interactions in governance systems for efficient and equitable outcomes. This review offers a research agenda to strengthen the theoretical and empirical scope of polycentric governance

<sup>1</sup> Drawing from Andersson and Agrawal (2011), Chhatre and Agrawal (2008) and Kashwan and Lobo (2014), I use 'forest commons' and 'community forests' interchangeably since both terms coincide with each another in reference to community based forest governance systems.

<sup>2</sup> Common-pool resources or commons refer to a resource system such as forests, grazing land from which potential beneficiaries obtain benefits (Ostrom 1990). These systems develop set of agreed upon rules and arrangement that govern access to and the use of natural resources.

scholarship, especially with the goal of building stronger bridges with scholarship on environmental justice, moral economy, and critical property. It is important to note that this appraisal should not be regarded as a comprehensive review of polycentric governance and social equity, but rather as a focused critical examination of the influence of polycentric forest governance on IPs social equity.

The following section establishes the theoretical framework of polycentric governance and outlines its essential characteristics. The methodological approach that guides this critical literature appraisal is then presented, including sampling strategy, coding and analysis. Subsequently, findings are presented on the nature and depth of polycentric studies concerning IPs social equity and how (or whether) polycentric forest governance influences IPs social equity. These findings are then discussed with broader polycentric governance arguments and key knowledge gaps. Finally, future research directions and agenda are proposed in the conclusion.

#### POLYCENTRIC GOVERNANCE: CONCEPTUAL STRUCTURE, HISTORY AND FEATURES

Conceptually, polycentric governance refers to a complex arrangement of multiple, overlapping decision-making centres who may operate with some degree of autonomy and act in ways that take account of each other through processes of cooperation, competition, conflict and conflict resolution (Carlisle and Gruby 2019, Ostrom 1991). In simple terms, polycentricity refers to many centres that enjoy the freedom to make individual contributions to decision-making on determining and enforcing the rules of law for effective delivery of public goods and services. In this sense, polycentric institutions and actors “act on their own behalf, without centralised coordination” in a governance system (Carlisle and Gruby 2019:933).

Michael Polanyi first used the term, referring to it as “a social system of many decision centers having limited and autonomous prerogatives and operating under an overarching set of rules” (Aligica and Tarko 2012:237). Later, the contours of the concept were operationalised by Ostrom *et al.* (1961) in their empirical examination of metropolitan governance and public administration in Los Angeles, USA. In line with Polanyi, they observed multiplicity in political jurisdictions<sup>3</sup> that function in independence to one another and note:

“Polycentric” connotes many centers of decision-making which are formally independent of each other. Whether they actually function independently, or instead constitute an inter-dependent system of relations, is an empirical question in particular cases. To the extent that they take each other into account in competitive relationships, enter

into various contractual and cooperative undertakings or have recourse to central mechanisms to resolve conflicts, the various political jurisdictions in a metropolitan area may function in a coherent manner with consistent and predictable patterns of interacting behavior. To the extent that this is so, they may be said to function as a “system”. (Ostrom *et al.* 1961:831)

Building on this conceptualisation, Ostrom and colleagues, found through a series of studies on police services in the United States that “polycentric arrangements with small, medium, and large departmental systems generally outperformed cities that had only one or two large departments” (Aligica and Tarko 2012: 243 citing McGinnis 1999). The idea was simple: more independent governments at different levels produce superior public service outcomes than a few large units. This notion spoke directly to emerging debates on efficiency of monocentrism and polycentricism in political-administrative governance systems. Importantly, polycentric governance not only optimizes outcomes for public goods and services but also “seems to be a necessary condition for achieving ‘political objectives’ such as liberty and justice” (Aligica and Tarko 2012:245) as it provides “more opportunity for citizens and their officials to innovate and to intervene so as to correct maldistributions of authority and outcomes” (Aligica and Tarko 2012:246 quoting Ostrom 1998).

In later work, Ostrom (1991:225) defined polycentric governance in a more succinct and structured manner, arguing that “a polycentric political system would be composed of: (1) many autonomous units formally independent of one another, (2) choosing to act in ways that take account of others, (3) through processes of cooperation, competition, conflict, and conflict resolution.” These ideas were subsequently adopted in the domain of governance of commons or common-pool resources by Elinor Ostrom to challenge the popular Gargantua model or “centralised command and control approach” of governance of socio-ecological systems. Since then, polycentric governance has become a subject of significant interest in commons and natural resource management.

It is important to note that polycentricity is considered richer than federalism (or even legal pluralism or hybrid or collaborative governance), where governance units extend beyond formal political units of government and may include formal and informal institutions or actors (including private enterprise and NGOs with some degree of independence) across and within scales in the process of governance (Aligica and Tarko 2012, McGinnis and Ostrom 2011, Morrison *et al.* 2017, Stephan *et al.* 2019). Moreover, in polycentric institutional arrangement, decision-making centres emerge spontaneously rather than through structured design, for “optimal allocation of resources and distribution of products” as

<sup>3</sup> Here, the term ‘political jurisdiction’ is not used in the traditional sense referring only to the state (which many scholars used in context to polycentric governance as highlighted by Stephan *et al.* (2019:23); rather, it is used in a broader sense that includes the critical roles of private firms and non-profit organisations, NGOs and local groups in operating and producing public goods (that may be under regulations set by state agencies (Ostrom *et al.* 1961)).

opposed to centralised planning (Polanyi 1951:179). Polycentric governance systems in this way incorporate a wide range of overlapping institutions, including formal government agencies, civil society organisations, businesses, courts, community institutions and individuals which may overlap at multiple geographic levels (e.g., local, state and national) and also cut across jurisdictional units (such as various departments of a government) to enforce decisions (Carlisle and Gruby 2019). Within this setup, while formal rule-making authority often resides with state and local institutions, other actors such as civil society organisation play ‘critical supporting roles’ in enforcing rules and influencing policies decisions (McGinnis and Ostrom 2012:15). For instance, Gupta and Koontz (2019) found that non-government organisations in India played a pivotal role in directing local communities toward available resources, facilitating training and providing information on policy instruments made available by the government while also acting as mediators for technical and financial support (see, Meinzen-Dick *et al.* 2021). In this sense, polycentric configuration at multiple levels and scales<sup>4</sup> is considered significant for striking a balance between centralised (or top-down) governance and decentralised or bottom-up management of resources (Imperial 1999).

Institutional autonomy, where many autonomous units are formally independent of one another without centralised control, is considered one of the most important aspects of polycentric governance. While initially formal *de jure* autonomy was considered an important qualifier of polycentric governance (Ostrom *et al.* 1961), informal *de facto* independence in decision making proves equally significant (Marshall 2015, Ostrom 1990). For instance, in the case of Maine fishery, user groups known as “harbor gangs” exercised authority in making and enforcing unwritten rules and norms on fishing regulations in the region (Low *et al.* 2003:105). However, shared autonomy is not the most common phenomenon observed in the majority of empirical studies. For instance, Marshall (2015) and Mudliar (2020) noted that while central governments may formally recognise devolution of, or independence in, decision-making to local community institutions, they may nevertheless continue to hold substantial control over decision-making through limited subsidiarity, fiscal dependence and lack of financial incentives, thus limiting shared autonomy.

In theory, polycentric institutional configurations should provide actors “a wide array of possible coordination mechanisms to structure their interactions.” (Baldwin 2023:5). However, polycentric interactions – where decision-making centres choose to act in ways that take account of others through processes of cooperation, competition, conflict, and conflict resolution – constitute a self-organising exercise. As Lebel *et al.* (2006) argue, governance systems can persist and adapt or co-operate without centralised control or direction.

To establish cooperative linkages, polycentric actors must be willing to undertake voluntary joint action, mutually adjust and trust each other (Kellner *et al.* 2019). For instance, formal institutions that lack the capacity or resources to perform production functions for delivery of a good or services related to natural resources would often outsource such production functions to capable actors, such as research scientists, NGOs and local community, as a means to cooperate in policy implementation (Carlisle and Gruby 2019). Polycentricity in this sense “allows considerable mixing and matching of consumption, provision, and production units operating at different scales of aggregation,” which forms part of a deliberative process (McGinnis 1999:4).

Carlisle and Gruby (2019) argued that cooperation, competition and conflict resolution are inextricably interconnected. Blomquist and Schröder (2019:55), in agreement with Carlisle and Gruby, noted that actors may compete or conflict with each other “for power and influence, for more material matters such as revenue or territory or personnel, or even for constituents.” Such competition and disputes over distributional issues can undermine cooperation and lead to intense conflict among actors (Poteete and Ostrom 2004). If competing interests remain unresolved, they can stymie improvements in a governance system. Therefore, maintaining equilibrium among competing interests becomes critical to conflict resolution and the effective functioning of a polycentric governance system. To enable conflict resolution, actors must either see diminishing incentives to engage in conflictual behaviours or be “willing to compromise on an issue” (Heikkila 2019:134). However, establishing these mechanisms is heavily influenced by political-economic interests, available resources and the level of authority an institution has or can exercise over another (Dietz *et al.* 2003).

Based on the foundational conceptualisation by Ostrom *et al.* (1961), Carlisle and Gruby (2018) proposed a set of enabling conditions (i.e., contextual characteristics) and key attributes necessary to achieve desired governance outcomes for effective socio-ecological systems. They identified two key attributes of polycentric systems: (1) multiple, overlapping decision-making centres with some degree of autonomy; (2) choosing to act in ways that take account of others through processes of cooperation, competition, conflict and conflict resolution. Within these two attributes, they offered theoretical proposition about seven enabling conditions that include: (1) decision-making centres employ diverse institutions, (2) decision-making centres exist at different levels and across political jurisdictions, (3) the jurisdiction or scope of authority of decision-making centres is coterminous with the boundaries of the problem being addressed, (4) generally applicable rules and norms structure actions and behaviours within the system, (5) decision-making centres participate in cross-scale linkages or other mechanisms for deliberation and learning,

<sup>4</sup> Drawing from Gibson *et al.*'s (2000) definition, I use the terms ‘level’ and ‘scale’ distinctly. Gibson *et al.* (2000:218) define ‘scale’ as “the spatial temporal, quantitative or analytical dimensions used to measure and study any phenomenon”. In contrast, ‘level’ is defined as “units of analysis that are located at different positions on scale”. In this study, I use the term scale to refer to the jurisdictional dimension of institutions and level to denote the unit of analysis within each jurisdictional scale.

(6) mechanisms for accountability exist within the governance system, (7) a variety of formal and informal mechanisms for conflict resolution exist within the system. They theorized that the presence of these enabling conditions and attributes makes polycentric governance robust and functional for effective management of natural resources. For instance, they noted that institutional diversity, cross-scale linkages for deliberation and learning and conflict resolution mechanism enhance the adaptive capacity of a governance system to manage actual or anticipated social or ecological change. Such polycentric models are considered advantageous not only to enhance adaptive capacity of institutions, but also reduce institutional redundancy and produce institutions that are a good fit to address the sustainability problem in question.

However, these benefits are subject to the inherent complexity of polycentric governance systems, their context, and the way they have evolved or changed over time (Baldwin 2023). It is important to note that the theoretical models of polycentricity have not yet been tested widely and there are only a handful of empirical studies that comprehensively speak to its normative assertions. Nonetheless, scholars argue that even though there are multiple, semi-autonomous decision units situated across different scales and levels, this does not guarantee that these units would take one another in account through cooperation, competition or conflict resolution (Marshall 2015, Pahl-Wostl and Knieper 2014). Since diverse decision centers may have varied perspectives, values, resources, interests and goals, or have different rules and procedures through which they balance conflicting interests, polycentric governance may not perform as normatively desired (Baldwin 2023). Studies show that polycentric systems can weaken democratic accountability (de Wit and Mourato 2022, Lieberman 2011, Thiel and Moser 2018), or dilute the powers of locally accountable actors (Greer *et al.* 2018, Müller and Chaliganti 2016). Similarly, multiplicity and power imbalances in polycentric systems can easily crowd out marginalized social groups and their traditional institutions, as they often lack the resources and capacity to participate in the complex governance arrangements (Carlisle and Gruby 2018, Ebel 2020, Komakech and Zaag 2013). Drawing on the normative assertions and practise of polycentric governance, focusing on attributes of shared autonomy, cooperation and conflict resolution mechanism, this review critically examines empirical research on polycentric forest governance vis-à-vis IPs social equity. The next section presents methodological approach that guides the critical appraisal, including sampling strategy, coding and analysis.

## METHODOLOGY

A systematic review of literature on polycentric governance systems was carried out to identify nuances and knowledge gaps in existing empirical research on IPs social equity in forests. Below, the sampling strategy and analysis employed in the study are presented.

## Sampling strategy

A series of searches on online databases was conducted using: Science Direct and Scopus, Web of Science, JSTOR, and Wiley Online Library; and search engines: Google Scholar and Australian National University Library SuperSearch. The search terms were initially informed by a review of scholarly research papers, review articles, book chapters, and webinar/seminar proceedings. A more comprehensive set of results from peer-reviewed journal articles, books and book chapters was ensured by using both databases and search engines (Levitt 2018).

The search terms include: “polycentricity”, “polycentric governance”, “community-forestry”, “community forests”, “community-based forest governance”, “decentralisation”, “decentralization”, “decentralised governance”, “decentralized governance”, “forest commons”, “forest”, “forest governance”, “social equity”, “Indigenous peoples”, “First Nation peoples”, “Aboriginal” “Indigenous justice” and “Indigenous social equity”. The search strategy was developed through an initial review of literature and was refined iteratively. For instance, initial terms were focused on ‘polycentric governance’ and ‘community-based forest governance’, which were later expanded to include terms such as forests, forest commons, community forestry, community forests. These search terms were combined using the Boolean operator ‘OR’ and ‘AND’ between each term to refine searches and retrieve relevant literature. In databases, searches were restricted to titles, abstracts, and keywords; in search engines, the terms were searched across the full text.

A total of 138 articles were retrieved from all the databases and search engines, covering publications up to 2023. All records were imported into Mendeley and duplicates were removed using automated detection followed by manual verification. Duplicates were defined as records with identical author, title, and publication year, or matching DOI numbers. Thirty-seven duplicates were removed through this process.

These articles were screened in three phases. In the first phase of screening, the articles (n=101) were separated into: (a) theoretical or review articles (n=32) and (b) empirical research articles (n=69). Abstracts of empirical research articles were reviewed at this phase. Theoretical articles were read in full to understand intricate details of normative assertions of polycentric governance, as presented in the previous section. In second screening phase, empirical research articles were further divided into case studies on forest commons (n=27) and other resource commons such as marine, coastal and fisheries management (n=42). Each article was individually screened using Mendeley’s search function, with terms such as forest, forestland, land, tenure and REDD+ being applied. Full texts were then reviewed.

Lastly, in the third screening phase, empirical studies on forest commons were assessed more strictly, as many studies were found to have referenced polycentric governance only in passing – often as a potential governance solution or narrative – without providing substantive empirical evidence on its arrangements or functions. A similar pattern was observed in studies addressing IPs social equity. The following exclusion

criteria were used to screen the empirical studies: (a) articles without explicit focus on or discussion of polycentric governance interactions based on the theoretical framework, and (b) articles without explicit reference to or discussion of IPs social equity (presented in Table 1). The full text of the articles was reviewed. To ensure screening reliability, 10 randomly selected abstracts were re-reviewed after one week, which yielded 100% agreement with initial decisions. Systematic random sampling was used, with every second record being selected from an alphabetically arranged list of articles and these being reviewed using search terms such as polycentric, polycentric governance, Indigenous, Indigenous peoples, tribal, Aboriginal and First Nations.

Ultimately, only four empirical case studies that fully or partially draw attention to and highlight polycentric forest governance in relation to IPs social equity were identified. To minimize potential bias and enhance reliability, all screening and extraction decisions were documented in detail, specifying the rationale for each decision. A detailed record was also maintained, outlining the rationale for each inclusion and exclusion decision (supplemental data available upon request).

### Coding and analysis

The analysis of the final set of articles involved retrieving, synthesising, and coding information, according to the elements of polycentric governance framework (i.e., shared autonomy,

cooperation and conflict resolution mechanism) and their effects on IPs social equity (i.e., distribution of resources, participation and authority in decision-making and recognition of socio-cultural rights). A codebook was developed to track polycentric attributes and social equity features in the empirical articles. Each paper's research questions, objectives and findings were also summarised in Mendeley.

Given the limited literature addressing IPs social equity in polycentric forest governance, empirical studies were also examined broadly based on social equity outcomes in forest and in other polycentric resource governance systems. Relevant studies were identified from forest commons (n=23) and other commons articles (n=42). For forest commons studies, the decision rationale used in third screening phase was referred to in order to identify relevant studies examining IPs social equity. For other resource commons, searches were conducted within each article for terms such as Indigenous peoples, First Nations, Aboriginal, tribal, equity, social equity, participation, participatory, decision-making, rights to identify relevant studies. An open-ended coding process was used to summarise key arguments and findings.

It is important to note that this review does not claim to provide a comprehensive survey of polycentric governance systems, and no claim is made regarding the extent to which the selected studies represent the full range of polycentric experiences. Instead, this appraisal offers critical understanding on: first, the existing knowledge gaps in polycentric

TABLE 1 *Systematic literature review process*

Identification	Records identified	n
	Databases: Science Direct, Scopus, Web of Science, JSTOR, Wiley Online Library	
	Search terms: polycentricity, polycentric governance, community-forestry, community forests, community-based forest governance, decentralisation, decentralized governance, forest commons, forest, forest governance, social equity, Indigenous peoples, First Nation peoples, Aboriginal, Indigenous justice and Indigenous social equity	
	Records retrieved (up to 2023)	138
Screening	Duplicates removed	37
	Records after duplicates	101
	Abstracts screened and classified:	
	Theoretical/review articles	32
	Empirical research articles	69
Empirical article screening	Review of 69 empirical papers, classified as:	
	– Forest commons case studies	27
	– Other resource commons (marine, coastal, fisheries)	42
Eligibility	Full-text review of empirical forest commons studies	27
	Exclusion criteria:	
	1. No explicit reference to Indigenous social (in)equity outcomes (e.g., distributive inequalities, participation, cultural rights) 2. No explicit discussion on polycentric governance interactions in the context of community forest management	
	Empirical case studies highlighting polycentric forest governance and Indigenous social equity	4
Qualitative synthesis	Due to limited empirical studies, forest and other commons studies are also synthesised in the analysis	65

literature in relation to IPs social equity outcomes, and second, the nature, scope and nuances missing in the available literature on IPs social equity in polycentric forest governance. The findings of this qualitative analysis are presented in the following section.

## FINDINGS

### **Nature and depth of studies on polycentric forest governance for IPs social equity**

There are very few empirical studies ( $n=27$ ) that either mention or engage (partially or fully) with polycentric forest governance in relation to social equity outcomes. Among these studies, the majority ( $n=11$ ) focus on polycentric governance interactions without specific emphasis on IPs social equity. A few studies ( $n=5$ ) engage with IPs social equity issues in forest commons but do not explicitly address polycentricity in theory or practice. Many studies ( $n=7$ ) examine forest commons without engaging with either IPs social equity or polycentric governance features. Only a handful of studies ( $n=4$ ) examine how polycentric forest governance systems affect IPs social equity by considering distributive benefits, participatory rights, and cultural recognition. Most studies examine these interlinkages partially, with limited focus on the full range of IPs social equity elements or polycentric governance system aspects. There is inconsistency in the literature in examining complex polycentric governance interactions (such as shared autonomy, coordination, conflict resolution mechanism) in relation to IPs social equity dimensions of distributive benefits, participatory rights and cultural recognition in forest commons.

The majority of the studies highlight only specific configurations of polycentric governance or particular aspects of IPs social equity. Most studies consider polycentricity as institutional diversity and overlapping jurisdictions that coordinate with each other, a few examine governance interactions and interlinkages concerning shared autonomy and conflict resolution mechanisms. For instance, studies rarely engage explicitly with how polycentric actors share decision-making autonomy with IPs and their formal or informal institutions (with the exception of de Wit and Mourato 2022). Similarly, research seldom addresses what conflict resolution mechanism exist, how they operate, for whose benefit, and how they affect collective action within a particular institutional contexts (except in studies such as Bissonnette *et al.* 2018, Meinzen-Dick *et al.* 2021). These finding regarding inconsistencies in examining polycentric governance echo the observations of empirical research on polycentric environmental governance by Baldwin *et al.* (2023).

The depth and nuance of IPs social equity analysis also remain limited in the majority of these studies. Even when studies account for polycentric forest governance systems in their complex multi-level (vertical institutions) multi-actor (horizontal institutions) configurations and interactions, many do not move beyond a narrow framing of IPs social

equity focused on participation and usufruct forest rights (with few exceptions such as de Wit and Mourato 2022 and Meinzen-Dick *et al.* 2021). Most studies narrowly define IPs social equity in terms of (a) distributive benefits i.e., equitable access to and use of forests, and (b) participation in collective forms or councils, where IPs involvement often remains limited to voicing concerns. Only de Wit and Mourato (2022) highlight the issue and importance of Indigenous autonomy (independence in decision-making) in forest governance, moving beyond mere participation or involvement in collective forums.

Furthermore, recognition of IPs territorial, cultural and spiritual rights remain entirely unaddressed in these studies, with the exception of de Wit and Mourato (2022). Polycentric forest governance studies do not explicitly engage with IPs decision-making autonomy in forest governance, their conservation and management rights, or the recognition of their cultural and territorial rights and knowledge systems in forest systems. In the study by de Wit and Mourato (2022) for instance, IPs in the Amazon face serious concerns regarding their rights over ancestral care, spirituality, and recognition of cultural and territorial rights, concerns that remain unaddressed in the polycentric arrangement of forest governance.

Overall, existing empirical research offers a limited understanding and insights into polycentric governance features and IPs social equity aspects in forest commons. Studies from other resource systems present similar patterns, with only a small amount of empirical research highlighting how polycentric governance hinders or supports IPs equity issues in natural resource governance (including Aswani *et al.* 2017, Ebel 2020, Rodriguez-Ward *et al.* 2018).

### **What do we know about how polycentric forest governance influences IPs social equity?**

Most empirical studies examine polycentric governance features for resource efficiency with only passing reference to the issue or importance of social equity or Indigenous peoples (with the exception of de Wit and Mourato 2022). Given the limited focus of existing literature on polycentric forest governance vis-à-vis IPs social equity, providing a concrete response to whether or how polycentric forest governance affects IPs social equity remains challenging. Nonetheless, a common trend emerges from these studies suggesting powerful higher-level authorities generally exclude IPs and ignore, undermine or crowd-out their traditional institutions and authorities in decision-making processes within commons (Bissonnette *et al.* 2018, Bixler 2014, Carlisle and Gruby 2018, de Wit and Mourato 2022, Ebel 2020, Gallemore *et al.* 2015, García López and Antinori 2018, Komakech and Zaag 2013, Long *et al.* 2018, Lorenzini 2022, Sovacool *et al.* 2017). For instance, in de Wit and Mourato's (2022) study in Peru and Brazil, IPs traditional institutions and authorities faced systematic undermining, even though some of the Indigenous regional organisations participated in Indigenous Working Groups for REDD+ low carbon development strategy. Indigenous organisations were mainly involved as participants in

sporadic working group discussions for the carbon development strategy with little to no decision-shaping authority. This participatory arrangement neglected IPs autonomy in decision-making and their distinct perceptions of nature – rooted in spirituality, ancestral care and cultural values – by reducing forests to carbon storage and stock indicators, that many Indigenous organisations did not relate to.

The studies highlight three key critical issues within polycentric forest governance mechanisms that affect IPs social equity, including, hierarchical institutional nestedness, inadequate political decentralisation and social heterogeneity. These critical issues also emerge in broader empirical research on polycentric governance across diverse resource systems. Regarding hierarchical institutional nestedness, several studies found that institutions which nested hierarchically (i.e., institutions taking orders or directives from above) substantially undermine IPs decision-making and sovereignty in forest governance, even when the institutional structure is formally designed to function in a polycentric way. For instance, studies highlight that powerful state and even non-state actors (such as civil society organisation and local leaders) at regional and sub-national levels determine IPs engagement in local community institutions or participatory forums (Adhikari 2026, Bixler 2014, Marshall 2008, Meinzen-dick *et al.* 2021). In diverse geographical and resource contexts, participatory and collaborative decision-making involving IPs remains largely limited to consultations (on paper or in terms of raising concerns) and coordination (to implement activities) on pre-determined conservation goals and objectives set by the higher-level powerful institutions or is entirely absent (Adhikari 2026, Bissonnette *et al.* 2018, Bixler 2014, de Wit and Mourato 2022, Jedd and Bixler 2015, Kashwan 2013, Long *et al.* 2018, Rodriguez-Ward *et al.* 2018). Powerful higher-level state and non-state actors often maintain and reinforce the hierarchical institutional status quo in forest governance. In doing so, they systematically disable venues, opportunities, and mechanisms for addressing conflicting interests and/or establishing cooperative linkages with Indigenous groups, in order to advance their own political-economic interests and priorities (Adhikari 2026, Kashwan 2013).

A slew of studies highlight inadequate political decentralisation – i.e., the absence of meaningful devolution of power, authority and resources to communities or their institutions – to marginalised Indigenous groups in polycentric systems (Agrawal and Ribot 1999, Carlisle and Gruby 2018, Komakech and Zaag 2013, Lorenzini 2022). Even though formal rules recognise the importance of IPs and their institutions in forest governance, their cultural and appropriation rights, and their free, prior and informed consent in developmental and conservation activities, the groups are most often kept devoid of authority, resources and capacity (Bissonnette *et al.* 2018, García López and Antinori 2018, Marshall 2008). Because of the lack of devolved decision-making authority, fiscal resources, or empowerment to uptake their responsibilities in forest governance, what results is a ‘top-heavy form of polycentricity’ where decision-making is dominated by high-level institutions and Indigenous groups involvement remain limited to either voicing concerns in collective forums

or public consultation (Carlisle and Gruby 2018:233, Long *et al.* 2018, Marshall 2008). Studies in other resource commons similarly highlight how inadequate devolution of authority and resources to marginalised social groups systematically excludes them from active participation due to high transaction costs in cross-scale and cross-level collaboration and conflict resolution mechanisms (Heikkila 2019, Gallemore *et al.* 2015, Larson and Lewis-Mendoza 2012, Lubell *et al.* 2020).

Only a handful of empirical studies on polycentric forest governance emphasize social heterogeneity as a critical factor in constraining IPs social equity. Studies show that socio-economic heterogeneity results in marginalised Indigenous groups and their institutions being either captured and controlled by powerful local elites and non-Indigenous groups, or disregarded entirely in top-down governance processes, thereby eroding IPs agency in collective decision-making (see, Adhikari 2026, Kashwan 2016, Kashwan *et al.* 2021, Larson and Lewis-Mendoza 2012, Mudliar and Koontz 2018). Such heterogeneity hinders cooperation within social milieu and with other actors, who may distrust each other due to differences in preferences and interests (Aswani *et al.* 2017, Ebel 2020, Komakech and Zaag 2013, Mudliar and Koontz 2018, Rodriguez-Ward *et al.* 2018). Deeply rooted social hierarchies further alienate IPs from their territorial and spiritual rights (Adhikari 2026). While some studies show that clear policy design and implementation (Bissonnette *et al.* 2018) and involvement of supporting actors such as civil society organisation (Baland and Platteau 1997, Long *et al.* 2018, Meinzen-dick *et al.* 2021, Pedersen 2016, Tormos-Aponte and García-López 2018), may help balance micro-power asymmetries and overcome cooperation failure, these measures do not necessarily encourage genuine shared autonomy with IPs or establish collaborative decision-making with marginalised IPs (Adhikari 2026, Ebel 2020, Rodriguez-Ward *et al.* 2018). As a result, IPs territorial and spiritual rights remain sidelined within polycentric forest governance. Moreover, intra-community heterogeneity marginalises certain sections of IPs from others. For example, in Acre (Brazil), Indigenous communities themselves highlighted that small Indigenous groups were excluded from REDD+ Indigenous Working Groups, with participation dominated by Indigenous stakeholders based in capital cities. In this case, the social heterogeneity within Indigenous communities is perpetuated by a top-down governance model, which not only solidifies existing social dynamics but also limits establishment of collaborative linkages and conflict resolution mechanisms (Ebel 2020, Komakech and Zaag 2013).

## DISCUSSION

Polycentric governance systems are proposed to resolve collective action problem when multiple independent actors across scales and levels decide to cooperate and establish conflict resolution mechanisms. Even though diversity of actors is contended to make governance more challenging

for resolving collective action problems, what is missing in polycentric governance studies is examination of how independence or autonomy of decision-making centers are configured and operationalised in polycentric governance systems. This literature review suggests that polycentric studies lack depth in examining the range of polycentric governance features (such as shared autonomy and conflict resolution mechanism) and IPs social equity aspects (including IPs distributive benefits, participatory rights and cultural recognition) in forest governance. Moreover, only a handful of studies examine polycentric governance in relation to social equity for Indigenous peoples. Most of these studies highlight critical issues within polycentric forest governance mechanisms that stifle IPs social equity outcomes, including, hierarchical institutional nestedness, inadequate political decentralisation and entrenched social heterogeneity.

While these issues may not capture the full range of dynamics within polycentric interactions, they are commonly observed across broader critical polycentric governance studies. In most polycentric governance systems, institutions are hierarchically nested where higher-level institutions establish partnerships with local institutions or communities (and not vice-versa) to advance their own political-economic interests (Adger *et al.* 2005, Young 2006). Such collaborations frequently take the form of state-controlled community-based natural resource management, in which state-designed initiatives steer coordination with community actors rather than fostering genuine subsidiarity and voluntary cooperation among overlapping actors across scales, especially IPs (Marshall 2008, Morrison 2017, Mudliar 2020, Mudliar and O'Brien 2021). Studies suggest that nested bureaucratic procedures commonly prioritise goal achievement while avoiding exhaustive coordination procedures and public deliberations. As a result, dominant actors and institutions bypass democratic principles and processes in governing the commons, thereby hindering effective integration of IPs in forest governance (Black 2008, Huitema *et al.* 2009, Lane and Morrison 2006, Rodriguez-Ward *et al.* 2018, Skelcher 2005).

Instead of enhancing the adaptive capacity of decentralised institutions, dominant actors tend to resist sharing technocratic expertise and maintain institutional nestedness, without granting shared autonomy in implementation and decision-making processes (Koontz 2006, Mudliar and O'Brien 2021). Consequently, decision-making becomes ad hoc (Wyborn 2015) and formal processes become dominated by powerful interests (Adger *et al.* 2005, Koehler and Koontz 2008, Purdy 2012). These dynamics skew information and knowledge in favour of powerful formal actors, limiting exchange of information considered in collaborative efforts, especially for marginalised social groups (Koontz 2019). Such imbalances often lead to heightened conflictual behaviours and weakened (or absent) formal conflict resolution mechanisms (Heikkila 2019). Ultimately, asymmetries of authority, information and resources result in grave marginalisation of Indigenous communities, even within Indigenous groups (Carlisle and Gruby 2018, de Wit and Mourato 2022, Hamilton *et al.* 2018, Kashwan 2015). Moreover, top-down

enforcement contributes to maladaptive governance procedures that fail to produce effective ecological and social outcomes (Aswani 2017, Ebel 2020, Mudliar 2020, Mudliar 2023, Rodriguez-Ward *et al.* 2018).

Marshall (2008), among other critical polycentric scholars, strongly argues that appropriate subsidiarity and shared autonomy among overlapping state and non-state actors, combined with structural governance reforms, can challenge hierarchically nested enterprises that entrench the dominance of powerful agencies (Adger *et al.* 2005, Biddle and Baehler 2019, Carlisle and Gruby 2018, Gruby and Basurto 2014, Young 2006). Devolution of authority and resources to IPs and their institutions to manage access, use and control of commons is also considered crucial to ensure accountability and transparency in governance systems (Xu and Ribot 2004). It also builds social capital and facilitates bargaining and enforcement in situations of competing interests (Biddle and Baehler 2019, Garrick and Villamayor-Tomás 2019). For meaningful commons management, policies are thus required to “transcend the ‘bundle of rights’ framework to embrace a ‘bundle of powers’ approach, empowering Indigenous communities, democratic institutions as well as relevant cross-scale and cross-level state and non-state actors” (Adhikari 2026:19). To achieve this, formal recognition and political decentralisation (sharing of autonomy) of traditional informal IPs institutions is warranted (Lorenzini 2022), along with reforms that address institutional political economy within policy design and community-based governance practices. Furthermore, political decentralisation requires strong fiscal, technical and administrative support from cross-scale state and non-state actors that can establish cooperative linkages and provide robust conflict resolution mechanisms (Carlisle and Gruby 2018, Koontz *et al.* 2019, Lorenzini and von Jacobi 2024, von Benda-Beckmann 1981).

Moreover, cross-level and cross-scale institutional interactions among quasi-autonomous institutions may create new synergies and partnerships capable of challenging dominant vested interests or advancing new social claims (Ebel 2020, Pedersen 2016). Such interactions may compel powerful elites or local institutions to partially, if not entirely, alter their positions and interests and facilitate more equitable distribution of resources in the commons. However, social heterogeneity at the local level restricts creation of equitable venues and opportunities for IPs to control, use, access and manage resources (Aswani *et al.* 2017, Ebel 2020, Mudliar and Koontz 2018, Rodriguez-Ward *et al.* 2018). This occurs because collaborative processes in heterogenous social milieus are often shaped by evolving, unwritten norms, where underlying values of difference, competition, and domination take precedence, thereby crowding out marginalised IPs, their traditional institutions, rights, priorities, aspirations and knowledge (Ebel 2020, Skelcher 2005). Ultimately, while most governance systems may inherently exhibit polycentric institutions, their ability to foster inclusivity, accountability and transparency is subject to intricate socio-economic, political and historical contexts (Berardo and Lubell 2019, Pahl-Wostl and Knieper 2014).

In contrast to simplified narratives that ‘institutional nest-ness’ fosters coordination, and mitigates institutional redundancy, the effectiveness of nested institutions depends heavily on aligning or ‘commoning’ institutional interests beyond single-agency priorities, particularly to advance IPs social equity (Adhikari 2026, da Silveira and Richards 2013). The extent to which cross-scale state and non-state actors acknowledge, legitimize, and strengthen the capacity and autonomy of IPs and their institutions at the local level proves crucial for enabling appropriation (access and use) and provisioning (management) rights over community forests (Baldwin *et al.* 2018, Favero *et al.* 2016). To achieve this, policy measures at the international, national and subnational levels are required to encourage polycentric institutions to share objectives of acknowledgement, legitimization, and strengthening autonomy of IPs and their institutions at the local level. Besides, polycentric actors – including civil society organisations, non-profit institutions, research centres and philanthropic organisation, individuals – can contribute by bringing polycentric actors together to deliver effective ecological and socially equitable outcomes.

Even though existing polycentric literature reveals stark connections between inclusive polycentric governance and IPs social equity outcomes, significant research gaps remain in critically examining these connections in-depth across diverse contexts (Baldwin *et al.* 2023). It is critical to address the issue and importance of IPs social equity in polycentric forest governance. More empirical research is thus needed that analyses power differentials across and within institutions at micro, meso and macro levels, as well as interlinked political and judicial processes that ensure inclusive forest governance (Lubell *et al.* 2017, van der Plank *et al.* 2022, von Benda-Beckmann 1981). Setting a research agenda on polycentric forest governance for IPs social equity is crucial to understand what factors shape polycentric performance for or against IPs social equity. How does shared autonomy in polycentric governance operationalise, and how can we create and maintain local autonomous institutions, especially for traditional informal institutions and marginalised social groups in resource commons, for emerging socio-ecological challenges? What also proves important to examine is how to establish and maintain autonomy among diverse polycentric actors (with particular attention to Indigenous institutions) in order to unlock cooperation and conflict resolution mechanism in effective resource governance.

Importantly, a just polycentric governance framework needs strong grounding based on a comprehensive set of social and environmental justice principles, encompassing not only distributive justice (concerning forest resource rights) but also procedural justice (involving participation, effective free, prior and informed consent mechanism, decision-making authority and capacity building) and recognition justice (acknowledging cultural significance, self-determination, knowledge systems, and skills) (see, Fraser 1998, Nussbaum 2003, Nussbaum and Sen 1992, Schlosberg 2007, Sen 2005). When these justice principles are integrated within polycentric systems of governance from the bottom-up into national and sub-national policies, sustainable development goals and

climate change initiatives, they can meaningfully advance IPs social equity in commons. Such inquiry proves crucial to fully demystify the intricacies of IPs distributive, recognition and procedural rights that works for just and effective polycentric forest governance.

Current empirical research has rarely considered IPs formal or informal institutions when analysing polycentric linkages in forest commons. It is thus important to incorporate IPs traditional institutions at the habitation level – from the ‘bottom of the bottom-up’ – in future research (Adhikari 2026). Ultimately, the relaxed approach to polycentric governance frameworks in existing research underscores the need for a theoretically rigorous and empirically grounded examination of what happens when polycentric institutions (including traditional Indigenous organisations) share autonomy in decision-making processes in forest and other resource systems.

## CONCLUSION

The existing literature provides unclear answers to whether and how polycentric forest governance works for Indigenous peoples’ social equity. While polycentric governance systems offer promising alternatives to resolve collective action problems in forest commons, critical in-depth empirical research to warrant such claims remains lacking. Research particularly lacks examination of how contextual nuances of socio-economic and political dynamics at the micro, meso, and macro levels underpin polycentric interactions (such as shared autonomy, coordination, and conflict resolution) to influence IPs social equity in community forests. Research on polycentric forest governance has yet to undertake theoretically rigorous and empirically rich analyses of inclusive polycentric governance processes and social outcomes.

Ample critical research on polycentric governance exists across diverse environmental domains – such as river and lake commons (da Silveira and Richards 2013, Koontz *et al.* 2019), fisheries management (Mudliar 2020), marine and coastal governance (Adger *et al.* 2005, Gruby and Basurto 2014, Morrison 2017) and climate change mitigation (Jordan *et al.* 2015, Sovacool *et al.* 2017, Sunderlin *et al.* 2015) – that could serve as a valuable foundation for investigating critical polycentric forest governance. However, several factors necessitate forest-specific insights prior to drawing on experiences from other resource systems. These factors include differences in the materiality (form and nature) of a resource unit and system, its affordance (uses and values) (Li 2014, Ostrom 1990), local and extra-local drivers (such as market scale and importance), and the complex set of experiences and patterns shaping institutional interactions and outcomes) (Armitage 2008). This review therefore argues for more critical, in-depth research on polycentric forest governance aimed at advancing just and inclusive performances of polycentric institutions for IPs (see for instance, Lorenzini and von Jacobi 2024).

This review offers a research agenda to strengthen the theoretical and empirical scope of polycentric governance scholarship, especially with the goal of building stronger

bridges with scholarship on environmental justice, moral economy, and critical property. The normative assertions and enabling conditions that polycentric governance research brings to praxis need to address the pressing issue of IPs social equity in forests by examining how distributional equality, procedural inclusivity and recognition of rights, values and knowledge systems of Indigenous communities, manifest across scales (Schlosberg 2007). In doing so, it is crucial to centre our attention on IPs traditional institutions and their stewardship within polycentrically governed community forests. Future research could coherently examine the normative and ontological aspects of polycentric governance systems in forests to identify the factors that most critically influence IPs social equity and its broader implications.

#### ACKNOWLEDGEMENT

This research was funded by Australian National University Research Scholarship. The author is grateful to Professor Kuntala Lahiri-Dutt and Professor Peter Kanowski, who reviewed earlier drafts of the paper and provided valuable feedback. The author thanks the anonymous reviewers and the editor for their timely responses and constructive feedback.

#### DECLARATION OF INTEREST

The author reports no conflict of interest. The author is solely responsible for the content and writing of this article.

#### REFERENCES

- ADGER, W.N., BROWN, K., and TOMPKINS, E.L. 2005. The political economy of cross-scale networks in resource co-management. *Ecology and Society* **10**(2).
- ADHIKARI, D. 2026. Critical Polycentric Governance: Indigenous Peoples' Tenure Security in India's Forest. *Society and Natural Resources* **39**(1): 1–27.
- AGARWAL, B. 2001. Participatory exclusions, community forestry, and gender: An analysis for South Asia and a conceptual framework. *World Development* **29**(10): 1623–1648.
- AGRAWAL, A., and RIBOT, J. 1999. Accountability in Decentralization: A Framework with South Asian and West African Cases. *The Journal of Developing Areas* **33**(4): 473–502.
- AGRAWAL, A. 2005. *Environmentality: Technologies of Government and the Making of Subjects*. Duke University Press. 243 pp.
- ALIGICA, P.D., and TARKO, V. 2012. Polycentricity: From Polanyi to Ostrom, and Beyond. *Governance* **25**(2): 237–262.
- ANDERSSON, K., and AGRAWAL, A. 2011. Inequalities, institutions, and forest commons. *Global Environmental Change* **21**(3): 866–875.
- ARMITAGE, D. 2008. Governance and the commons in a multi-level world. *International Journal of the Commons* **2**(1): 7–32.
- ASWANI, S., ALBERT, S., and LOVE, M. 2017. One size does not fit all: Critical insights for effective community-based resource management in Melanesia. *Marine Policy* **81**: 381–391.
- BALAND, J.M., and PLATTEAU, J.P. 1997. Coordination problems in local-level resource management. *Journal of Development Economics* **53**: 197–210.
- BALDWIN, E., MCCORD, P., DELL'ANGELO, J., and EVANS, T. 2018. Collective action in a polycentric water governance system. *Environmental Policy and Governance* **28**(4): 212–222.
- BALDWIN, E., THIEL, A., MCGINNIS, M., and KELLNER, E. 2023. Empirical research on polycentric governance: Critical gaps and a framework for studying long-term change. *Policy Studies Journal* **52**(2): 319–348.
- BECK, T., and NESMITH, C. 2001. Building on poor people's capacities: The case of common property resources in India and West Africa. *World Development* **29**(1): 119–133.
- VON BENDA-BECKMANN, K. 1981. Forum shopping and shopping forums: Dispute processing in a minangkabau village in west sumatra. *Journal of Legal Pluralism and Unofficial Law* **13**(19): 117–159.
- BERARDO, R., and LUBELL, M. 2016. Understanding What Shapes a Polycentric Governance System. *Public Administration Review* **76**(5): 738–751.
- BERARDO, R., and LUBELL, M. 2019. The Ecology of Games as a Theory of Polycentricity: Recent Advances and Future Challenges. *Policy Studies Journal* **47**(1): 6–26.
- BIDDLE, J.C., and BAEHLER, K.J. 2019. Breaking bad: When does polycentricity lead to maladaptation rather than adaptation?. *Environmental Policy and Governance* **29**(5): 344–359.
- BIJOY, C.R. 2021. Democracy In The Forests: The Governance That Is To Be. *Law, Environment and Development Journal* **17**(1): 20–39.
- BISSONNETTE, J.F., BLOUIN, D., DUPRAS, J., CHION, C., and BOUTHILLIER, L. 2018. Comparing polycentric configuration for adaptive governance within community forests: Case studies in Eastern North America. *International Journal of the Commons* **12**(1): 352–377.
- BIXLER, R.P. 2014. From Community Forest Management to Polycentric Governance: Assessing Evidence from the Bottom Up. *Society and Natural Resources* **27**(2): 155–169.
- BLACK, J. 2008. Constructing and contesting legitimacy and accountability in polycentric regulatory regimes. *Regulation and Governance* **2**(2): 137–164.
- BLAIKIE, P., and BROOKFIELD, H. 1987. *Land Degradation and Society*. London. Routledge. 222 pp.
- BLOMQUIST, W.A., and SCHRÖDER, N.J.S. 2019. Seeing polycentrically: Examining governance situations using a polycentricity lens. Thiel, A., Blomquist, A., and Garrick D.E. (eds) *Governing Complexity: Analyzing and Applying Polycentricity*. Cambridge. Cambridge University Press. 296 pp.

- BOSE, P. 2012. *Forest Rights: The micro-politics of decentralisation and forest tenure reform in tribal India*. Thesis. Wageningen University.
- BOSE, PURABI., ARTS, B., and DIJK, H.V. 2012. "Forest governmentality": A genealogy of subject-making of forest-dependent 'scheduled tribes' in India. *Land Use Policy* **29**(3): 664–673.
- CALDERÓN-CONTRERAS, R., and WHITE, C.S. 2020. Access as the Means for Understanding Social-Ecological Resilience: Bridging Analytical Frameworks. *Society and Natural Resources* **33**(2): 205–223.
- CARLISLE, K., and GRUBY, R.L. 2019. Polycentric Systems of Governance: A Theoretical Model for the Commons. *Policy Studies Journal* **47**(4): 921–946.
- CARLISLE, K.M., and GRUBY, R.L. 2018. Why the Path to Polycentricity Matters: Evidence from Fisheries Governance in Palau. *Environmental Policy and Governance* **28**(4): 223–35.
- CHHATRE, A., and AGRAWAL, A. 2008. Forest commons and local enforcement. *Proceedings of the National Academy of Sciences of the United States of America* **105**(36): 13286–13291.
- DAWSON, N.M., COOLSAET, B., STERLING, E.J., LOVERIDGE, R., GROSS-CAMP, N.D., WONGBUSARAKUM, S., SANGHA, K.K., SCHERL, L.M., PHAN, H.P., ZAFRA-CALVO, N., LAVEY, W.G., BYAKAGABA, P., IDROBO, C.J., CHENET, A., BENNETT, N.J., MANSOURIAN, S., and ROSADOMAY, F.J. 2021. The role of indigenous peoples and local communities in effective and equitable conservation. *Ecology and Society* **26**(3).
- DE WIT, F., and MOURATO, J. 2022. Governing the diverse forest: Polycentric climate governance in the Amazon. *World Development* **157**: 105955.
- DIETZ, T., OSTROM, E., and STERN, P.C. 2003. The struggle to govern the commons. *Science* **302**(December): 1907–1912.
- EBEL, S.A. 2020. Moving beyond co-management: Opportunities and limitations for enabling transitions to polycentric governance in Chile's territorial user rights in fisheries policy. *International Journal of the Commons* **14**(1): 278–295.
- FAVERO, M., GATTO, P., DEUTSCH, N., and PETTENELLA, D. 2016. Conflict or synergy? Understanding interaction between municipalities and village commons (Regole) in polycentric governance of mountain areas in the Veneto region, Italy. *International Journal of the Commons* **10**(2): 821–853.
- FRASER, N. 1998. Social justice in the age of identity politics: redistribution, recognition, and participation. GB Peterson (eds) *The Tanner Lectures on Human Values*. Salt Lake City. University of Utah Press.
- GALLEMORE, C., DI GREGORIO, M., MOELIONO, M., BROCKHAUS, M., and PRASTI, H.R.D. 2015. Transaction costs, power, and multi-level forest governance in Indonesia. *Ecological Economics* **114**: 168–179.
- GARCÍA LÓPEZ, G., and CAMILLE, A. 2018. Between Grassroots Collective Action and State Mandates: The Hybridity of Multi-Level Forest Associations in Mexico. *Conservation and Society* **16**(2): 193–204.
- GARRICK, DE., and VILLAMAYOR-TOMÁS, S. 2019. Competition in polycentric governance systems. Thiel, A., Blomquist, A., and Garrick, D.E. (eds) *Governing Complexity: Analyzing and Applying Polycentricity* 152–172. Cambridge. Cambridge University Press.
- GREER, R.A., TIMA, M.T., and TYLER, A. 2018. Polycentric Governance and the Impact of Special Districts on Fiscal Common Pools. *International Journal of the Commons* **12**(2): 108–36.
- GRUBY, R.L., and BASURTO, X. 2014. Multi-level governance for large marine commons: Politics and polycentricity in Palau's protected area network. *Environmental Science and Policy* **36**: 48–60.
- GUPTA, D., and KOONTZ, T.M. 2019. Working together? Synergies in government and NGO roles for community forestry in the Indian Himalayas. *World Development* **114**: 326–340.
- HAMILTON, M., LUBELL, M., and NAMAGANDA, E. 2018. Cross-level linkages in an ecology of climate change adaptation policy games. *Ecology and Society* **23**(2).
- HEIKKILA, T. 2019. Conflict and conflict resolution in polycentric governance systems. Thiel, A., Blomquist, A., and Garrick, D.E. (eds) *Governing Complexity: Analyzing and Applying Polycentricity*. Cambridge. Cambridge University Press. 296 pp.
- HUITEMA, D., MOSTERT, E., EGAS, W., MOELLENKAMP, S., PAHL-WOSTL, C., and YALCIN, R. 2009. Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecology and Society* **14**(1).
- JEDD, T., and BIXLER, R.P. 2015. Accountability in Networked Governance: Learning from a case of landscape-scale forest conservation. *Environmental Policy and Governance* **25**: 172–187.
- JODHA, N.S. 1998. Poverty and Environmental Resource Degradation: An Alternative Explanation and Possible Solutions. *Economic and Political Weekly* **33**(36/37): 2384–2390.
- JOHNSON, CRAIG. 2001. Local democracy, democratic decentralisation and rural development: Theories, challenges and options for policy. *Development Policy Review* **19**(4): 521–532.
- JORDAN, A.J., HUITEMA, D., HILDÉN, M., VAN ASSELT, H., RAYNER, T.J., SCHOENEFELD, J.J., TOSUN, J., FORSTER, J., and BOASSON, E.L. 2015. Emergence of polycentric climate governance and its future prospects. *Nature Climate Change* **5**(11): 977–982.
- KASHWAN, P. 2013. The politics of rights-based approaches in conservation. *Land Use Policy* **31**: 613–626.
- 2015. Forest Policy, Institutions and REDD+ in India, Tanzania and Mexico. *Global Environmental Politics* **15**(3): 95–117.
- 2016. Power asymmetries and institutions: landscape conservation in central India. *Regional Environmental Change* **16**(1): 97–109.

- 2017. *Democracy in the Woods: Environmental Conservation and Social Justice in India, Tanzania, and Mexico*. New York: Oxford University Press.
- KASHWAN, P., and LOBO, V. 2014. Of Rights and Regeneration: The politics of governing forest and non-forest commons. Lele, S. and Menon, A. (eds) *Democratizing Forest Governance in India*. Oxford: Oxford Press. 432 pp.
- KASHWAN, P., MUDALIAR, P., FOSTER, S.R., and CLEMENT, F. 2021. Reimagining and governing the commons in an unequal world: A critical engagement. *Current Research in Environmental Sustainability* **3**: 100102.
- KAUR, K. P., CHANG, K., and ANDERSSON, K. 2023. Collective forest land rights facilitate cooperative behavior. *Conservation Letters* **16**(4): 1–8.
- KELLNER, E., OBERLACK, C., and GERBER, J.D. 2019. Polycentric governance compensates for incoherence of resource regimes: The case of water uses under climate change in Oberhasli, Switzerland. *Environmental Science and Policy* **100**(July): 126–135.
- KOEHLER, B., and KOONTZ, T. 2008. Citizen Participation in Collaborative Watershed Partnerships. *Environmental management* **41**: 143–154.
- KOMAKECH, H.C., and VAN DER ZAAG, P. 2013. Polycentrism and pitfalls: the formation of water users forums in the Kikuletwa catchment, Tanzania. *Water International* **38**(3): 231–249.
- KOONTZ, T.M. 2006. Collaboration for sustainability? A framework for analyzing government impacts in collaborative-environmental management. *Sustainability: Science, Practice and Policy* **2**(1): 15–24.
- 2019. Cooperation in polycentric governance systems. *Governing Complexity: Analyzing and Applying Polycentricity* (2019): 115–132.
- KOONTZ, T.M., HEIKKILA, T., GARRICK, DE., and VILLAMAYOR-TOMÁS, S. 2019. Assessing performance of polycentric governance system interactions. A Thiel, WA Blomquist, and DE Garrick (eds) *Governing Complexity: Analyzing and Applying Polycentricity*, Cambridge: Cambridge University Press.
- LANE, M.B., and MORRISON, T.H. 2006. Public interest or private agenda?: A meditation on the role of NGOs in environmental policy and management in Australia. *Journal of Rural Studies* **22**(2): 232–242.
- LARSON, A.M., and LEWIS-MENDOZA, J. 2012. Decentralisation and devolution in Nicaragua's North Atlantic Autonomous Region: natural resources and indigenous peoples' rights. *International Journal of the Commons* **6**(2): 179–199.
- LEBEL, L., ANDERIES, J.M., CAMPBELL, B., FOLKE, C., HATFIELD-DODDS, S., HUGHES, T.P., and WILSON, J. 2006. Governance and the Capacity to Manage Resilience in Regional Social-Ecological Systems. *Ecology and Society* **11**(1).
- LEVITT, H.M. 2018. How to conduct a qualitative meta-analysis: Tailoring methods to enhance methodological integrity. *Psychotherapy Research* **28**(3): 367–378.
- LI, T.M. 2007. *The will to improve: governmentality, development and the practice of politics*. Duke: Duke University Press.
- 2014. What is land? Assembling a resource for global investment. *Transactions of the Institute of British Geographers* **39**(4): 589–602.
- LIEBERMAN, E. 2011. The perils of polycentric governance of infectious disease in South Africa. *Social Science and Medicine* (1982) **73**: 676–684.
- LONG, H., LIU, J., TU, C., and FU, Y. 2018. From State-controlled to Polycentric Governance in Forest Landscape Restoration: The Case of the Ecological Forest Purchase Program in Yong'an Municipality of China. *Environmental Management* **62**(1): 58–69.
- LORENZINI, S. 2022. Rethinking Forests Governance as Global Commons: Devolution of Quasi-Property Rights to Indigenous Communities. *Bandung: Journal of the Global South* **9**(3): 357–382.
- LORENZINI, S., and VON JACOBI, N. 2024. Whose forest? A two-level collective action perspective on struggles to reach polycentric governance. *Forest Policy and Economics* **158**(November 2023): 103093.
- LOUGHLIN, N., and MILNE, S. 2020. After the Grab? Land Control and Regime Survival in Cambodia since 2012. *Journal of Contemporary Asia* 2336.
- LOW, B., OSTROM, E., CARL, S.A., and WILSON, J. 2003. Redundancy and Diversity: Do They Influence Optimal Management?. F Berkes, A Johan Colding, and C Folke (eds) *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge, UK: Cambridge University Press.
- LUBELL, M., MEWHIRTER, J.M., BERARDO, R., and SCHOLZ, J.T. 2017. Transaction Costs and the Perceived Effectiveness of Complex Institutional Systems. *Public Administration Review* **77**(5): 668–680.
- LUBELL, M., MEWHIRTER, J., and BERARDO, R. 2020. The Origins of Conflict in Polycentric Governance Systems. *Public Administration Review* **80**(2): 222–233. <https://doi.org/10.1111/puar.13159>
- MARSHALL, G.R. 2008. Nesting, subsidiarity, and community-based environmental governance beyond the local level. *International Journal of Commons* **2**(1): 75–97.
- 2015. Polycentricity and adaptive governance. *15th Biannual International Conference of the International Association for the Study of the Commons* (July): 1–19.
- MCGINNIS, M.D. 1999. *Polycentricity and Local Public Economies: Readings from the Workshop in Political Theory and Policy Analysis*. Ann Arbor: University of Michigan Press.
- MCGINNIS, M.D., and OSTROM, E. 2011. Reflections on Vincent Ostrom, Public Administration, and Polycentricity. *Public Administration Review* **72**(1): 15–25.
- MEINZEN-DICK, R., CHATURVEDI, R., KANDIKUPPA, S., RAO, K., RAO, J.P., BRUNS, B., and ELIDIDI, H. 2021. Securing the commons in India: Mapping polycentric governance. *International Journal of the Commons* **15**(1): 218–235.
- MEWHIRTER, J., COLEMAN, E.A., and BERARDO, R. 2019. Participation and Political Influence in Complex Governance Systems. *Policy Studies Journal* **47**(4): 996–1019.

- MORRISON, T.H. 2017. Evolving polycentric governance of the Great Barrier Reef. *Proceedings of the National Academy of Sciences of the United States of America* **114**(15): E3013–E3021.
- MORRISON, T.H., ADGER, W.N., BROWN, K., LEMOS, M.C., HUITEMA, D., and HUGHES, T.P. 2017. Mitigation and adaptation in polycentric systems: sources of power in the pursuit of collective goals. *Wiley Interdisciplinary Reviews: Climate Change* **8**(5): 1–16.
- MORRISON, T.H., ADGER, W.N., BROWN, K., LEMOS, M.C., HUITEMA, D., PHELPS, J., EVANS, L., COHEN, P., SONG, A.M., TURNER, R., QUINN, T., and HUGHES, T.P. 2019. The black box of power in polycentric environmental governance. *Global Environmental Change* **57**(June): 101934.
- MUDALIAR, P. 2023. What matters for coordination? Examining overlaps and interactions in Lake Victoria's polycentric fisheries in Tanzania. *Regional Environmental Change* **23**(4):1–11.
- MUDLIAR, P. 2020. Polycentric to monocentric governance: Power dynamics in Lake Victoria's fisheries. *Environmental Policy and Governance* **31**(4):302–315.
- MUDLIAR, P., and KOONTZ, T. 2018. The muting and unmuting of caste across inter-linked action arenas: Inequality and collective action in a community-based watershed group. *International Journal of the Commons* **12**(1): 225–248.
- MUDLIAR, P., and O'BRIEN, L. 2021. Crowding-out lower-level authorities: Interactions and transformations of higher and lower-level authorities in Kenya's polycentric fisheries. *Environmental Science and Policy* **118**(December 2020): 27–35.
- MÜLLER, U., and CHALIGANTI, R. 2016. Bargaining over Local Public Good Provision in Nested Social Dilemmas: A Comparative Study of Variation from South India. *India Review* **15**(3): 302–31.
- NAGENDRA, H., and OSTROM, E. 2012. Polycentric governance of multifunctional forested landscapes. *International Journal of the Commons* **6**(2):104–133.
- NUSSBAUM, M. 2003. Capabilities as fundamental entitlements: Sen and social justice. *Feminist Economics* **9**(2–3): 33–59.
- NUSSBAUM, M., and SEN, A. 1992. *The Quality of Life*. Oxford. Oxford University Press. 444 pp.
- OSTROM, E. 1990. *Governing the Commons*. doi:10.1017/cbo9780511807763.
- 1998. The Comparative Study of Public Economies. Presented upon acceptance of the Frank E. Seidman Distinguished Award in Political Economy. (P.K. Seidman Foundation, Memphis, TN).
- 2009. Social-Ecological Systems. *Science* **325**(5939): 419–422.
- 2010. Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change* **20**(4): 550–557.
- OSTROM, V., TIEBOUT, C.M. and WARREN, R. 1961. The organization of government in metropolitan areas: A theoretical inquiry. *The American Political Science Review* **55**(4): 831–842.
- PAHL-WOSTL, C., and KNIEPER, C. 2014. The capacity of water governance to deal with the climate change adaptation challenge: Using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. *Global Environmental Change* **29**: 139–154.
- PARSONS, M., FISHER, K., and CREASE, R.P. 2022. Environmental Justice and Indigenous Environmental Justice. (eds) Meg Parson, Karen Fisher and Roa Petra Crease. *Decolonising Blue Spaces in the Anthropocene: Freshwater management in Aotearoa New Zealand*. Palgrave Macmillan Cham. 39–73 pp.
- PEDERSEN, R.H. 2016. Access to land reconsidered: The land grab, polycentric governance and Tanzania's new wave land reform. *Geoforum* **72**: 104–113.
- VAN DER PLANK, S., COX, S.A., CUMBERBATCH, J., MAHON, R., THOMAS, B., TOMPKINS, E.L., and CORBETT, J. 2022. Polycentric Governance, Coordination and Capacity: The Case of Sargassum Influxes in the Caribbean. *Coastal Management* **50**(4): 285–305.
- POLANYI, M. 1951. *The Logic of Liberty*. Chicago. University of Chicago Press. 214 pp.
- POTEETE, A.R., and OSTROM, E. 2004. Heterogeneity, group size and collective action: The role of institutions in forest management. *Development and Change* **35**(3): 435–461.
- PURDY, J.M. 2012. A Framework for Assessing Power in Collaborative Governance Processes. *Public Administration Review* **72**(3): 409–417.
- RIBOT, J., and PELUSO, N.L. 2003. A Theory of Access. *Rural Sociology* **68**(2): 153–181.
- RIBOT, J.C. 1998. Theorizing access: Forest profits along Senegal's charcoal commodity chain. *Development and Change* **29**(2): 307–341.
- ROBBINS, P. 2017. Authority and environment: Institutional landscapes in Rajasthan, India. *Development: Critical Essays in Human Geography* **88**(3): 315–340.
- RODRIGUEZ-WARD, D., LARSON, A.M., and RUESTA, H.G. 2018. Top-down, Bottom-up and Sideways: The Multilayered Complexities of Multi-level Actors Shaping Forest Governance and REDD+ Arrangements in Madre de Dios, Peru. *Environmental Management* **62**(1): 98–116.
- RESOURCES AND RIGHTS INSTITUTE. 2020. Rights-based conservation: The path to preserving Earth's biological and cultural diversity? Resources and Rights Institute 1–43.
- SCHLAGER, E., and OSTROM, E. 1992. Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land Economics* **68**(3): 249–262.
- SCHLOSBERG, D. 2007. *Defining Environmental Justice: Theories, Movements and Nature*. Oxford, Oxford University Press. 212 pp.
- SEN, A. 2005. Human Rights and Capabilities. *Journal of Human Development and Capabilities* **6**(2): 151–166.
- SEN, A., and PATTANAIK, S. 2019. A paradox of the "community": contemporary processes of participatory forest conservation in the Sundarban Biosphere Reserve (SBR) region of West Bengal. *Environmental Sociology* **5**(1): 33–46.

- SENGUPTA, M. 2021. Conserving and commercialising forests: tribal women and subjectivity in Bagafa forest of Tripura (Northeast India). *Gender, Place and Culture* **28**(3): 420–441.
- DA SILVEIRA, A.R., and RICHARDS, K.S. 2013. The Link Between Polycentrism and Adaptive Capacity in River Basin Governance Systems: Insights from the River Rhine and the Zhujiang (Pearl River) Basin. *Annals of the Association of American Geographers* **103**(2): 319–329.
- SKELCHER, C. 2005. Jurisdictional integrity, polycentrism, and the design of democratic governance. *Governance* **18**(1): 89–110.
- SOVACOOOL, B.K., TAN-MULLINS, M., OCKWELL, D., and NEWELL, P. 2017. Political economy, poverty, and polycentrism in the Global Environment Facility's Least Developed Countries Fund (LDCF) for Climate Change Adaptation. *Third World Quarterly* **38**(6): 1249–1271.
- STEPHAN, M., MARSHALL, G., and MCGINNIS, M. 2019. An introduction to polycentricity and governance. *Governing Complexity: Analyzing and Applying Polycentricity* **1431487**: 21–44.
- SUNDERLIN, W.D., SILLS, E.O., DUCHELLE, A.E., EKAPUTRI, A.D., KWEKA, D., TONIOLO, M.A., BALL, S., DOGGART, N., PRATAMA, C.D., PADILLA, J.T., ENRIGHT, A., and OTSYINA, R.M. 2015. REDD+ at a Critical Juncture: Assessing the Limits of Polycentric Governance for Achieving Climate Change Mitigation. *International Forestry Review* **17**(4): 400–413.
- THIEL, A. 2017. The Scope of Polycentric Governance Analysis and Resulting Challenges. *Journal of Self-Governance and Management Economics* **5**(3): 52–82.
- THIEL, A., and MOSER, C. 2018. Toward comparative institutional analysis of polycentric social-ecological systems governance. *Environmental Policy and Governance* **28**: 269–283.
- TORMOS-APONTE, F., and GARCÍA-LÓPEZ, G.A. 2018. Polycentric struggles: The experience of the global climate justice movement. *Environmental Policy and Governance* **28**(4): 284–294.
- WYBORN, C. 2015. Co-productive governance: A relational framework for adaptive governance. *Global Environmental Change* **30**: 56–67.
- XU, J., and RIBOT, J.C. 2004. Decentralisation and accountability in forest management: A case from Yunnan, Southwest China. *European Journal of Development Research* **16**(1): 153–173.
- YOUNG, O. 2006. Vertical interplay among scale-dependent environmental and resource regimes. *Ecology and Society* **11**(1).

# The transformation of institutional capacity for social forestry policy in Java, Indonesia

M. ADIB<sup>a</sup>, M. SAUD<sup>b</sup>, R. RUSTINSYAH<sup>a</sup> and I. ABDULLAH<sup>c</sup>

<sup>a</sup>*Department of Anthropology, Faculty of Social and Political Sciences, Universitas Airlangga, Indonesia*

<sup>b</sup>*Department of Sociology, Faculty of Social and Political Sciences, Universitas Airlangga, Indonesia*

<sup>c</sup>*Department of Anthropology, Faculty of Humanities, Universitas Gadjah Mada, Indonesia*

Email: moh.adib@fisip.unair.ac.id, muhammad.saud@fisip.unair.ac.id, rustinsyah@fisip.unair.ac.id, irwan.fib@ugm.ac.id

---

## HIGHLIGHTS

- The 2014–2023 institutional transformation of social forestry (SF) in Java marked a strategic shift from state-centric control toward community-based management.
- Policy evolution progressed through three distinct stages: initiation (political vision), institutionalization (structural creation), and stabilization (legal consolidation).
- Intense public resistance and legal lawsuits during the stabilization stage revealed a critical gap between top-down regulations and grassroots expectations.
- While the transformation was systematically structured in official documents, it remains a ‘paper-based’ change that lacks robust implementation at the field level.
- The 2024 ministerial decoupling of forestry and environment served as a pivotal turning point to address previous bureaucratic stagnation and policy resistance.

## SUMMARY

This paper examined regulators’ institutional capacity in transforming Java’s forest management through social forestry (SF) policy. Motivated by massive public resistance and lawsuits against the 2022 Forest Area with Special Management (KHDPK) policy, this study employed thematic content analysis of official documents (2014–2023). The research identified three transformative stages: initiation (*Nawacita* vision), institutionalization (PSKL Directorate establishment), and stabilization (Job Creation Law and KHDPK). Findings revealed that despite systematic legal structuring, transformation remains trapped in a state-centric paradigm, prioritizing internal bureaucratic consolidation over substantive community-based management. Failure to adapt to stakeholder needs has triggered policy stagnation. The study acknowledges the 2024 ministerial restructuring as a critical turning point for future research to evaluate whether the new institutional dichotomy can overcome previous bureaucratic failures.

Keywords: institutional capacity, social forestry policy, forest management transformation, public resistance, Java

---

## INTRODUCTION

The institutional transformation of social forestry (SF) management in Indonesia, which was designed to move towards community-based management (2014–2023), has stagnated and sparked massive public controversy in Java (Adib *et al.* 2024a). This stagnation occurred because the reform efforts undertaken by the government through the merger of ministries into the Ministry of Environment and Forestry (2014) tended to focus on integration and internal bureaucratic restructuring, but failed to adapt effectively to the external environment and stakeholder demands in the field (Widiyanto *et al.* 2025, Purwanti *et al.* 2023). This is clear in the three stages of institutional change – initiation (the *Nawacita* idea), institutionalization (the formation of the Directorate General of PSKL), and stabilization (the issuance of laws 11/2020 and KHDPK) – which in practice only transferred control of

forest area management from one state-owned enterprise (Perum Perhutani) to another (KLHK). Ultimately, the stabilization policy through the Decree of the Minister of Environment and Forestry No. P. 287/2022 concerning Forest Areas with Special Management (KHDPK) in Java was strongly opposed by thousands of demonstrations, petitions of rejection, and lawsuits at the State Administrative Court (PTUN) (Adib *et al.* 2024a). Therefore, the Institutional Capacity Transformation that occurred during this period demonstrates that the paradigm shift from state-centric to community-centric has failed to be substantively realized and remains trapped within a centralized state control scheme.

The SF policy in Java has been in place since the Dutch colonial era (1873), and modern implementation only began in the 1970s (Pujo *et al.* 2018, Rahayu *et al.* 2024, Fisher *et al.* 2018). In that era, studies were generally conducted that focused on social aspects (Nurfatriani *et al.* 2023, Ramadhan

*et al.* 2025), economics (Rakatama and Pandit 2020, Piabuo *et al.* 2025, Hidayat, Bahruni, and Trison 2025), and ecology (Santika *et al.* 2019). However, research specifically addressing institutional aspects and institutional capacity building is rare, creating a crucial knowledge gap. This gap occurs because most studies tend to analyze SF from the perspective of impacts and outcomes at the site level (Supriyanto *et al.* 2024, Santika *et al.* 2019), while there is a lack of attention to policy mechanisms, the dynamics of regulatory structures, and the underlying transformational processes. Furthermore, regulators' failure to prepare adequate monitoring and evaluation mechanisms (Budi *et al.* 2021) often reflects a lack of interest in strengthening forest management capabilities, including critical dimensions such as human resource capacity (Lawasi 2024) and technology (Chandra *et al.* 2025). Therefore, research on institutional capacity transformation is crucial to providing a more comprehensive understanding of the successes and failures of SF programs within the broader context of public policy.

This study aimed to explain the institutional transformation of SF in Java (Adib and Rustinsyah 2025, Adib 2025). Although formulated systematically from 2014 to 2023 (Widiyanto *et al.* 2025), the process failed to shift the paradigm from state control to community-based management. This failure was evidenced by public resistance to the stabilization policy (KHDPK) (Adib *et al.* 2024a). The reasons for this failure were driven, among other things, by the Ministry of Environment and Forestry's (KLHK) regulator's focus on internal consolidation and institutional restructuring (through three stages: initiation, institutionalization, and stabilization). Internal consolidation was carried out while ignoring the need for adaptation to the external environment and stakeholder participation (Adib *et al.* 2024a). This is evident in the transformation process, which practically only transferred forest management authority from one state-owned enterprise (Perum Perhutani) to another state agency (KLHK), with a more centralized management system through the establishment of the Indicative Map and SF Area (PIAPS) since 2016 (Widiyanto *et al.* 2025, Rahayu *et al.* 2024). This study sought to uncover the roots of structural and institutional problems that cause programs intended for social justice and sustainability to end in controversy and innovation stagnation.

The institutional transformation of SF in Java (2014–2023) resulted only in the transfer of authority from one state agency to another (Perum Perhutani to the Ministry of Environment and Forestry), rather than a community-based paradigm shift (Widiyanto *et al.* 2025). This occurred because, in the process, the Ministry of Environment and Forestry, as the new regulator, focused too much on completing internal institutional integration, such as developing internal regulations and performance structures, thus neglecting communication (C. Nugroho *et al.* 2025) and adapting to the external environment and the needs of forestry stakeholders in Java. This shift in authority took place through three stages: initiation (the *Nawacita* initiative), institutionalization (the establishment of the Directorate General of PSKL and PIAPS), and stabilization (the ratification of the Job Creation Law No. 11/2020 and the Ministerial Decree No. 287/2022 concerning KHDPK)

(Adib *et al.* 2024a). Although this legal framework appears robust and systematic in the documents, the implementation of the KHDPK stabilization policy has sparked strong public opposition, including demonstrations, petitions, and lawsuits before the State Administrative Court. Thus, this institutional transformation of SF has become merely a centralized administrative change, confirming that the policy remains under a rigid state control system and fails to meet the expectations of local communities.

### Transformation of institutional capacity

The transformation of institutional capacity in managing forest areas in Java urgently needs to be discussed, not only within the island but also in the region of ASEAN countries (Wong *et al.* 2020). The institutional capacity transformation involves a series of steps taken to strengthen the capabilities of an organization into two major dimensions, i.e., strengthening human resource capacity and technological resources in the form of information technology infrastructure (Pujo *et al.* 2018).

The transformation of institutional capacity in forest area management in Java demonstrated that, the formulation of policy and regulatory evaluation through institutional analysis, community participation, analysis of inter-agency cooperation, and capacity development (Uda *et al.* 2020, Rahayu *et al.* 2024, Kailola *et al.* 2023) is essential for bridging the gap between national mandates and local implementation. Through the identification of implementation weaknesses and obstacles (Carson *et al.* 2018), this policy evaluation mechanism introduces more effective, inclusive, and sustainable regulations (Adib *et al.* 2024a, Adib *et al.* 2024b). By addressing these challenges, the framework ensures that future regulatory adjustments are grounded in empirical field realities rather than purely administrative ideals.

The institutional analysis describes the institutions' structure and dynamics, including roles, responsibilities, and interactions between relevant parties (stakeholders) in the policy-making environment (regulators), operators and forest care communities. Active participation by local forest communities in planning and decision-making processes is crucial for the successful implementation of forest policies and long-term sustainability. Moreover, analyzing cooperation among institutions by strengthening social networks focuses on preserving forests (Garrett *et al.* 2021). Therefore, transforming institutional capacity in the management of forest areas in Java holds great importance and requires the attention of academia and policymaking by improving the capacities of relevant institutions, involving local communities, and building strong collaboration towards sustainable forest management and more effective land conservation in Java.

### Social forestry: operationalization of agrarian reform policy

Social forestry (SF) is sustainable forest management carried out in state forest areas or privately operated forests by the engagement of local communities and the implementation of

customary laws as the main actors to improve welfare, environmental balance, and socio-cultural dynamics (Nancy Lee Peluso 1993, Zulkarnain 2021). This community-based sustainable forest management (Rakatama and Pandit 2020) continues the agrarian reform policy, which was established to restructure resource ownership, control and consumption (Zakaria et al. 2018). This management system is seen as progressive in the interest of the people associated with forest areas (Murti 2018, Peluso and Poffenberger 1989). SF policy continues to develop internationally with four formal objectives, namely institutional, social, environmental, and economic (Rakatama and Pandit 2020).

SF policy is a series of agrarian reform policies designed to ensure the legality of assets and land redistribution to the main actors participating in forest management within a legal structure (Supriyanto et al. 2021). The Ministry of Environment and Forestry Regulation No. 83/2016 establishes the legal framework for SF, setting a national target for SF areas at 12.7 million hectares (Pambudi 2020). Specifically in the region of Java, the functional area of the state-owned forestry sector, Perhutani, has been in place since the enactment of Regulation P. 39 of 2017, covering an area of approximately 1.1 million hectares (Pane et al. 2021). As soon as the regulation was published, there was a substantial public response which was not only controversial, narrating both pros and cons (Ramadhan and Amalia 2021, Pane, Yanis, and Susanto 2021), but also contradictory (Wibowo, Race, and Curtis 2013, Rakatama and Pandit 2020).

Alongside these regulatory changes, institutional reforms have been implemented to strengthen the governance of forest management in Java. Most of these studies on this issue have discussed social, economic, and ecological aspects (Siscawati 2013, Fisher et al. 2018, Rakatama and Pandit 2020, Fisher et al. 2018). It is still rare to find studies that discuss institutional aspects and capacity building on SF. This institutional aspect explains the pros and cons of structuring forest management in Java. Ultimately, this institutional gap highlights regulators' failure to fulfill their mandates, primarily due to the absence of robust monitoring and evaluation mechanisms (Sunarso 2022).

To date, monitoring and evaluation of social forestry have failed to focus on the strategic roles of regulators, particularly the Ministry, which appears less prioritized in institutional strengthening efforts (Pujo et al. 2018). This lack of focus is critical because effective forest management requires a balanced development of both human resource capacities and technological infrastructure to ensure policy targets are met. As such, strengthening the human resource capacity as part and section of institutional capacity transformation should involve three aspects: the transformation process, factors influencing transformation, and transformation models. The process of transformation of institutional capacity focuses on the establishment and formation of institutions, community empowerment (Jopang, Tunda, and Tarifu 2022, Tàbara et al. 2018), liaising partnerships, capacity building (Langseth et al. 2023), and the mechanism of monitoring and evaluation (Iriyani et al. 2020).

Valuable lessons can be learned from studying the experiences of other countries that have incorporated SF within their agrarian reform programs. For example, in Brazil and Denmark, SF was implemented as a direct continuation of agrarian reform policies to ensure social equity (Robles 2018, Boberg-Fazlić et al. 2022). Similarly, the Chinese government targeted landscape governance through systematic implementation (Zhang 2019), while Sweden's approach involved over two decades of institutional stabilization (Pemer and Skjølsvik 2018). Gaining insights from these diverse international experiences provides essential benchmarks for the execution and implementation of SF policy in Indonesia.

## METHODS

This study employed a qualitative approach with thematic content analysis to explore the transformation of institutional capacity within SF policies in Java from 2014 to 2023. The research focused on the paradigm shift in forest management – moving from a state-centric model toward community involvement – through three transformative phases: initiation, institutionalization, and stabilization. Primary data sources were gathered from official regulatory documents, government policy reports, and scientific publications relevant to the *Nawacita* vision and the implementation of Forest Area with Special Management (KHDPK). The data were analyzed using a systematic five-stage coding technique, progressing from initial identification to final verification, to translate regulatory texts into a concrete narrative of institutional change. The systematic research workflow, encompassing data input, the multi-stage analysis process, and the synthesis of findings, is illustrated in the following flowchart.

This study was qualitative research with a descriptive approach focusing on thematic content analysis to explore the transformation of institutional capacity within SF policies in Java. The scope of this research covered the period from 2014 to 2023, specifically examining the shift in forest management paradigm from a state-centric model toward community involvement through three transformative stages: initiation, institutionalization, and stabilization. The primary geographical focus was the working areas of Perum Perhutani across four provinces in Java (See Map), namely Central Java, East Java, West Java, and Banten.

As a content analysis study, the participants in this research did not refer to individuals as direct informants, but rather to policy and regulatory documents issued by regulatory institutions as the units of observation. The primary data sources were derived from official documents of the Ministry of Environment and Forestry (MoEF), government policy reports, and scientific publications related to the transformation of SF in Indonesia. The document selection criteria were based on online accessibility, relevance to the *Nawacita* vision, institutional strengthening (Directorate General of PSKL), and implementing regulations such as the Job Creation Law Number 11/2020 and the ministerial decree on KHDPK (SK 287/2022).

FIGURE 1 Flow Chart of the Research Method



The primary instrument in this study was the researcher as the key instrument, assisted by Mendeley reference management software to organize and classify the data. Additionally, data extraction tables were employed as instruments to filter essential information, such as keywords (*Nawacita*, conflict resolution, community welfare), strategic phrases (President's vision and mission, community participation), and abstract concepts (paradigm shifts, public resistance). These instruments ensured that all data were systematically documented in accordance with the institutional capacity transformation framework.

Data collection was conducted through digital documentation studies from July to September 2023 by accessing official government databases and scientific journal repositories. The collection process followed strict document filtration stages to ensure the relevance of the texts to the policy phases under study. The collected data included legal regulations, strategic plans (Renstra of the Directorate General of PSKL 2015–2019), Indicative Maps of SF Areas (PIAPS), and data related to public resistance, such as lawsuits in the Administrative Court (PTUN) that emerged during the policy stabilization stage.

Data analysis was conducted using thematic content analysis consisting of five systematic steps: comprehensive document collection, repetitive reading and initial coding, grouping codes into major themes, data extraction into tables, and final verification. The data were categorized into three main phases: initiation (*Nawacita* vision), institutionalization (establishment of the Directorate General of PSKL), and stabilization (formalization through the Job Creation Law and KHDPK policy). Specifically, during the stabilization stage, the analysis was expanded to include data on public resistance, such as documentation of demonstrations, rejection petitions, and legal lawsuits in the Administrative Court (PTUN). The inclusion of resistance data is crucial to verify whether the institutional capacity transformation, which appears administratively robust in policy documents, aligns with field-level acceptance. This analytical flow aimed to reveal the contradictions between regulatory progress and substantive implementation barriers that trigger obstacles in policy stabilization.

## RESULTS

The transformation of forest area management in Java from state-based to community-based has been implemented through the SF program in three stages: initiation, institutionalization, and stabilization. These stages were implemented through the structuring and implementation of statutory regulations. Moreover, the Ministry of Environment and Forestry (KLHK), Indonesia, offers to enforce rules in the SF policy.

### The initiation stage (2014–2015): *Nawacita* and the vision for social forestry

The initial stage of SF was proposed by President Joko Widodo when he was running for the presidential candidacy in 2014. This agenda of change was portrayed in the vision, mission, and campaign platform known as *Nawacita* Jokowi (Vision and mission). The vision and mission of Jokowi were intended to allow the people to achieve a politically sovereign, economically independent, and culturally diverse Indonesia. As such, *Nawacita* has a vision of organizing change into nine agendas (Table 1). Among three of the nine agendas, the first, sixth, and seventh were focused on or related to forest management. The first agenda was designed to strengthen the state system with reforms and law enforcement that could be dignified, trustworthy and free from corruption. The sixth agenda aimed to increase people's capabilities and skills to meet international standards. The seventh agenda was focused on economic independence by targeting strategic sectors of the domestic economy (Widodo and Kalla 2014, Ditjen PSKL KLHK RI 2016). The initiation stage of this institutional arrangement was also carried out by merging two ministries (Tables 1 and 2) by the President of the Republic of Indonesia (KLHK) (Table 1). Thus, the Ministry of Environment and Forestry prepared a strategic plan for 2015–2019 in this regard (Table 1).

TABLE 1 *Social Forestry Program through Vision and Mission (Nawacita) in 2014*

No.	Initiation of the Formation of Social Forestry Institutions	Basic Regulations / Legislation / Ideas	Source
1.	<i>Nawacita</i> is a policy of the Joko Widodo and Jusuf Kalla administration to realize community welfare starting from the outskirts. The main objective of the <i>Nawacita</i> program is to improve the lives and welfare of the community, quality of life of the Indonesian people through Agrarian Reforms. The target of agrarian reform is abandoned Land Use Rights (LUR) and barren lands to be redistributed to farm workers, while also providing legalization for state lands	Joko Widodo's speech in the Presidential Campaign in the 2014 Indonesian Presidential Election	(Widodo and Kalla. 2014, Widodo <i>et al.</i> 2018)
2.	Article 4 (ii). The Directorate General of Social Forestry and Environmental Partnerships; ... (Article 30), ... The Directorate General of Social Forestry and Environmental Partnerships has the task of formulating and implementing policies in increasing community participation in forest management, handling customary forests, and environmental partnerships.	Presidential Regulation (PERPRES) No. 16 of 2015 concerning the Ministry of Environment and Forestry (Article 4 (i) and Article 30)	(Presiden RI. 2015, Presiden RI. 2020)
3.	Regulation of the Ministry of Environment and Forestry, Indonesia Number P.39/Menlhk-Setjen/2015 concerning the Strategic Plan for 2015–2019.	Strategic Plan of the Ministry of Environment and Forestry for 2015–2019	(Menteri LHK. 2015, Menteri LHK. 2020)

### The institutionalization stage (2015–2019): structural integration within the MOEF

The President and the Minister of Environment and Forestry planned the institutional transformation in SF. The President established SF institutions by merging two ministries into one, the Ministry of Environment and Forestry (KLHK). In KLHK, article 4 (i), the Directorate General of SF and Environmental Management (Ditjen PSKL) was established (Table 2). In establishing the PSKL institution, the Ministry of Environment and Forestry focused on three steps for completing the institutional structure of the PSKL Directorate General including the scope of roles, responsibilities and functions for 2013–2017 (Table 2), preparation of the Strategic Plan (*Renstra*) of the Directorate General of PSKL, Ministry of Environment and Forestry for 2015–2019 (Table 2), and to determine a map of the area of forest areas in Java in an indicative SF map (PIAPS). Thus, during these changes, PIAPS underwent its 7th revision in 2016 (Table 2), indicating SF in a yielded area in 2017.

Forestry operations in Java cover forest areas of four provinces, including Central Java, East Java, West Java, and Banten (Table 2). This policy, implemented by the President and the Minister of Environment and Forestry, has become the legal basis for determining the SF policy in the work of *Perum Perhutani* in four provinces in Java. However, among these four provinces, only Yogyakarta (a special region) is not managed by the *Perum Perhutani*.

### The stabilization stage (since 2020): the Job Creation Law and KHDPK implementation

The stabilization of SF policy implemented by the President emphasized legal certainty by enacting Law number 11/2020, Government Regulation (PP) 23/2021 (see Table 3). According

to policy 11/2020 articles No. 29A and 29B, the SF program focuses on the sustainability and protection of forest areas. A giant forest area was given to individual farmers, forest farmer groups, and companies pursuing business permits. In policy document 23 of 21, article 108 para (1) and para (2), the implementation of forestry for various purposes is defined as a forest area with special management determined by the Ministry of Environment and Forestry.

The respective Ministry, based on these two legal frameworks, then issued a Decree (Kepmen LHK) SK.8878/2021 concerning Indicative Maps and SF Areas (PIAPS) revision VII (see Table 3). After a year, SK 9978/2021 was followed by with Decree Number 287/2022 concerning Forest Areas with Special Management (KHDPK) in Java covering Central Java Province, East Java Province, West Java Province, and Banten Province. Since 2020, the SF program was started through the stipulation of legislation, implementing regulations by the President, and two technical rules by the Ministry of Environment and Forestry, as a basis for structuring the forest area management in Java, except Yogyakarta.

## DISCUSSION

The three stages of institutional transformation have established their legal frameworks through the legislation and regulations implemented in Java. However, the Ministry further stipulates policies and rules for implementation at the stabilization stage. The special implementing regulations on the island of Java issued a decree of the Minister of Environment and Forestry number 287 related to Forest Areas with Special Management (KHDPK). However, the public resisted the decree P. 287 circulated by the concerned Ministry of Indonesia.

TABLE 2 Institutionalization of Social Forestry from 2015–2017

No.	Establishment of Social Forestry Institutions	Basic Regulations/Legislation	Sources
1.	Presidential Decree Number 16 of 2015 concerning the Ministry of Environment and Forestry's duties (Article 2) status revoked and replaced with Presidential Decree 92/2020 regarding the Ministry of Environment and Forestry, CHAPTER II ORGANIZATION, Part One Organizational Structure "...Article 6 (i) Directorate General of Social Forestry and Environmental Partnership."	Presidential Decree Number 16 of 2015 concerning the Ministry of Environment and Forestry's duties (Article 2) status revoked and replaced with Presidential Decree 92/2020 regarding the Ministry of Environment and Forestry, CHAPTER II ORGANIZATION, Part One Organizational Structure	(Presiden RI. 2015) is revoked and replaced with (Presiden RI. 2020a)
2.	"..... after the merger of the organization and work procedures of the directorates by the Regulation of the Minister of Environment and Forestry Number P.18/MenLHK-II/2015 concerning the Organization and Work Procedures of the Ministry of Environment and Forestry. According to Article 1005, the Directorate General of Social Forestry and Environmental Partnerships has the task of formulating and implementing policies in the field of increasing community participation in forest management, handling customary forests, and environmental partnerships." "..... to carry out its duties and functions, as regulated in Article 1007, its organizational structure consists of; (1) Secretariat of the Directorate General; (2) Directorate of Preparation of Social Forestry Areas; (3) Directorate of Handling Conflict, Tenure, and Customary Law; (4) Directorate of Social Forestry and Customary Forest Business Development; and (5) Directorate of Environmental Partnerships."	Establishment of the Directorate of Social Forestry and Environmental Management, Organizational Structure and Scope at the Directorate General of PSKL 2013–2017	(Sambodo 2015, Ditjen PSKL KLHK. 2015:4)
3.	"Ministry of Environment and Forestry Directorate General of Social Forestry and Environmental Partnership. Regulation of the Director General of Social Forestry and Environmental Partnership Number: P. 11/Pskl – Setdit/2015 Concerning the Strategic Plan of the Directorate General of Social Forestry and Environmental Partnership for 2015–2019"	Rencana Strategis Ditjen PSKL Kementerian LHK (2015–2019). Strategic Plan of the Directorate General of PSKL, Ministry of Environment and Forestry (2015–2019)	(Ditjen PSKL KLHK. 2015)
4.	Regulation of the Minister of Environment and Forestry of the Republic of Indonesia "Number P.83/MENLHK/SETJEN/KUM.1/10/2016 Concerning Social Forestry" "Number 39 of 2017 concerning Social Forestry in the Working Area of Perum Perhutani"	Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.83/MENLHK/SETJEN/KUM.1/10/2016 Concerning Social Forestry. Number P.39/MENLHK/SETJEN/KUM.1/6/2017 concerning Social Forestry in Perhutani Working Areas.	(Men LHK. 2016, Men LHK. 2017)

The vision and mission (*Nawacita*) is the idea of Presidential Candidate (*Capres*) Joko Widodo (Table 1), which was put forward at the launch of the campaign to run for the presidential nomination in 2014 (Hastangka 2020), not only as a mandate that covers direction and strategy in the forestry sector (Hastangka 2020, Zulkarnain 2021, Utomo 2021), but also as a translation of agrarian reform and Indonesia's development strategy from the periphery, starting from the grassroots level (Pambudi 2020, Supriyanto *et al.* 2021, Zulkarnain 2021). These Agrarian Reforms were then designated as a national priority to improve community welfare (Waryanta 2016, Aldillah 2020). As such, agrarian reforms

are the basis for initiating the SF program as an embodiment of *Nawacita* and for identifying other potential forest areas. These areas were considered barren land, therefore, the government declared these areas through Presidential Regulation (Perpres) Number 86/2018 as land for agrarian reform (TORA).

The Minister of Environment and Forestry identified and highlighted the TORA program in the form of land redistribution (Wicaksono *et al.* 2019). Moreover, the TORA is an implementation of *Nawacita* focusing on nine million hectares of forest area (Aldillah 2020), to utilize the areas that were no longer productive in improving welfare and creating social

TABLE 3 *Stabilization of Social Forestry Programs through Legislation 2020–2022*

No.	Stabilization of Social Forestry Programs	Basic Regulations / Legislation / Implementation Provisions	Source
1.	<p>“Article 29A. (1) Utilization of protected forests and production forests, as referred to in Article 26 and Article 28, may be carried out for social forestry activities. (2) Social forestry, as referred to in paragraph (1), may be given to: a. individuals; b. forest farmer groups; and c. cooperatives.”</p> <p>“Article 29B. Further provisions regarding business licensing for forest utilization and social forestry activities are regulated by government regulation.”</p>	Law Number 11 of 2020 concerning Job Creation Articles 29A and 29B	(Presiden RI. 2020b)
2.	<p>Article 108 paragraphs (1) and (2);</p> <p>“Part Three Forest Areas with Specific Purposes. Paragraph 1 (General).</p> <p>Article 108. (1) For specific purposes, Forest Areas may be designated as: a. Forest Areas with specific purposes; b. Forest Areas with special management; or c. Forest Areas for food security. (2) The Minister shall make the determination as referred to in paragraph (1).”</p> <p>Article 125 paragraphs (1), (7),</p> <p>“(1) The Central Government may delegate the implementation of Forest management to state-owned enterprises in the Forestry sector.”</p> <p>“(7) For Protected Forest Areas and Production Forest Areas that are not delegated the implementation of Forestry as referred to in paragraph (2), their management shall be delegated to state-owned enterprises in the field of being designated as Forest Areas with Forest Area management in the context of the Establishment of Special Areas for the interests of Social Forestry, Forest Arrangement and Forest Area Arrangement in the context of Utilization of Forest Areas, Use of Forest Areas, Forest Rehabilitation or Utilization of Environmental Services which are the authority of the Central Government.”</p>	Government Regulation no. 23 of 2021 concerning Forestry Implementation Article 108 paragraphs (1) and (2); Article 125 paragraphs (1), (7)	(Presiden RI. 2021)
3.	<p>“Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. SK.8878/MENLHK-PKTL/REN/PLA.0/12/21 Concerning Indicative Maps and Social Forestry Areas Revision VII”</p>	Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. SK.8878/MENLHK-PKTL/REN/PLA.0/12/21 Concerning Indicative Maps and Social Forestry Areas Revision VII	(Men LHK. 2021, Men LHK. 2021)
4.	<p>“Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. SK.287/MENLHK/SETJEN/PLA.2/4/2022 concerning Determination of Forest Areas with Special Management in Parts of State Forests in Production Forest and Protected Forest Areas in Central Java Province, East Java Province, West Java Province, Banten Province.”</p>	Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. SK.287/MENLHK/SETJEN/PLA.2/4/2022 concerning Determination of Forest Areas with Special Management in Parts of State Forests in Production Forest and Protected Forest Areas in Central Java Province, East Java Province, West Java Province, Banten Province.	(Men LHK. 2022)

and economic justice for the community (Nugroho *et al.* 2021). The goal of agrarian reform from an institutional perspective has also faced criticism (Aldillah 2020) due to its top-down approach and lack of clarity in its implementation. Moreover, the TORA locations determined by the Ministry

were not only the targeted forest areas but also many agrarian conflicts and even conflicting community claims over forest areas. The criticism of TORA policy as a basic framework for institutional structuring of the SF program emphasizes the need for revisions.

The implementation of agrarian reform in Java differs significantly from the experiences reported in the literature concerning Brazil and Denmark. Agrarian reform in Brazil, driven by farmers for more than three decades since 1985, has had only a limited impact on changing the situation (Robles 2018). In this movement, Agrarian reform was still treated as a political promise by the elite, but the political elite could not shift the dominance of agribusiness. The democratic government in Brazil has encouraged the opening of new land frontiers by providing significant economic incentives (Hershaw and Sauer 2023). The land redistribution has been balanced by further land ownership. In response to this policy, investors weakened agrarian reforms efforts and opened up a dependency on the agricultural economy, which is sensitive in a social and environmental context. In these circumstances, the political and economic crises that occurred in Brazil have increasingly eroded the struggle for agrarian reforms. In Denmark, it was designed and portrayed as a pro-market and pro-farmer policy in the 18th century, which increased inequality (Boberg-Fazlić *et al.* 2022). The gap in land ownership is based on land type, which has increased in areas classified as productive. As a result, many regions have disproportionately received surpluses, whereas, in other places, poor people are emulated to rural areas. Although in a different period, agrarian reforms experienced in these two countries compared to Indonesia, even though it started with an initiation action in 2014, has shown a step forward with the designation of land as an objective of agrarian reform (TORA).

The institutionalization of SF in continuation to the initiation stage was executed with the establishment of the Directorate General of SF and Environmental Management (Ditjen PSKL). This PSKL represents an increase in responsibility status to echelon I level (Directorate General), which was previously under a work unit equivalent to echelon II. This increase in institutional status requires the Ministry of Environment and Forestry to abide by internal improvements and regulate the policies that support the directions given by the President (Pambudi 2020). The formation of the Directorate General of PSKL is a response to the implementation of agrarian reform, which has faced various challenges. The challenges in institutional improvements include consolidating strong regulations, licensing updates, human resource qualifications, budget allocations, updating coordination, policies, and joint ownership with the local governments (Ayuningutami and Najicha 2022). The institutional improvements and internal consolidation are also intended to achieve the target of 20% (approximately 4.2 million hectares) of the 12.7 million hectare area from 2015 to 2019 (Fisher *et al.* 2018, Pambudi 2020, Pane *et al.* 2021). Launching the SF permit involves several steps, including the regional government and community-based organization (CSOs). The limited internal capacity also triggers conflict. The conflict occurs when the community feels the SF policy does not align with the existing guidelines. And there is no legal certainty in managing forest areas around their settlements (Pane *et al.* 2021). Thus, more substantial legal certainty in the form of a law is needed to stabilize the SF program.

Furthermore, the Chinese government has also launched an institutional improvement program in line with efforts to achieve environmental development targets through landscape management policies and landscape governance systematically by linking six inseparable elements (Zhang 2019). These six elements include improving conflict resolution, which has implications for social and ecological environmental problems, increasing the capacity of state administrators in landscape management, developing new land use management systems with good ecological security and broader ecosystem services, providing more significant public benefit to the landscape, developing civil society and democracy, and structuring the landscape architecture education and research curriculum. These elements of governance change the conventional paradigm of landscape as an 'ecological environment' into an institutional system of 'ecological civilization.' Thus, strengthening the institutions of ecological civilization has also been directed at various dimensions of education and research in landscape architecture. Further, institutional analysis is also introduced in courses such as the sociology of landscape in educational institutions. The discussion in these courses focuses on the influence of social institutions, laws and regulations, policies related to the landscape, and the applicability of rules and regulations. The institutional improvements are also based on the experiences of China, which have been launched systemically, including structuring the curriculum in formal activities such as through education and research.

The establishment of a legal framework through legislation, even though it has a strong position as institutional stabilization of the SF program, is seen as a tenure that guarantees certainty and boom in businesses of forest areas. The institutional stabilization to improve more technical forest management mechanisms can be done by strengthening managerial skills to reduce disparities by encouraging community forest management (Rakatama and Pandit 2020, Wollenberg *et al.* 2007). Besides, this strong structure of legal certainty has become an important legal milestone for the stakeholders so that they may not be evicted from the designated areas when implementing the SF program (Syanurisma 2022). However, efforts to overcome the gap between expectations and reality have reportedly faced five challenges. Firstly, SF activities are still under a strict state control scheme through administrative procedures and bureaucratic design (Adib 2025), making the forest management system ineffective and increasing operational costs. Secondly, contesting forest area management rights leads to conflict between community members. Thirdly, the SF schemes have an unequal distribution of rights and responsibilities. Fourthly, unfair compensation for the contributions made by each stakeholder, SF is often still viewed within the framework of the interests of each stakeholder. And lastly, local village elites receive forest concessions more as compared to the ordinary village residents. These differences in getting concessions give rise to internal conflicts between local village communities. In line with managerial weaknesses in implementing this forestry program, FAO research in 2015 conducted on 23 countries found out that only three

countries had provided SF provisions in their forestry laws. However, there is lack of implementation (Aggarwal *et al.* 2021). The institutional stabilization for strengthening legalities is insufficient to effectively implement SF policy, which requires strong management skills at various levels and in the field.

A longitudinal study conducted by Pemer and Skjølvsvik (2018) in Sweden regarding the implementation of new regulations involving institutional work found that the regulatory implementation process was carried out through four waves: the initial impact as a result of institutional shocks (1994–1999), the response (2000–2004), recovery (2004–2008), and the stabilization (2009–2013). The first wave describes the dissemination of information in the field. In the second wave, the response dealt with navigating a new institutional landscape. In the third wave, the public procurement/service landscape remained fragmented. Meanwhile, in the wave of stabilization, public organizations and local businesses collaborated to encourage dialogue and the development of public services. In each wave, different bureaucratic, market, and professional techniques were used, but the regulators also implemented top-down hierarchical institutional activities. These four waves follow sequential processes as the phases of institutional work relate to each other and give rise to new types of institutional work.

Therefore, implementing these new regulations is not always one-way but a two-way process of action and counter-action that moves forward until resolution. Sweden's experience shows that reaching the stabilization stage can take up to two decades; this requirement for policy stability offers a significant lesson for structuring policies in other regions.

### Recent developments: The 2024 ministerial restructuring and its implications

The stabilization stage, which combined the two previous stages, initiation and institutionalization, was ineffective. The failure to structure forest area management in Java is not only marked by resistance from the public, with various rejections, lawsuits, and demands for revocation in the Court of Justice (PTUN) but also proved a failure in implementing changes in the established paradigm. The paradigm established in forest area management through SF from state-based to community-based practically shifted authority from one state (BUMN in the forestry sector Perhutani) to another state (Ministry of Environment and Forestry), with a more centralized management system by establishing Indicative Maps and SF Areas (PIAPS) since 2016 (Rakatama and Pandit 2020). Thus, the determination of PIAPS is revised every six months, the latest in 2023 being the 8<sup>th</sup> revision (MenLHK 2023). The Ministry of Environment and Forestry took over this forest area of 1.1 million and 2.4 million hectares in Java to manage it through the Forest Area with Special Management policy – KHDPK (Men LHK 2022). The shift in authority from one state to another, followed by massive resistance from the public, is a sign of the stagnation of innovation carried out by the Ministry of Environment and Forestry. This stagnation

occurred due to the failure to adapt to the external environment, which focused on structuring the internal integration of Ministry of Environment and Forestry (KLHK) institutions.

The first element is internal integration. In carrying out its duties, the bureaucracy of the Ministry of Environment and Forestry (KLHK) must concentrate on completing internal integration matters. Internal integration (Rosenberg 2020), carried out by the Ministry of Environment and Forestry, deals with structuring internal regulations and performance in its institutions in three stages. The arrangement of legal rules has been uploaded on the official website since February 2017 (Ditjen PSKL KLHK 2017). The publication, launched by the Ministry of Environment and Forestry (KLHK) at the Directorate General SF and Environmental Partnerships (Ditjen PSKL), includes the documents related to statutory regulations, Presidential regulations, Government regulations, Decree of the Minister of Environment and Forestry, regulation of the Minister of Environment and Forestry (Permen LHK), Decree (SK) of the Minister of Environment and Forestry, and Decree of the Directorate General of PSKL. A total of 15 regulations from 2015–2023, Minister of Environment and Forestry's Decree (SK) (3 SK 2016–2017), Minister of Environment and Forestry's Decree concerning PAPS revision 1 Per Province (10 provinces in 2017) and Decree of the Director General of PSKL (2017) concerning changes to the SF Working Group (POKJA PS). The publications prepared since 2015 are in the strategic plan of the Directorate General of PSKL 2015–2019, Directorate of SF Area Preparation (Dit PKPS), Directorate of SF Business Development and Customary Law (Dit BUPSHA), Directorate of Conflict Management, Tenurial and Customary Forests (Dit PKTHA), Directorate of Environmental Partnerships (Dit KL), SF and Environmental Partnership Center (BPSKL) strategic plan for Sumatra, Java Bali Nusa Tenggara, Kalimantan, Sulawesi, Maluku Papua 2015–2019. The work plan and performance report (2018 to 2023) and the publication of the 2023 document are up to the budget and performance program of the Ditjen of PSKL (KLHK 2023). This focus on completing internal integration has forgotten an inseparable part of the KLHK's duties as a regulator: adapting to the external environment (Fatem *et al.* 2018, Klein *et al.* 2019) for forest area management stakeholders in Java. Thus, the stakeholders managing forest areas in Java (Perhutani), environmental NGOs, and LMDH (Forest Village Community Institutions) at the local, regional, and national levels.

Secondly, the institutional transformation, which emphasizes structuring internal integration within the Ministry of Environment and Forestry, does not necessarily reduce stakeholders' ability to adapt to the changes in the external environment. The external environment in managing forest areas in Java is undergoing multiple changes, including climate change, environmental observers and researchers, community demands, the Perhutani, and non-governmental organizations. The flexibility in responding to change is a challenge for innovative action in maintaining sustainable forest area management. The flexibility of innovative actions is oriented towards building solid partnerships between KLHK regulators and stakeholders, strengthening strong multi-actor partnerships, and

encouraging innovation in adapting to environmental changes. Additionally, the regulators drive stakeholders' collaboration as a structural component of the innovation system of the organizations. Fieldsend and colleagues (2022) examined 200 European partnerships involving farmers and foresters. As a result, the innovation process and stakeholders successfully determined the structure that is more appropriate for specific stakeholders given the circumstances. The influential factors in this regard include actor capacity, aspirations, and networks. Furthermore, the discussion encompasses the topic of co-innovation, its influence on partnership size and work plan structure, the types of activities, and the need to engage with 'larger fringe groups' within the supporting environment.

Third, the institutional landscape of Indonesian forestry underwent a seismic shift in late 2024 with the dissolution of the integrated Ministry of Environment and Forestry (MOEF) and the re-establishment of a standalone Ministry of Forestry (Rahmi *et al.* 2025). This restructuring represents a critical response to the bureaucratic 'overload' and policy stagnation identified during the 2014–2023 period (Ekowanti *et al.* 2025). While the previous integrated model aimed for synergistic land management, the findings of this study suggest that it often resulted in internal consolidation. This process prioritized state-centric administrative control rather than community-centric empowerment.

The new dichotomy – separating forestry's production and conservation functions from environmental oversight – offers a dual-edged sword for SF in Java. On the one hand, it provides the Ministry of Forestry with an opportunity to specialize its institutional capacity and streamline the implementation of KHDPK without the burden of overlapping environmental mandates. On the other hand, it risks resurrecting old 'sectoral egos' and coordination barriers that could further delay the resolution of public resistance and legal disputes. Ultimately, the success of this 2024 transformation will depend on whether the new Ministry can move beyond 'paper-based' legalism and foster a more inclusive, equal partnership model as a core strategy for forest governance (Adib *et al.* 2024b).

## CONCLUSION

The present study discussed the SF policy in Java, Indonesia, which the government of President Joko Widodo institutionally transformed. The SF policy has not changed from its original form, although the President can change or revise it. The institutional transformation through the initiation, institutionalization, and stabilization stages is simply shifting the implementation of forestry in Java from Perum Perhutani to the Ministry of Environment and Forestry (KLHK) through the Directorate General of SF and Environmental Management (Ditjen PSKL). The SF policy is still under the control of the state paradigm in management, which is more centralized. The centralization of forest area management in SF can be seen as a scheme which ensures that land and forest resources are under the strict control of the state through various administrative procedures and bureaucratic structures.

This state-based management scheme is equivalent to the management carried out by Perum Perhutani from the 1970s to 2014.

The concept of institutional capacity transformation used in this research reveals three main stages for forest area management: initiation, institutionalization and stabilization. Mr. Joko Widodo carried out the initiation stage of the SF program during his 2014 presidential candidacy campaign under *Nawacita*, the idea of which is a national vision used as a basis for the documents written in the 2015–2019 RPJMN. The institutionalization stage was carried out through Presidential Regulation (Perpres) Number 16 of 2015, which merged two ministries in the Ministry of Environment and Forestry (KLHK). Presidential Decree 16/2015 confirms the establishment of the Directorate General of SF and Social Management (Ditjen PSKL).

The Ministry of Environment and Forestry executed the institutionalization of the SF program in Java by establishing Indicative Maps and SF Areas (PIAPS) and its implementation in the working area of Perum Perhutani (P 39/2017). The stabilization stage of the SF program is strengthened in the Job Creation Law - UUCK (11/2020 articles 29A and 29B). In this UUCK, the term 'SF' was written explicitly in the legal system in Indonesia for the first time. Further, it concludes that, through the content analysis of the stages of policy determination, evaluation of institutional capacity transformation, and recommendations for community empowerment, this research makes a significant contribution to improving environmental sustainability, community welfare, sustainable resource management, community empowerment and achieving sustainable development goals as a whole. Thus, this research provides new insight for establishing more sustainable forest area management policies and more prosperous communities in and around forests.

The limitations of this research lie in its primary reliance on statutory documents and official technical provisions available through public domains, which may not fully capture the informal dynamics of institutional change. Furthermore, this study is bounded by the temporal context of 2014–2023, during which the forestry and environmental sectors were integrated under a single ministry (MOEF). The significant structural separation of these sectors into the Ministry of Forestry and the Ministry of Environment in late 2024 marks a new era that necessitates further investigation. Future research should transition from document-based analysis to longitudinal panel data surveys or ethnographic approaches to evaluate how this new institutional dichotomy influences the effectiveness of SF in Java, particularly in overcoming the public resistance and bureaucratic stagnation identified in this study.

## GENERATIVE AI STATEMENT

During the preparation of this manuscript, the author used Scopus AI in order to validate data and verify key statements within the text. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the published article.

## ACKNOWLEDGEMENTS

This research was conducted independently. The authors would like to thank the Dean of the Faculty of Social and Political Sciences, Universitas Airlangga, Surabaya, Indonesia, Prof. Dr. Bagong Suyanto, Drs., M.Si., who facilitated not only for providing the opportunity of Penelitian Unggulan Fakultas (PUF) with the number 1870 /UN3.1.7/PT/2021 but also the presentation of the main ideas of this article on 25–26 August 2023 at Universiti Sultan Zainal Abidin (UniSZA) Terengganu, Malaysia in the 9th International Conference on Contemporary Social and Political Affairs (ICocSPA) on the theme ‘Hitting the Barriers: ASEAN Epicenter of Growth.’ The authors also thank the participants for their comments and input during the presentation. We also want to acknowledge Prof. Alan Pottinger, the editorial team of the International Forestry Review (IFR), and anonymous reviewers for their comments and suggestions to improve the quality of this paper.

## DECLARATION OF INTEREST

The authors report no conflict of interest. The authors are responsible for the content and writing of this article.

## REFERENCES

- ADIB, M. 2025. *Pidato pengukuhan: antropologi ekologi untuk perhutanan sosial di indonesia(mendesak keadilan lingkungan dan keberlanjutan hutan tropis)*. Pertama. Surabaya: Airlangga University Press.
- ADIB, M., ABDULLAH, I., ARTARIA, M.D., RUSTINSYAH, R., ASMOROWATI, S., WARDHANI, B., ROSNON, M.R., and MASHUD, M. 2024. The controversy of social forestry policy: public reaction on the Ministry of Environment and Forestry Decree No. 287/2022/KHDPK in Java, Indonesia. *Forest Science and Technology* **20**(4): 383–400. doi:10.1080/21580103.2024.2409212.
- ADIB, M., HENDRAWATI, L.D., and SANTOSO, P. 2024. Kolaborasi yang inklusif, membangun kemitraan yang setara dalam perhutanan sosial. Pp. 58–76 in *Menjaga Tradisi Membangun Itentias: Narasi Budaya di Era Digital*, edited by Anwari, I.R.M. Surabaya: SAGA.
- ADIB, M., and RUSTINSYAH, R. 2025. *Perhutanan sosial – konsep, praktik, serta dampaknya pada masyarakat dan lingkungan*. Pertama. Surabaya: Airlangga University Press.
- AGGARWAL, S., LARSON, A., MCDERMOTT, C., KATILA, P., and GIESSEN, L. 2021. Tenure reform for better forestry: an unfinished policy agenda. *Forest Policy and Economics* **123**: 102376. doi:10.1016/j.forpol.2020.102376.
- ALDILLAH, R. 2020. Dynamics of the tora program at 2015–2019 period in Indonesia agricultural development. *Sustainability in Food and Agriculture* **1**(1): 37–41. doi:10.26480/sfna.01.2020.37.41.
- AYUNINGUTAMI, P.I., and NAJICHA, F.U. 2022. Regulasi hukum terhadap penerapan program reforma agraria dalam lingkup kehutanan. *YUDISIA: Jurnal Pemikiran Hukum Dan Hukum Islam* **13**(1): 39. doi:10.21043/yudisia.v13i1.12899.
- BOBERG-FAZLIĆ, N., LAMPE, M., LASHERAS, P., and SHARP, P. 2022. Winners and losers from agrarian reform: evidence from danish land inequality 1682–1895. *Journal of Development Economics*. doi:10.1016/j.jdeveco.2021.102813.
- BUDI, KARTODIHARDJO, H., NUGROHO, B., and MARDIANA, R. 2021. Implementation gap of social forestry policy: the case of HKm Beringin Jaya and HTR Hajran. *Jurnal Manajemen Hutan Tropika* **27**(1): 1–14.
- CARSON, S.L., KENTATCHIME, F., NANA, E.D., NJABO, K.Y., COLE, B.L., and GODWIN, H.A. 2018. Indigenous peoples’ concerns about loss of forest knowledge: implications for forest management. *Conservation and Society* **16**(4): 431–40. doi:10.4103/cs.cs\_17\_105.
- CATUR, N., WULAN, R.R., WULANDARI, A., NOFHA, R., DEWI, J.K., and AL GHOZALI, C.M. 2025. Examining communication strategy and implementation of the social forestry program of the Ministry of Environment and Forestry Indonesia in Bandung West Java. *Cogent Social Sciences* **11**(1). doi:10.1080/23311886.2025.2527391.
- CHANDRA, B.R., ROY, A., VINAY, P., KAUR, N., JHA, S., and PRADHAN, N.R. 2025. Forest 5.0: internet of things-based transformation of forests. *Internet Technology Letters* **8**(4). doi:10.1002/itl2.600.
- DITJEN PSKL KLHK. 2015. *Rencana Strategis Direktorat Jenderal Perhutanan Sosial dan Kemitraan Lingkungan Tahun 2015–2019*.
- DITJEN PSKL KLHK. 2017. Publikasi. <http://pskl.menlhk.go.id/publikasi.html>.
- EKOWANTI, M.R.L., TAMRIN, M.H., and MADANIYAH, R.N. 2025. Challenges and policy framework of hazardous and poisonous waste management in Indonesia: policy implementation and public impact. *IOP Conference Series: Earth and Environmental Science* **1473**(1): 012064. doi:10.1088/1755-1315/1473/1/012064.
- FATEM, S., AWANG, S.A., PUDYATMOKO, S., SAHIDE, M.A.K., PRATAMA, A.A., and MARYUDI, A. 2018. Camouflaging economic development agendas with forest conservation narratives: a strategy of lower governments for gaining authority in the re-centralising Indonesia. *Land Use Policy* **78**: 699–710. doi:10.1016/J.LANDUSEPOL.2018.07.018.
- GARRETT, R.D., CAMMELLI, F., FERREIRA, J., LEVY, S.A., VALENTIM, J., and VIEIRA, I. 2021. Forests and sustainable development in the Brazilian Amazon: history, trends, and future prospects. *Annual Review of Environment and Resources* **46**: 625–52. doi:10.1146/annurev-environ-012220-010228.
- HASTANGKA. 2020. Doktrin filsafat politik Jokowi dan janji Nawacita (mengurai gagasan revolusi mental). *Jurnal Pancasila* **1**(2): 39–44.

- JOPANG, J., TUNDA, A., and TARIFU, L. 2022. BUM desa: strategi pengembangan untuk transformasi sosial ekonomi desa (studi di Kabupaten Konawe Utara, Sulawesi Tenggara). *NeoRespublica: Jurnal Ilmu Pemerintahan*. doi:10.52423/neores.v3i2.25611.
- KLHK, DITJEN PSKL. 2023. Publikasi Ditjen PSKL. <http://pskl.menlhk.go.id/publikasi/publikasi-ditjen-pskl/664-publikasi-tahun-2023.html>.
- LANGSETH, I., JACOBSEN, D.Y., and HAUGSBAKKEN, H. 2023. Correction: the role of support units in digital transformation: how institutional entrepreneurs build capacity for online learning in higher education. *Technology, Knowledge and Learning* **28**(4): 1783–85. doi:10.1007/s10758-022-09622-w.
- LAWASI, M.A. 2024. Unveiling the shortcomings of social forestry programs in Indonesia: a critical analysis of farmer empowerment initiatives. *Jurnal Sylva Lestari* **12**(3): 866–89. doi:10.23960/jsl.v12i3.945.
- MENTERI LHK. 2015. *Rencana Strategis Kementerian Lingkungan Hidup Dan Kehutanan Tahun 2015–2019*.
- MENTERI LHK. 2020. *Rencana Strategis Kementerian Lingkungan Hidup Dan Kehutanan THUN 2020–2024*.
- MEN LHK. 2016. *Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor P.83/MENLHK/SETJEN/KUM.1/10/2016 Tentang Perhutanan Sosial*. 1–45.
- MEN LHK. 2017. *Peraturan Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia Nomor 39 Tahun 2017 Tentang Perhutanan Sosial Di Wilayah Kerja Perum Perhutani*. 16.
- MEN LHK. 2021. *Peta Indikatif dan Area Perhutanan Sosial Revisi (Revisi VII)*. 1–10.
- MEN LHK. 2022. Keputusan Menteri Lingkungan Hidup Dan Kehutanan Nomor SK.287/MENLHK/SETJEN/PLA.2/4/2022 Tentang Penetapan Kawasan Hutan Dengan Pengelolaan Khusus pada sebagian hutan negara yang berada pada kawasan hutan produksi dan hutan lindung di Provinsi Jawa Tengah.
- MENLHK. 2023. *Peta Indikatif Dan Areal Perhutanan Sosial (Revisi VIII)*.
- NUGROHO, A.I., BASUNI, S., JUNAEDI, G., KUSUMAH, P.A., HARDJASAMITA, K., KUSUMAWINATA, A., DJUWITA, F., RAHMAWATI, K., JUNIANDRI, A., ARDESIANTO, BANGUN, F.B., FADHLI, M., MURPRATIWI, L., and MUNIATI, S. 2021. Strategi on releasing non-productive of forest of onversion area for tora program in Riau Province. *Jurnal Analisis Kebijakan Kehutanan* **18**(1): 1–16. doi:10.20886/jakk.2021.18.1.1-16.
- NURFATRIANI, F., ERWIDODO, TARIGAN, H., and PERKASA, H.W. 2023. The role of the social forestry programs in increasing farmers' income and conserving forests in the Upstream Citarum Watershed, West Java, Indonesia. *International Forestry Review* **25**(2): 211–22. doi:10.1505/146554823837244455.
- PAMBUDI, A.S. 2020. The development of social forestry in Indonesia: policy implementation review, 2007–2019. *The Journal of Indonesia Sustainable Development Planning* **1**(1): 57–66. doi:10.46456/jisdep.v1i1.11.
- PANE, E., YANIS, A.M., and SUSANTO, I. 2021. Social forestry: the balance between welfare and ecological justice. *International Journal of Criminology and Sociology* **10**: 71–78. doi:10.6000/1929-4409.2021.10.10.
- PELUSO, N., and POFFENBERGER, M. 1989. Social forestry in Java: reorienting management systems. *Human Organization* **48**(4): 333–44. doi:10.17730/humo.48.4.a4r82227p5065638.
- PRESIDEN RI. 2015. Perpres Nomor 16 Tahun 2015 Tentang Kementerian Lingkungan Hidup Dan Kehutanan. *Lembaran Negara Republik Indonesia Tahun 2015 Nomor 17* **1**(1).
- PRESIDEN RI. 2020a. *Peraturan Presiden Republik Indonesia No.92 Tahun 2020 Tentang Kementerian Lingkungan Hidup dan Kehutanan*. 2(042491).
- PRESIDEN RI. 2020b. Undang-Undang Republik Indonesia Nomor 11 Tahun 2020 Tentang Cipta Kerja. *Republik Indonesia* 418.
- PRESIDEN RI. 2021. *Peraturan Pemerintah Indonesia Nomor 23 Tahun 2021 Tentang Penyelenggaraan Kehutanan*.
- PUJO, SOFHANI, T.F., GUNAWAN, B., and SYAMSUDIN, T.S. 2018. Community capacity building in social forestry development: a review. *Journal of Regional and City Planning* **29**(2): 113–26. doi:10.5614/jrcp.2018.29.2.3.
- RAHMI, E., FITRIA, F., EKO, NURIYATMAN, T.Y., and TOSCANY, A.N. 2025. Strengthening the coordination function of the forestry ministry: legal reform in the 'Merah Putih' Cabinet for modern bureaucracy. *Journal of Law and Legal Reform* **6**(4): 2177–2218. doi:10.15294/jllr.v6i4.22067.
- RAKATAMA, A., and PANDIT, R. 2020. Reviewing social forestry schemes in Indonesia: opportunities and challenges. *Forest Policy and Economics* **111**(1): 102052. doi:10.1016/j.forpol.2019.102052.
- RAMADHAN, R., and AMALIA, R.N. 2021. Analisis narasi/diskursus terhadap kebijakan perhutanan sosial di wilayah kerja Perhutani. *Wahana Forestra: Jurnal Kehutanan* **16**(1): 1–13.
- ROBLES, W. 2018. Revisiting agrarian reform in Brazil, 1985–2016. *Journal of Developing Societies* **34**(1): 1–34. doi:10.1177/0169796X17749658.
- SAMBODO, B.W., and WAHYUNI. 2015. *Peraturan Direktur Kemitraan Lingkungan Nomor P.01/KL-8/2015 Tentang Rencana Strategis Direktorat Kemitraan Lingkungan Tahun 2015–2019*.
- SANTIKA, T., WILSON, K.A., BUDIHARTA, S., KUSWORO, A., MEIJAARD, E., LAW, E.A., FRIEDMAN, R., HUTABARAT, J.A., INDRAWAN, T.P., JOHN, F.A.V.S., and STRUEBIG, M.J. 2019. Heterogeneous impacts of community forestry on forest conservation and poverty alleviation: evidence from Indonesia edited by J. McPherson. *People and Nature* **1**(2): 204–19. doi:10.1002/pan3.25.
- SUPRIYANTO, B., INTAN, P.J., NURYANTO, I., and HASNAWIR. 2024. Integrated area development: a new social forestry landscape approach in Indonesia. *IOP Conference Series: Earth and Environmental Science* **1299**(1): 012006. doi:10.1088/1755-1315/1299/1/012006.

- SUPRIYANTO, H., SUDARMO, S., and SETYOWATI, K. 2021. Implementation of social forestry in Perum Perhutani KPH Telawa. *Jurnal Analisis Kebijakan Kehutanan* **18**(1): 31–43. doi:10.20886/jakk.2021.18.1.31-43.
- SYANURISMA, S. 2022. Villages in forest areas in Java: agrarian reform policy-social forestry in Banyuwangi. *Marcapada: Jurnal Kebijakan Pertanahan* **1**(2): 123–38. doi:10.31292/mj.v1i2.12.
- WARYANTA. 2016. Reforma agraria: momentum mewujudkan kemandirian ekonomi masyarakat kecil dalam mendukung ketahanan pangan. *Jurnalbhumi.Stpn.Ac.Id* **2**(2): 179.
- WICAKSONO, M.B.A., HANDAYANI, I.G.A.K.R., and KARJOKO, L. 2019. State policy's analysis in the redistribution of reformed agrarian lands from forest areas in Indonesia (Study of Presidential Regulation Number 86 Year 2018 regarding Agrarian Reform). Pp. 174–78 in *Proceedings of the 3rd International Conference on Globalization of Law and Local Wisdom (ICGLOW 2019)*. Vol. **358**. Paris, France: Atlantis Press.
- WIDIYANTO, A., NURROCHMAT, D.R., TRISON, S., SUBARUDI, and NURFATRIANI, F. 2025. Social forestry institutional transformation under the State Forest Area with Special Management (KHDPK) policy. *Asian Journal of Forestry* **9**(2): 196–209. doi:10.13057/asianjfor/r090204.
- WIDODO, J., and KALLA, J. 2014. *Jalan perubahan untuk Indonesia yang berdaulat, mandiri, dan berkepribadian (Joko Widodo-Yusuf Kalla 2014: Visi, Misi, Dan Program Aksi)*. Jakarta.
- FERDIAN, K.J., and ODE, S. 2018. Reforma agraria belum berakhir menuju kesejahteraan masyarakat adat melalui reforma agraria pemerintahan Joko Widodo dan Jusuf Kalla. *Jurnal Sosial Soedirman* **2**(1). doi:10.20884/1.juss.2018.2.1.1182.
- WONG, G.Y., MOELIONO, M., BONG, I.W., PHAM, T.T., SAHIDE, M.A.K., NAITO, D., and BROCKHAUS, M.. 2020. Social forestry in Southeast Asia: evolving interests, discourses and the many notions of equity. *Geoforum* **117**: 246–58. doi:10.1016/j.geoforum.2020.10.010.
- ZAKARIA, R.Y., WIYONO, E.B., FIRDAUS, A.Y., SUHARJITO, D., MUHSI, M.A., SUWITO, SALAM, R., APRIANTO, T.C., and ULİYAH, L. 2018. *Perhutanan sosial: dari slogan menjadi program*. Jakarta: Sekretariat Reforma Agraria dan Perhutanan Sosial.
- ZULKARNAIN, A.A. 2021. Strategi kebijakan percepatan perhutanan sosial di Provinsi Riau. *Journal of Governance Innovation* **3**(2): 172–88. doi:10.36636/jogiv.v3i2.822.

# A comparative legal analysis of silvicultural interventions for sustainable forest management

Ü. BIRBEN<sup>a\*</sup> and F. ÇAKIR<sup>b</sup>

<sup>a</sup>*Çankırı Karatekin University, Faculty of Forestry, Department of Forest Engineering, Division of Forest Economics, Çankırı-Türkiye*

<sup>b</sup>*Çankırı Karatekin University, Faculty of Forestry, Department of Forest Engineering, Division of Silviculture, Çankırı-Türkiye*

\*Corresponding author

Email: birben@karatekin.edu.tr - <https://orcid.org/0000-0002-3042-220X>, figencakir@karatekin.edu.tr - <https://orcid.org/0000-0002-7576-7260>

---

## HIGHLIGHTS

- Forest law serves as a direct indicator of a nation's commitment to sustainability.
- The ownership structure directly determines the legal model.
- The 'implementation gap' constitutes a widespread cause of policy failure.
- Legal protection is unlikely to succeed without an effective enforcement chain.
- Climate adaptation has replaced sustainable yield as the primary driver of forest law reform since 2020.

## SUMMARY

The legal regulation of silvicultural interventions – science-based practices for establishing, tending, and regenerating forests – serves as a direct indicator of a nation's commitment to sustainable forest management (SFM). This study conducts a structured comparative legal analysis of legislative frameworks governing silviculture in five countries, each exemplifying a distinct governance model: Türkiye (prescriptive state-centric), Sweden (liberal, goal-oriented), Germany (federal, incentive-based), Canada (provincial jurisdiction with Indigenous rights), and Brazil (private-land focused, implementation-challenged). Employing the Institutional Analysis and Development (IAD) framework, the research systematically compares national legal regimes across six analytical variables: regulatory system, ownership-governance nexus, silvicultural standards specificity, enforcement architecture, adaptive capacity, and transnational norm integration. Primary legal texts were analyzed through directed content analysis, supplemented by secondary sources and recent jurisprudence.

The analysis yields three principal findings. First, ownership structure operates as a constitutive element shaping regulatory architecture, resulting in five governance paradigms with functionally equivalent yet formally distinct silvicultural controls. Second, a cross-cutting 'implementation gap paradox' demonstrates that the two countries with the strongest constitutional protections, Türkiye and Brazil, exhibit the greatest divergence between de jure protections and de facto outcomes. Third, since 2020, climate adaptation has supplanted sustainable yield as the primary driver of forest law reform in Europe, while recognition of Indigenous rights has become the dominant reform impetus in Canada. The study introduces a 'Regulatory-Institutional Alignment Framework' to account for the differential effects of governance on the interaction among legal design, institutional capacity, enforcement integrity, and political commitment. These findings provide practical guidance for policymakers and legal researchers, with several reform proposals supported by comparative evidence.

Keywords: silviculture, forest governance, comparative law, sustainable forest management

---

## INTRODUCTION

The world forests play a key role in addressing the two interconnected crises of climate change and biodiversity destruction, holding around 30% of the world's annual levels of anthropogenic CO<sub>2</sub> emissions as well as providing for more than 80% of the world's terrestrial species (Pan *et al.* 2011, Marques *et al.* 2019). Forest services and socio-economic value for 1.6 billion peoples forests need governance to balance conservation and use for productive purposes (Agrawal *et al.* 2008). The Sustainable Forest Management (SFM) paradigm, defined at the 1992 Rio Earth Summit and further developed in the UN Forum on Forests, assumes forests as

resilient systems stewarded for long-term ecological sustainability, productivity and equity from generation to generation (Odera 2004, Burton 2025, Mishra and Agarwal 2024). SFM translation into practice focuses on silvicultural practices which control the selection, establishment, growth and structure of forest to conform to various functional requirements (Matthews 1989). These interventions (thinning, selective logging, clear-cutting and regeneration) are the concrete mechanisms of establishing forest ecosystems. Contemporary silviculture is increasingly influenced by an ecological theory that aims at replicating the natural processes and increasing resilience and is a departure from production-led approaches (e.g. Puettmann 2021, Puettmann, *et al.* 2025, Messier *et al.*

2022). They are constructed through forestry government policy and by legislation which provides rules, inducements, and sanctions that shape human behavior (Cashore *et al.* 2006). The legal framework thus has the duty of navigating the basic contradiction between active intervention in silviculture and ecological limits determined by sustainability (Siry *et al.* 2005). The formation and enforcement of these legal systems are, therefore, critical as to whether SFM is maintained as an aspiration goal or becomes an operational reality.

Despite a growing body of research on SFM, comparative forest law scholarships have been predominantly descriptive, focusing on single-country case studies or high-level policy narratives rather than systematic, institutionally grounded comparison of specific silvicultural provisions (Giessen 2013, Godechot 2018). Scholarship on comparative legal methodology in environmental law has highlighted constant challenges in multilingual legal source analysis and the distinction between functional and structural comparison (Viñuales 2024).

This study fills these gaps via addressing the following main research question: How different national legal and governance regimes regulate silvicultural interventions to pursue SFM goals, and what institutional considerations account for the different efficiency of these strategies?

The period since 2020 represents an inflection point in global forest governance. Sustainable yield has now been replaced as the major reason for forest law reform in Europe by climate adaptation: Germany adopted the Bundes-Klimaanpassungsgesetz (Federal Climate Adaptation Act) in 2023, and Sweden's inability to achieve its goal of achieving 'Sustainable Forests' environmental quality has been officially recognized by the OECD (2025). In Canada, landmark decisions such as *Yahey v. British Columbia* (2021) and *Gitxaala v. British Columbia* (2023) have extended Indigenous rights to forest resources, and the 2023 wildfire season that scorched 2.84 million hectares in British Columbia alone revealed systemic governance failures (Daniels *et al.* 2024). Furthermore, in Brazil, when enforcement revived post-2023 under a new government, infraction notices doubled and alerts surrounding deforestation dropped by 43% (Nunes *et al.* 2024), and the Supreme Federal Tribunal mandated a reduction of deforestation in the Amazon to zero by 2030 (STF ADPF 743/760). Concurrently, the European Union Deforestation Regulation (EUDR), with enforcement deadlines now set for December 2026 (Council of the EU 2025), heralds a new era of decision-making (Sandström *et al.* 2017) – from voluntary governance to mandatory extraterritorial compliance. These developments stress the critical need for a rigorous comparative analysis that reflects the contemporary dynamics remaking forest law around the world.

This paper challenges these dynamics by drawing on a structured institutional comparison: How do national legal regimes regulate silvicultural interventions to promote SFM, and what institutional features strengthen or weaken their performance amid the climate-biodiversity nexus? To address this, the study compares and contrasts five countries which are representative of a spectrum of governance paradigms:

Türkiye (prescriptive state-centric), Sweden (liberal, goal-oriented), Germany (federal, incentive-based), Canada (federally decentralised, judicially constrained), and Brazil (private-land focused, implementation-challenged). This choice reflects differences in legal traditions (civil vs. common law), political institutions (unitary vs. federal), patterns of forestry ownership, and mechanisms for enforcement. The analysis is structured with the help of the Institutional Analysis and Development (IAD) framework (Ostrom 2005), operationalised in six specified analytical variables, allowing a systematic cross-national comparison across countries that goes beyond descriptive legal narration to institutional explanation.

## METHOD

### Conceptual framework

The analysis within the paper is based on three interconnected conceptual models which together present a comprehensive lens for the evaluation of forest law as an institutional phenomenon.

#### *Institutional Analysis and Development (IAD) Framework.*

The IAD approach (Ostrom 2005) casts forest law as a set of 'rules-in-use' that organize interactions among actors (state agencies, landowners, communities, markets) within an 'action arena.' Using the operationalisation methodology proposed by Cole *et al.* (2019) and the institutional grammar tool refined by Epstein *et al.* (2024), the current study analyses legal rules at three nested levels: operational rules (e.g., clearcut area limits, regeneration deadlines, riparian buffer widths), collective-choice rules (e.g., management plan approval processes, stakeholder consultation requirements), and constitutional rules (e.g., ownership regimes, constitutional forest protections). The biophysical conditions component of the IAD framework recognises how ecological contexts (boreal, temperate, tropical) shape both the design and effectiveness of silvicultural regulation. Recent systematic reviews which have applied IAD to forest governance attest that institutional diversity – rather than a single optimal model – characterises effective forest management worldwide (Kimengsi *et al.* 2023, Carlisle and Gruby 2019, Nagendra and Ostrom 2012).

*Adaptive governance.* By stressing the unpredictable structure of forest ecosystems under climate change, the current study considers legal systems against the lens of learning, flexibility, and polycentricity dimensions (Folke *et al.* 2005, Chaffin *et al.* 2014). These rigid, top-down systems are opposed to systems that employ feedback loops and stakeholder engagement. In agreement with Abrams and Elbakidze (2023), the analysis posits four primary components of adaptive forest governance: political will, legal framework flexibility, higher-level institutional support, and local capacity building. This lens has special significance in this regard for appreciating how legal frames react to a climate adaptation imperative post-2020.

*Transnational Legal Orders (TLOs).* The EUDR, on the other hand, is viewed not simply as a trade regulation but as a

transnational legal order that penetrates domestic legal systems, establishing new compliance architectures and redefining ‘legality’ through supply chain due diligence (Halliday and Shaffer 2015). Recent literature has stressed the legitimacy challenges and possible market leakage effects of such extraterritorial regulations (Muradian and May 2026, Boston and Tanager 2025). These dimensions are explored in the comparative examination below.

### Analytical variables and comparison matrix

To enhance comprehensiveness in the legal narrative, six analytical variables were defined a priori to enable systematic cross-national comparison. These variables ground the institutional dimensions of the IAD framework in the silvicultural regulation context:

### Case selection and justification

Five countries were selected through purposive sampling designed to maximize variation along the main dimensions identified in the IAD framework (George 2018, Seawright and Gerring 2008). By this ‘most different systems’ design we can ascertain how institutional variables – rather than their shared cultural or historical features – shape regulatory outcomes (Przeworski and Teune 1970). A summary of selection criteria and case characteristics is given in Table 2.

### Data sources and analytical procedure

The study utilizes both primary legal texts (constitutions, forest acts, implementing regulations, judicial decisions), and secondary sources (policy documents, academic literature, government audits, NGO reports). For each jurisdiction, analysis was conducted in three sections: (1) finding and carefully extracting legal provisions of the six analytical variables, (2) structured content analysis of extracted provisions based on the institutional grammar tool protocol (Epstein *et al.* 2024),

whereby institutional statements were coded into their components (actors), objects (targets), deontic operators (permissions, obligations, and prohibitions), conditions, and consequences, and (3) a cross-national comparison of coded provisions for convergence, divergence, and functional equivalence.

### Methodological limitations

The core legal analysis of non-Turkish jurisdictions relied on translations in English of Swedish, German, and Portuguese-language laws. Although the principal forest acts of Sweden (Skogsstyrelsen 2022), Germany (BWaldG as amended), and Brazil (Forest Code Law 12,651/2012) have official English translations, not all regulatory contents that are situated within subordinate regulations or judicial opinions can be translated accurately. In order to counterbalance this limitation, the analysis was triangulated with peer-reviewed secondary literature written by authors with knowledge of jurisdiction-specific legal matters. Primary sources were accessed first-hand for Canadian law, which was in English. A fully rigorous comparative legal analysis ideally would entail collaboration alongside legal experts at the local level in each jurisdiction (Viñuales 2024), so this represents an avenue for extending future research.

## FINDINGS

This section presents the results of the directed content analysis for each jurisdiction, structured according to the six analytical variables defined. The presentation is organized by country to preserve the internal coherence of each legal system, followed by a systematic cross-national comparison.

### The Prescriptive State-Centric Model: Türkiye

*Regulatory system:* Türkiye’s forest governance operates within a prescriptive, command-and-control framework. The

TABLE 1 Analytical variables for comparative legal analysis

Analytical Variable	Definition	IAD Level
Regulatory Design	The nature and specificity of legal rules governing silvicultural activities (prescriptive vs. goal-oriented, command-and-control vs. incentive-based)	Operational / Collective-choice rules
Ownership-Governance Nexus	How forest ownership structures determine regulatory philosophy and the allocation of management authority	Constitutional rules
Silvicultural Standards Specificity	The degree to which legal texts specify concrete silvicultural parameters (clearcut limits, regeneration deadlines, riparian buffers, species requirements, diameter limits)	Operational rules
Enforcement Architecture	The institutional chain from detection to sanctioning, including monitoring technology, administrative capacity, judicial processing, and fine collection	Operational / Collective-choice rules
Adaptive Capacity	Legal mechanisms for incorporating new scientific knowledge, responding to climate change, and enabling stakeholder participation in management decisions	Collective-choice / Constitutional rules
Norm Integration	The degree to which domestic legal systems incorporate or respond to international instruments (EUDR, CBD, FSC/PEFC, UNDRIP)	Constitutional rules

TABLE 2 Case selection: key institutional dimensions

Dimension	Türkiye	Sweden	Germany	Canada (BC)	Brazil
Legal tradition	Civil (Continental)	Civil (Nordic)	Civil (Germanic)	Common law	Civil (Iberian)
Political structure	Unitary (presidential)	Unitary (parliamentary)	Federal	Federal	Federal
Forest ownership	99% state	~75% private	~48% private	94% Crown (public)	~54% private
Primary regulatory logic	Prescriptive command	Goal-oriented	Incentive-based	Rights-based / plan-based	Conservation obligations on private land
Enforcement capacity	Moderate (political interference)	Moderate (relies on self-compliance)	High (differentiated by Länder)	Weak (chronic underfunding)	Volatile (politically dependent)
Climate adaptation legal status	Climate Law No. 7552 (2025)	No dedicated act (SFM objective failing)	Klimaanpassungsgesetz (2023)	Province-level policy	STF judicial mandates

Constitution (Article 169) declares all forests state property, prohibits their reduction in area, and mandates state management for the public benefit (Coşkun 2002, Aydın and Elvan 2005, Coşkun 2006). Forest Law No. 6831 (1956, as amended) and its implementing communiqués vest near-exclusive silvicultural decision-making authority in the General Directorate of Forestry (GDF), which functions simultaneously as law-maker, manager, and enforcer. This dual capacity creates a structural imperative for detailed technical specifications governing all aspects of forest management across the national territory (Baskent *et al.* 2005, Köse and Daşdemir 2023).

*Ownership-governance nexus:* The state owns 99% of Türkiye's forests, and so is effectively both a regulator and operator. This monopoly does not provide a requirement for negotiation in relation to private owners, but leaves accountability gaps: but unlike private-sector forestry operations in other jurisdictions, the state's own management decisions are not subject to independent judicial review, creating a structural deficit in oversight. This constitutional protection of forest areas under Article 169 paradoxically coexists with systematic political erosion: 63 979 permits were granted under various legislative exceptions between 2012 and 2022, converting 406 202 hectares of forest land to non-forest uses (Atmış *et al.* 2024, Tolunay 2021, Yıldırım and Ayanoğlu 2014). Presidential reclassification authority under the 2/B provision has been exercised 27 times since 2018, removing 26.7 km<sup>2</sup> from forest status (Özgür 2024).

*Specificities in silvicultural standards:* Silvicultural interventions are regulated through detailed management and silviculture plans prepared by the GDF. Clearcut sites are determined by these plans, with blocks of more than 10–15 hectares generally not preferred. Until criteria for success are met (e.g., 80% seedling survival within two years), reforestation obligations apply. Any harvesting, thinning and regeneration activities should have GDF authorization and be strictly in line with the specified technical specifications provided by central authorities.

*Enforcement regime:* Criminal (imprisonment and fines) punishments for illegal cutting and forest damage were

prescribed in Law No. 6831. The effectiveness of enforcement is, however, obstructed by political interference. Caliskan *et al.* (2025) that have shown that legislative changes have repeatedly prioritised economic consumption over environmental protection. The catastrophic 2021 Manavgat fire (60 000 ha from four concurrent arson ignition points) highlighted weaknesses in both prevention and response capacity (Ekberzade *et al.* 2025).

*The capacity for adaptability:* Türkiye's 2024–2030 Climate Adaptation Strategy was adopted in 2024 and Climate Law No. 7552 enacted in July 2025, establishing a legal foundation for climate-responsive forest management. But this top-down governance structure does not allow for incorporation of local ecological knowledge and community role in decision-making. Elvan *et al.* (2021) has revealed that Turkish legislation meets FAO criteria to 78.1%, but has significant deficiencies on adaptive management practices and mechanisms for stakeholder engagement.

The export market is creating indirect EUDR compliance pressures on the economy with transnational norm integration: Türkiye is not an EU member state. The country's pursuit of alignment with EU governance of forests has been sporadic, with domestic priorities repeatedly overshadowing international commitments.

### The liberal goal-oriented model: Sweden

*Regulatory system:* Sweden is based on the principle of 'Freedom with Responsibility,' which is written into the Forestry Act of 1993 (Skogsvårdslagen). This aim-driven strategy confers substantial freedom upon forest operators to make management decisions, while placing certain law-based obligations on them. It is thus this Act, whose pioneering aim is the equitable value-based attribution of production and environmental goals, that legally recognises forests as complex ecosystems rather than mere timber production sites and is a progressive mandate (Appelstrand 2007, Lindahl *et al.* 2017).

*Ownership-governance nexus:* More than 75% of forest land is privately held by around 330 000 individual owners

and businesses. It can be said that this divided structure of ownership renders prescriptive command-and-control regulation infeasible and mandates that the approach must have this specific purpose. The Swedish Forest Agency (Skogsstyrelsen) uses consultative services, field inspections and remote monitoring as a tool for the Swedish Forest Agency to stimulate compliance instead of by directing it, rather than coercing it (Olofsson and Jakobsson 2023, Nylund and Ingemarson 2007).

*Specificities in silvicultural standards:* Clearcut operations involve notifying Skogsstyrelsen when they exceed 0.5 ha. Based on species and site productivity minimum harvest age limits are 45 to 100 years. The most significant law is the legally obligatory reforestation duty ‘without delay’ (interpreted as within approximately three years). Biodiversity safeguards include compulsory retention of trees, dead wood, and buffer zones. Yet there are no clearcutting area limits: 97% of logging is carried out by method of clearcutting (Angelstam *et al.* 2020, Heder Brandt 2023). Approximately 3% of productive forestland is managed under continuous-cover forestry (Hertog *et al.* 2022).

*Enforcement regime:* The system relies primarily on self-compliance by landowners and is done primarily by Skogsstyrelsen who conduct post-harvest inspections on a sample basis. Non-compliance carries administrative penalties. Limitations of the enforcement model are reflected in the continued gap between the environmental goals and ecological targets (Eckerberg 1987).

*The capacity for adaptability:* The OECD (2025) indicated that Sweden has yet to reach the objective of the ‘Sustainable Forests’ on environmental quality by 2030 and more than 400 species are categorised as threatened by forest activities (Skogsstyrelsen 2022). The forest sector has portrayed clearcutting as ‘the best way to produce profits and also the most sustainable mode of harvesting’, even as scientific literature suggests that biodiversity continues to erode (Angelstam *et al.* 2020). The Swedish model is also hampered in this respect by the continuous exclusion of Sámi reindeer herding rights from forest governance. Despite the ground breaking 2020 case of Girjas Supreme Court awarding Sámi communities unique hunting and fishing rights in their territories (Allard and Brännström 2021), about 70% of the top yielding lichen pastures have been lost to commercial forestry activities (Uboni *et al.* 2020), which is a failure of the ‘responsibility’ part in reconciling production processes of resource extraction with the rights and survival of peoples.

*Transnational norm integration:* Sweden as an EU-member state is responsible to implement EUDR requirements. FSC certification has adopted tougher standards than national law, however, the effectiveness of certification is contested in its relationship to intensive industrial forestry.

### **Federalism and incentive-based regulation: Germany**

*Regulatory system:* Forest governance in Germany is organized along two tiers of the federal level. The Federal Forest Act (Bundeswaldgesetz, BWaldG) of 1975 lays down the basic laws and minimum standards, and 16 state (Länder)

forest laws detail implementation policies adjusted to fit local ecological and economic conditions in a specific area (Winkel 2014). The ‘Close-to-Nature Forestry’ (Naturnahe Waldwirtschaft) philosophy has been incorporated in most state-level laws as the guiding principle.

*Ownership-governance nexus:* Germany’s relatively complex ownership structure, which combines about 48% private (typically in small plots less than 20 hectares) 29% state 19% corporate, and 4% federal, requires an approach uniting legal responsibilities with financial incentives. The approximately two million small private forest owners demand broad guidance to install technically challenging close-to-nature silvicultural systems (Bieling 2004, O’hara 2016, Puettmann *et al.* 2015)

*Silvicultural standards specificity:* Clearcutting is generally prohibited or severely restricted in most jurisdictions, requiring state approval and limited to rare occasions. Natural regeneration is favored over artificial planting. Native species are mixed with uneven-aged stands through legal and financial incentives. Regeneration timelines are typically determined 2–4 years after harvest and vary across states. According to the latest report released by the Technical Assessment Bureau in 2024, 3.3 million hectares of German forest must undergo a transformation towards climate-resilient mixed stands by 2050 (TAB 2024, BMEL 2021, BMEL 2024, Holzwarth *et al.* 2020).

*Enforcement regime:* State forest agencies conduct periodic inspections. Implementing financial incentive programs creates positive compliance incentives along with administrative sanctions for non-compliance. The system is also well-suited to Germany’s high institutional capacity as well as its rule-of-law nature (Ebbesson 2010, Mann 2012).

*The capacity for adaptability:* The Federal Climate Adaptation Act of 2023 elevated climate-resilient forests as a national legal priority in which legal and financial support for the forest conversion program would be strengthened. Due to events such as the collapse of the governing coalition in November 2024 and the failed Federal Forest Act reform plan, the Federal Forest Act reform was abandoned altogether yet the example shows that political discontinuity obstructs adaptive governance. Between 2018 and 2021, Germany lost 501 000 hectares of canopy cover as a result of drought, storms, and outbreaks of bark beetles (Thonfeld *et al.* 2022, BMEL 2021), demonstrating the need for prompt adaptation. Kreuer *et al.* (2025) describe the current moment as a ‘forest policy crisis that needs urgent transformation.’

*Transnational norm integration:* As an EU member state, Germany is directly subject to EUDR implementation requirements. The EUDR’s integration into Germany’s existing regulatory architecture is facilitated by the country’s established framework for forest monitoring and certification.

### **Provincial jurisdiction and Indigenous rights: Canada (British Columbia)**

*Regulatory system:* Canada’s forest governance is shaped by constitutional federalism, with primary jurisdiction over natural resources delegated to provinces and territories. British

Columbia (BC), which contains 60% of Canada's remaining old-growth forest, is used as the primary case. The Forest and Range Practices Act (FRPA) and the Forest Planning and Practices Regulation establish the regulatory framework through mandatory forest management plans and results-based compliance (Howlett 2001, Howlett and Rayner 2006).

*Ownership-governance Nexus:* Ninety-four percent of Canada's forests are publicly owned Crown land, managed through tenure agreements with forestry companies. This creates a principal-agent relationship where the government (principal) delegates management to licensees (agents) under contractual terms specifying silvicultural obligations. The constitutional 'duty to consult' with Indigenous peoples fundamentally constrains provincial authority.

*Silvicultural standards specificity:* clearcut area limits in BC generally range from 40 to 60 hectares based on management plans. Riparian reserves are 0–50m depending on stream classification, but there are also other management zones of 20–100m. Regeneration obligations specify 3–5 years for setting up and 9–20 years for free-growing status. It is found only around 2.7% of high-productivity big-tree old growth remained in BC, which led to the Fairy Creek protests (2021–2025) – the biggest civil disobedience campaign in Canadian history, with over 1 100 arrests (Merkel and Gorley 2020).

*Enforcement regime:* Sanctions consist of fines, suspension of harvesting rights, and timber seizure, but ongoing chronic underfunding of enforcement staff makes a preventative field investigation almost impossible.

*The capacity for adaptability:* The judicial activism in Canada profoundly defines the Canadian model's adaptive capacity. The *Yahey v. British Columbia* decision of 2021 found that cumulative effects of industrial activity – which includes forestry – infringed Treaty 8 rights, which posed a direct threat to BC's forestry regime at the center of its jurisdiction. The 2023 *Gitxaala v. British Columbia* decision (upheld by BCCA in 2025) established mineral claims regimes inconsistent with the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) and set precedent that applies to forestry as well. The catastrophic 2023 wildfire season (2.84 million hectares burned in BC, Daniels *et al.* 2024) has simply intensified demands for governance reform.

*Transnational norm integration:* Canada adopted UNDRIP into domestic law through the United Nations Declaration on the Rights of Indigenous Peoples Act (2021), creating binding domestic obligations. EUDR compliance pressures affect Canadian softwood lumber exports to European markets.

### **Conservation obligations and the implementation gap: Brazil**

*Regulatory system:* Brazil's Forest Code (Law 12.651/2012) controls land use on private land through two core mechanisms: Permanent Preservation Areas (APPs) – ecologically significant areas with 30–500 m buffers, steep slopes, and the like where development is not permitted – and Legal Reserves (LR) – requiring landowners to maintain natural vegetation on a percentage of their property: 80% in the Amazon biome, 35% in Amazon cerrado transition zones, and 20% elsewhere (Brançalion *et al.* 2016).

*Ownership-governance Nexus:* Approximately 54% of Brazilian forest area is private, so that private responsibility under the Forest Code serves as the central focus of forest governance. The Environmental Rural Registry (CAR) system, which recorded more than 6.5 million rural properties, is the main source for compliance monitoring. However, Furumo *et al.* (2024) have shown that legal reserves have been overestimated by 9.7 million hectares because CAR registrations overlap, severely hurting the system's reliability.

*Silvicultural standards specificity:* Clearcutting is banned in Legal Reserves and APPs. Legally approved management plans are required for sustainable forest management in Legal Reserves. Of the 5 jurisdictions studied, Brazil's riparian buffer requirements (by river width, 30–500 m) are the most protective. But the amnesty provisions for illegal deforestation committed before July 2008 and the 20-year period under Environmental Regularisation Programmes (PRAs) have had a serious effect on effective implementation.

*Enforcement regime:* Brazil is one of the countries equipped with world-leading detection capacity via DETER and PRODES satellite systems. The post-2023 enforcement resurgence saw some striking results: data indicates that Amazon deforestation decreased from 9 001 km<sup>2</sup> (2022) to 6 288 km<sup>2</sup> (2024, 30.6%) and further down to an estimated 5 796 km<sup>2</sup> (2025) (Mingoti and da Silveira 2025, Pinheiro 2024). The numbers of violations notices double and deforestation alerts decrease by 43% (Nunes *et al.* 2024). The Amazon Fund has collected R\$3.9 billion in new donations since 2023, returning international cooperation to balance. Still, the actual rates of collection by fine-taker remains really low and so undermine deterrence in the long term.

*The capacity for adaptability:* In ADPF 743/760 the Supreme Federal Tribunal decreed through its decisions the federal government must cut the Amazon deforestation amount to 3,925 km<sup>2</sup>/year by 2027 and achieve zero deforestation by 2030, this is the first intervention into an area of forest policy. Such judicial activism offers potent adaptive tools and is contingent on political will.

*Transnational norm integration:* Brazil's inclusion in EUDR's norms is undergoing pressure. The regulation designated 140 countries as low risk and four (Belarus, Myanmar, North Korea, Russia) high-risk. Brazil's classification will have an outsized impact on its agricultural exports to the EU, providing strong external incentives for tighter domestic enforcement.

### **Comparative analysis**

This section synthesizes the country-level results presented, comparing the five jurisdictions across the six analytical variables and identifying cross-cutting patterns that inform the theoretical analysis.

### **Comparative silvicultural standards**

Table 3 provides a systematic comparison of the specific silvicultural provisions identified through the directed content analysis.

TABLE 3 Comparative silvicultural standards across five jurisdictions

Provision	Türkiye	Sweden	Germany	Canada (BC)	Brazil
Clearcut regulation	Permitted via management plans, >10–15 ha discouraged	Notification >0.5 ha, no strict max, age limits 45–100 yrs	Generally banned, state permit required	40–60 ha max via plans	Prohibited in LR and APP
Regeneration deadline	Until 80% survival (result-based)	‘Without delay’ (≈3 years, process-based)	2–4 years (state-level)	3–5 yrs establishment, 9–20 yrs free-growing	20-year PRA window
Riparian buffers	General duty under management plans	General conservation duty	State-level rules (variable)	0–50 m reserve + 20–100 m management zone	30–500 m (by river width), most protective
Legal reserve requirement	Not applicable (state land)	Not applicable	Not applicable	Not applicable	80% Amazon, 35% cerrado 20% elsewhere
Retention / biodiversity	Natural regeneration emphasis in plans	Mandatory retention trees, dead wood	Mixed species, natural regeneration preferred	Wildlife tree patches, riparian retention	APPs, connectivity corridors
Primary sanction type	Criminal (imprisonment + fine)	Administrative fine	Administrative fine	Fine, licence suspension, timber seizure	High fines (very low collection)

There are three striking patterns in the comparison:

- 1) *Functional equivalence despite formal divergence*: All five jurisdictions accomplish the essential goal of controlling timber extraction and guaranteeing regeneration, but through formally dissimilar means. Türkiye employs result-based criteria (survival rates), Sweden uses process-based timelines, and Brazil relies on spatial restrictions (legal reserves).
- 2) *Brazil’s regulatory outlier status*: Brazil’s Legal Reserve requirement, obligating landowners to maintain up to 80% natural vegetation, which has no equivalent in other jurisdictions, and it also represents an utterly new regulatory logic – one based not on public land management regulation but on the restriction of the use of private land.
- 3) *Orders-of-magnitude variation in regeneration time-lines*: The range of regeneration deadline extends from Türkiye’s indefinite result-based framework, through Sweden’s approximately three-year process obligation, to the 20-year PRA window in Brazil, demonstrating that there are orders of magnitude differences between the time frames available for forest recovery.

### The implementation gap paradox

A key conclusion from the comparison is the ‘implementation gap paradox’: countries with the best provision, constitution or legislation, for forests show the greatest disparity between the implementation of their laws and practice. Türkiye’s Article 169 as a constitutional provision guarantees the best protection of forest land in the tested jurisdiction, but 406,202 hectares of forest land were converted under legal exceptions from 2012 to 2022 (Atmış *et al.* 2024, Tolunay 2021, Yıldırım

and Ayanoğlu 2014). Brazil’s Forest Code implements the boldest of private-land conservation requirements (80% legal reserves in the Amazon), with the 2012 amnesty and 20-year PRA period undermining progress. In contrast, Sweden and Germany, with less constitutionally-mandated protections, exhibit a more consistent and although imperfect, linkage between legal goals and practical effects.

This paradox provides the hint that constitutional entrenchment is not sufficient to deliver a solution and can thus generate moral hazard as it promotes reliance on formal protections and disregards institutional capacity. The efficient enforcement chain would need coordinated capacity across three dimensions: (1) Technology of detection (Brazil first with DETER/PRODES) (2) Administrative and judicial processing (Germany second with Länder-based institutional structure) and (3) Persistent political commitment (to where all five are vulnerable).

### Ownership structure as a constitutive element

In line with institutional theory (Ostrom 1990 2005), the analysis shows that ownership structure is not only considered a contextual factor but a constitutive element in formulating regulatory systems. From the comparison, five distinct ownership–governance paradigms emerge:

1. *The state monopoly paradigm* (Türkiye), which results in prescriptive, centralised regulation in which the state constructs, implements, and enforces rules – a structure that, while granting uniformity, cultivates accountability shortfalls.
2. *The fragmented private ownership paradigm* (Sweden) requires goal-driven regulation that is dictated by owner discretion, resulting in flexibility but inadequate environmental outcomes.

3. *The hybrid incentive model* (Germany) addresses the issues of complex mixed ownership by offering financial remuneration and advisory services, it yields higher ecological standards, but at the cost of scale bureaucratic difficulties.
4. *The public stewardship paradigm* (Canada) governs Crown land in negotiated delegated tenure agreements limited by Indigenous rights – a paradigm increasingly disrupted by judicial intervention.
5. *The private conservation obligation paradigm* (Brazil) creates a relatively new and unprecedented set of conservation responsibilities on private landowners, which has led to severe political pushback and enforcement difficulties.

### Transnational norm integration and the EUDR

The EUDR represents a qualitative shift in international forest governance from voluntary soft-law instruments to binding extraterritorial regulation. The regulation's repeated postponement (enforcement now set for December 30 2026 for large/medium operators, June 30 2027 for micro/small) underscores the implementation challenges of extraterritorial governance (Council of the EU 2025). For EU member states (Sweden, Germany), the EUDR creates additional compliance layers atop domestic forest law. For non-EU exporters (Türkiye, Canada, Brazil), it generates market-access pressures that effectively extend EU regulatory standards beyond its borders. Recent literature raises concerns that EUDR unilateralism creates legitimacy problems and risks market leakage to non-EU markets (Muradian and May 2026, Zabel *et al.* 2025), while others question the regulation's consistency with GATT principles (Boston and Tanger 2025, Nasution *et al.* 2025). These tensions will likely intensify as enforcement begins.

## DISCUSSION AND CONCLUSION

### Toward a regulatory-institutional alignment framework

The comparison demonstrates that one institutional variable will not explain the effectiveness of silvicultural regulation from any one institutional variable. Rather, it is a product of the interaction of four perspectives: (1) *legal design adequacy* – how well the operational provisions respond to the particular silvicultural challenges of the jurisdiction, (2) *institutional capacity* – the bureaucratic and technological capacity for implementation, (3) *enforcement integrity* – the independence and efficacy of the enforcement chain from discovery through punishment, and (4) *political commitment* – the ongoing readiness to emphasize environmental interests over rival claims and demands.

This 'Regulatory-Institutional Alignment Framework' provides some theoretical basis beyond the widely observed 'ownership structure determines legal model' concept in a new sense. For this reason, even though ownership structure

does inform regulatory systems, misalignment in the four dimensions creates the implementation gap paradox across jurisdictions, as this framework explains. Türkiye demonstrates good legal design but weak enforcement integrity (political interference leads to weak enforcement integrity). Brazil shows strong legal design and detection technology but weak political commitment (historically shaky with instability). Sweden features a moderate legal design with high levels of institutional capacity but few legal aims for environmental standards. Germany displays the most alignment across all aspects – but unprecedented biophysical pressures resulting from climate change come ahead of institutional response.

### The climate adaptation inflection point

The post-2020 era means a structural shift in the relationship between silvicultural regulation and its purpose. Climate adaptation has replaced sustainable yield on the policy agenda: Germany's Climate Adaptation Act (2023) and the identification of 3.3 million hectares needing conversion (TAB 2024), and Sweden's recognition of falling short of its sustainability goals (OECD 2025) indicate a fundamental change. In Canada, the 2023 wildfire season (2.84 million hectares in British Columbia alone) and landmark Indigenous rights determinations are reforming governance from the ground up. In Brazil, the Supreme Federal Court's zero-deforestation mandate represents a judicial intervention of unprecedented scale. These developments challenge the traditional comparative law assumption that legal systems change gradually.

On the contrary, there is evidence that the climate crisis, the recognition of Indigenous rights, and extraterritorial governance (EUDR) are acting as simultaneous external shocks that are compressing timelines for institutional adaptation. Legal systems developed for steady-state resource management are now being forced into the service of major change, with varying degrees of success.

For Türkiye, which has a complex state forestry tradition grounded in tradition and experience, the comparative evidence points to specific reform pathways guided by the following lessons learned from similar jurisdictions:

*Germany* the development of a systematic financial incentive program for climate-adapted silviculture could, based on Germany's forest conversion experience, promote forest conversion in a way that does not require state management to be exchanged for forest conversion. More precisely, Law No. 6831 could be revised to create a 'Forest Ecosystem Services Fund' funded by timber proceeds, directly paying for carbon sequestration, biodiversity enhancement, and water protection services.

*Sweden* While Türkiye's ownership structure does not allow direct adoption of the 'Freedom with Responsibility' model, the inclusion of result-based outcome monitoring (using Sweden-type remote sensing technology for forest monitoring) can help strengthen enforcement application while keeping its administrative burden low.

*Canada* Türkiye's forest village communities (approximately 7 million people living in or near forests) have structural similarities with Canada's Indigenous forest communities. For instance, establishing a statutory 'duty to consult' with forest village councils before management plans proceed could improve both legitimacy and adaptive capacity. The Canadian experience also warns that such provisions need sufficient institutional support to be meaningful.

*Brazil* Türkiye ought to reinforce constitutional protections against political erosion by introducing an independent 'Forest Ombudsman,' with jurisdiction to judicially challenge 2/B reclassifications and other exceptions. Brazil's experience shows that constitutional safeguards without an independent guardian of these institutions can make them vulnerable to political manipulation. The removal or strict judicial limitation of the 2/B reclassification mechanism, through which 406,202 hectares of constitutionally protected forest area have been converted, is the single most significant reform measure found in the comparison.

This comparative legal analysis of silvicultural regulation in Türkiye, Sweden, Germany, Canada, and Brazil has made three key contributions to the literature on forest governance. Firstly, the paper demonstrates that ownership structure acts as a constitutive feature – not solely as a contextual factor – resulting in five different regulatory paradigms with functionally similar but formally distinct sets of silvicultural controls. This finding goes beyond the established observation that 'ownership determines legal model' by detailing how different ownership forms lead to different regulatory outcomes. Secondly, the discovery of the 'implementation gap paradox' – where countries with the strongest formal protections have the largest implementation gaps – challenges the widely held belief that constitutional entrenchment ensures environmental protection. The proposed Regulatory-Institutional Alignment Framework provides an explanatory model based on the combined effectiveness of legal design, institutional capacity, enforcement integrity, and political commitment, which accounts for this paradox. Thirdly, the analysis shows a post-2020 turning point in global forest governance marked by three concurrent pressures: climate adaptation as the primary reform driver in Europe, Indigenous rights recognition as the main reform vector in Canada, and extraterritorial regulation (EUDR) as an emerging regulatory system. These forces are shortening the timelines for institutional adaptation and placing unprecedented demands on domestic legal systems.

It is important to note that since the legislation was translated from Swedish, German, and Portuguese, there are potential interpretive limitations. The analysis of legal texts, with a focus on *de jure* analysis supplemented by secondary evidence of implementation, should not be seen as an empirical measurement of *de facto* outcomes. While the policy developments discussed in the letter (notably the EUDR timeline, Brazilian enforcement practices, and Canadian

jurisprudence) are evolving, this will require updating particular data points.

As far as potential future research is concerned, three directions have been identified: (1) to quantify empirically the implementation gap through paired comparison of legal provisions and measurable ecological outcomes (e.g., regeneration success rates, biodiversity indicators), (2) to broaden the comparative lens to include additional governance models, particularly community-based forestry regimes in South and Southeast Asia, (3) longitudinal monitoring of EUDR implementation effects on domestic forest law reform in both EU member states and exporting countries. This evidence suggests that effective forest governance in the era of climate crisis mandates not just well-crafted legal texts, but sustained institutional alignment across the full spectrum from legal design through enforcement to political commitment.

#### ACKNOWLEDGEMENTS

The authors thank the anonymous reviewers who provided valuable feedback that improved this manuscript.

#### AUTHOR CONTRIBUTION

Üstüner Birben suggested the subject and the method of the manuscript, Figen Çakır and Üstüner Birben designed the research process, conceptualization, and methodology. Üstüner Birben conducted the legislation analysis, and Figen Çakır performed situational assessments. All authors wrote the conclusion section and final draft. All authors read and approved the final manuscript.

#### FUNDING

No funding was obtained for this study.

#### AVAILABILITY OF DATA AND MATERIAL

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

#### DECLARATIONS

'All authors have read, understood, and have complied as applicable with the statement on 'Ethical responsibilities of Authors' as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.'

#### CONFLICT OF INTEREST

The authors declare no competing interests.

## GENERATIVE AI STATEMENT

During the preparation of this manuscript, the author(s) utilized Claudia AI for the purpose of the translation of relevant foreign-language legal texts into their respective native languages. Following its use, the author(s) thoroughly reviewed and revised the content as necessary and assume full responsibility for the final published article.

## REFERENCES

- ABRAMS, J., and ELBAKIDZE, M. 2023. Adaptive governance in forest management. In *Handbook on Adaptive Governance*, Edward Elgar Publishing.
- AGRAWAL, A., CHHATRE, A., and HARDIN, R. 2008. Changing governance of the world's forests. *Science* **320**(5882): 1460–1462.
- ALLARD, C., and BRÄNNSTRÖM, M. 2021. Girjas Reindeer Herding Community v. Sweden. *Arctic Review on Law and Politics* **12**: 56–79.
- ANGELSTAM, P., MANTON, M., GREEN, M., JONSSON, B.G., MIKUSIŃSKI, G., SVENSSON, J., and SABATINI, F.M. 2020. Sweden does not meet agreed national and international forest biodiversity targets: A call for adaptive landscape planning. *Landscape and Urban Planning* **202**: 103838.
- APPELSTRAND, M. 2007. *Miljömålet i skogsbruket: Styrning och frivilighet*. Lunds Universitet.
- ATMIŞ, E., YILDIZ, D., and ERDÖNMEZ, C. 2024. A different dimension in deforestation and forest degradation: Non-forestry uses of forests in Türkiye. *Land Use Policy* **139**: 107086.
- AYDIN, A., and ELVAN, O.D. 2005. An Evaluation of Turkish Forest Legislation in Scope of the Outline of European Union Forest Legislation, Legal Aspects of European Forest Sustainable Development, Proceedings of the 11th International Symposium 2–3 May 2005. Brasov, Romania.
- BAŞKENT, E.Z., KÖSE, S., and KELEŞ, S. 2005. The forest management planning system of Türkiye: Constructive criticism towards the sustainable management of forest ecosystems. *International Forestry Review* **7**(3): 208–217.
- BIELING, C. 2004. Non-industrial private-forest owners: possibilities for increasing adoption of close-to-nature forest management. *European Journal of Forest Research* **123**(4) : 293–303.
- BMEL. 2021. German Forests: Forests for Nature and People. Federal Ministry of Food and Agriculture.
- BMEL. 2024. Der Wald in Deutschland, Ausgewählte Ergebnisse der dritten Bundeswaldinventur, [https://www.bundeswaldinventur.de/fileadmin/Projekte/2024/bundeswaldinventur/Downloads/BMEL\\_Wald\\_Broschuere\\_3\\_Auflage\\_RZ2\\_web.pdf](https://www.bundeswaldinventur.de/fileadmin/Projekte/2024/bundeswaldinventur/Downloads/BMEL_Wald_Broschuere_3_Auflage_RZ2_web.pdf). Access Date: 29.01.2026.
- BOSTON, K., and TANGER, S. 2025. Achieving sustainability while maintaining sovereignty: Do the United States Forest Act and European Union Deforestation Regulation violate the General Agreement on Tariffs and Trade?. *Journal of Forest Business Research* **4**(1): 96–105.
- BRANCALION, P.H., GARCIA, L.C., LOYOLA, R., RODRIGUES, R.R., PILLAR, V.D., and LEWINSOHN, T.M. 2016. A critical analysis of the Native Vegetation Protection Law of Brazil (2012): updates and ongoing initiatives. *Natureza and Conservação* **14** 1-15.
- BURTON, P.J. 2025. *Resilient Forest Management*. Oxford University Press.
- CALISKAN, H., BIRBEN, U., and OZDEN, S. 2025. Forest management in Türkiye: economic pressures, legal frameworks, and ecological consequences. *International Environmental Agreements: Politics, Law and Economics* **25**(1): 21–39.
- CARLISLE, K., and GRUBY, R.L. 2019. Polycentric systems of governance: A theoretical model for the commons. *Policy Studies Journal* **47**(4): 927–952.
- CASHORE, B., GALE, F., MEIDINGER, E., and NEWSOM, D. 2006. *Confronting sustainability: forest certification in developing and transitioning countries*. Press.
- CHAFFIN, B.C., GOSNELL, H., and COSENS, B.A. 2014. A decade of adaptive governance scholarship: synthesis and future directions. *Ecology and Society* **19**(3).
- COLE, D.H., EPSTEIN, G., and MCGINNIS, M.D. 2019. The utility of combining the IAD and SES frameworks. *International Journal of the Commons* **13**(1).
- COŞKUN, A.A. 2002. Forest and Forestry within the Framework of Turkish Environmental Law, *Forstwissenschaftliche Beiträge* **27**.
- COŞKUN, A.A. 2006. Legal aspects of Benefiting from Forests in Türkiye, 8th International Symposium on Legal Aspects of European Sustainable Development, Istanbul (Türkiye), May 10–14, İstanbul.
- COUNCIL OF THE EU. 2025. EUDR enforcement timeline. Press release, December 2025.
- DANIELS, L.D., DICKSON-HOYLE, S., BARON, J.N., COPES-GERBITZ, K., FLANNIGAN, M.D., CASTELLANOS-ACUNA, D., Hoffman, K.M., BOURBONNAIS, M., WILKINSON, S.L., ROESER, D., HARVEY, J.L., LAFLAMME, J., TIRIBELLI, F., WHITEHEAD, J., LEVERKUS, S.E.R., and GRAY, R.W. 2024. The 2023 wildfires in British Columbia, Canada: impacts, drivers, and transformations to coexist with wildfire. *Canadian Journal of Forest Research* **55**: 1–18.
- EBBESSON, J. 2010. The rule of law in governance of complex socio-ecological changes. *Global Environmental Change* **20**(3): 414–422.
- ECKERBERG, K. 1987. *Environmental protection in Swedish forestry: a study of the implementation process* (Doctoral dissertation, Umeå universitet).
- EKBERZADE, B., GÖRÜM, T., KARABACAK, F., AKAY, S.S., and ŞEN, Ö.L. 2025. Up in flames: the human factor behind a megafire in Mediterranean Türkiye. *npj Natural Hazards* **2**(1): 65.

- ELVAN, O.D., BIRBEN, Ü., ÖZKAN, U.Y., YILDIRIM, H.T., and TÜRKER, Y.Ö. 2021. Forest fire and law: an analysis of Turkish forest fire legislation based on Food and Agriculture Organization criteria. *Fire Ecology* **17**(1): 12.
- EPSTEIN, G., APETREI, C.I., BAGGIO, J., CHAWLA, S., CUMMING, G., GURNEY, G., MORRISON, T., UNNIKRISHNAN, H., and TOMAS, S.V. 2024. The Problem of Institutional Fit: Uncovering Patterns with Boosted Decision Trees. *International Journal of the Commons* **18**(1): 1–16.
- FOLKE, C., HAHN, T., OLSSON, P., and NORBERG, J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* **30**(1): 441–473.
- FURUMO, P.R., YU, J., HOGAN, J.A., TAVARES de CARVALHO, L.M., BRITO, B., and LAMBIN, E.F. 2024. Land conflicts from overlapping claims in Brazil's rural environmental registry. *Proceedings of the National Academy of Sciences* **121**(33): e2407357121.
- GEORGE, A.L. 2018. Case studies and theory development: The method of structured, focused comparison. In Alexander L. George: A pioneer in political and social sciences: With a foreword by Dan Caldwell (pp. 191–214). Cham: Springer International Publishing.
- GIESSEN, L. 2013. Reviewing the Main Characteristics of the International Forest Regime Complex and Partial Explanations for its Fragmentation: Une revue des principales caractéristiques du régime forestier international et des explications partielles de sa fragmentation Revisión de las características principales del complejo del régimen forestal internacional y explicaciones parciales de su fragmentación.
- GODECHOT, O. 2018. 'The Laws of Economics': Economic Devices, Economics, Economists, and the Making of the Economy.
- HALLIDAY, T.C., and SHAFFER, G. 2015. Transnational legal orders. Cambridge University Press.
- HEDER BRANDT, P., OLSSON, A., DAHLQUIST, K., and INAL, T. 2023. 'Profitability is sustainability:' framing of forest management practices by the Swedish forest industry. *Scandinavian Journal of Forest Research* **38**(7–8): 429–441.
- HERTOG, I.M., BROGAARD, S., and KRAUSE, T. 2022. Barriers to expanding continuous cover forestry in Sweden for delivering multiple ecosystem services. *Ecosystem Services* **53**: 101392.
- HOLZWARTH, S., THONFELD, F., ABDULLAHI, S., ASAM, S., DA PONTE CANOVA, E., GESSNER, U., HUTH, J., KRAUS, T., LEUTNER, B., and KUENZER, C. 2020. Earth observation based monitoring of forests in Germany: a review. *Remote Sensing* **12**(21): 3570.
- HOWLETT, M. 2001. Canadian forest policy: Adapting to change (Vol. 13). University of Toronto Press.
- HOWLETT, M., and RAYNER, J. 2006. Globalization and Governance Capacity: Explaining Divergence in National Forest Programs as Instances of 'Next-Generation' Regulation in Canada and Europe. *Governance* **19**(2): 251–275.
- KIMENGSI, J.N., OWUSU, R., CHARMAKAR, S., MANU, G., and GIESSEN, L. 2023. A global systematic review of forest management institutions: towards a new research agenda. *Landscape Ecology* **38**(2): 307–326.
- KÖSE, M., and DAŞDEMİR, I. 2023. Multidimensional analysis of the factors affecting the organizational and managerial structure of state forest management: Türkiye example. *Forest Systems* **32**(2): 3.
- KREUER, D., STUBENRAUCH, J., BORTIC, F., SCHWARZER, D., BERGHÖFER, A., and WITTMER, H. 2025. From crisis to transformation: Exploring pathways for German forest policy. *People and Nature* **7**(12): 3344–3356.
- LINDAHL, K.B., STENS, A., SANDSTRÖM, C., JOHANSSON, J., LIDSKOG, R., RANIUS, T., and ROBERGE, J.M. 2017. The Swedish forestry model: More of everything?. *Forest Policy and Economics* **77**: 44–55.
- MANN, S. 2012. Forest Protection and Sustainable Forest Management in Germany and the PR China. In Results and Documentation of a Comparative Study and the 'Fourth Sino-German Workshop on Biodiversity Conservation' 29 June–2 July 2011, Isle of Vilm (p. 311). BFN (Federal Agency for Nature Conservation), Skripten.
- MARQUES, A., MARTINS, I.S., KASTNER, T., PLUTZAR, C., THEURL, M.C., EISENMENGER, N., HUIJBREGTS, M.A.J., WOOD, R., STADLER, K., BRUCKNER, M., CANELAS, J., HILBERS, J.p., TUKKER, A., ERB, K., and PEREIRA, H.M. 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature Ecology and Evolution* **3**(4): 628–637.
- MATTHEWS, J.D. 1989. Silvicultural systems. Oxford University Press.
- MERKEL, G., and GORLEY, A. 2020. A new future for old forests. A strategic review of how British Columbia Manages for Old Forests within its Ancient Ecosystems. Ministry of Forest, Lands and Natural Resource Operations. Old Growth Review Panel, British Columbia, Canada.
- MESSIER, C., BAUHUS, J., SOUSA-SILVA, R., AUGE, H., BAETEN, L., BARSOUM, N., HELGE BRUELHEIDE, H., CALDWELL, B., CAVENDER-BARES, J., DHIEDT, E., EISENHAEUER, N., GANADE, G., GRAVEL, D., GUILLEMOT, J., HALL, J.S., HECTOR, H., HÉRAULT, B., JACTEL, H., KORICHEVA, J., KREFT, H., MEREU, S., MUYS, B., NOCK, C.A., PAQUETTE, A., PARKER, J.D., PERRING, M.P., PONETTE, Q., POTVIN, C., REICH, P.B., SCHERER-LORENZEN, M., SCHNABEL, F., VERHEYEN, K., WEIH, M., WOLLNÉ, M., and ZEMP, D.C. 2022. For the sake of resilience and multifunctionality, let's diversify planted forests!. *Conservation Letters* **15**(1): e12829. <https://doi.org/10.1111/conl.12829>
- MINGOTI, R., and da SILVEIRA, H.L.F. 2025. Deforestation and agricultural expansion in Brazil's Amazon and Cerrado biomes: 2000–2024. Intl Food Policy Res Inst.

- MISHRA, R.K., and AGARWAL, R. 2024. Sustainable forest land management to restore degraded lands.
- MURADIAN, R., and MAY, P. 2026. Innovations and Dilemmas in Global Forest Governance-The Tortuous Pathway toward a Deforestation-free World: Introduction to the Special Issue. *Ecological Economics* **241**: 108840. <https://doi.org/10.1016/j.ecolecon.2025.108840>
- NAGENDRA, H., and OSTROM, E. 2012. Polycentric governance of multifunctional forested landscapes. *International Journal of the Commons* **6**(2).
- NASUTION, A.R., FIKRI, R.A., FATMAWATI, I., and PERANGIN-ANGIN, M.E. 2025. Conflicts Between Environmental and Trade Norms: A Legal Analysis of the Application of the European Union Deforestation Regulation (EUDR) to Indonesian Palm Oil Exports Based on the GATT-WTO Legal Framework. *International Journal of Economic, Technology and Social Sciences (Injects)* **6**(1): 308–317.
- NUNES, F.S., SOARES-FILHO, B.S., OLIVEIRA, A.R., VELOSO, L.V., SCHMITT, J., VAN DER HOFF, R., ASSIS, D.C., COSTA, R.P., BÖRNER, J., RIBEIRO, S.M.C., RAJÃO, R.G.L., OLIVEIRA, U.de., and COSTA, M.A. 2024. Lessons from the historical dynamics of environmental law enforcement in the Brazilian Amazon. *Scientific Reports* **14**(1): 1828.
- NYLUND, J.E., and INGEMARSON, F. 2007. Forest tenure in Sweden—a historical perspective. Rapport 5 (SLU, Institutionen för skogens produkter).
- ODERA, J. 2004. Lessons learnt on community forest management in Africa. A report prepared for the project ‘Lessons Learnt on Sustainable Forest Management in Africa’. Royal Swedish Academy of Agriculture and Forestry (KSLA), African Forest Research Network (AFORNET) and Food and Agriculture Organization of the United Nations (FAO).
- OECD. 2025. OECD Environmental Performance Reviews: Sweden 2025. OECD Publishing.
- O’HARA, K.L. 2016. What is close-to-nature silviculture in a changing world?. *Forestry: An International Journal of Forest Research* **89**(1): 1–6.
- OLOFSSON, E., and JAKOBSSON, R. 2023. The potential to develop environmental values on privately owned forest land in southern Sweden. *Scandinavian Journal of Forest Research* **38**(5): 300–315.
- OSTROM, E. 1990. Governing the commons: The evolution of institutions for collective action. Cambridge University Press.
- OSTROM, E. 2005. Understanding institutional diversity. Princeton University Press.
- ÖZGÜR, B. 2024. Plots, farmlands, and forests: The real existential threat to Türkiye. <https://www.duvarenglish.com/plots-farmlands-and-forests-the-real-existential-threat-to-türkiye-article-64892>. Access Date: 25.01.2026.
- PAN, Y., BIRDSEY, R.A., FANG, J., HOUGHTON, R., KAUPPI, P.E., KURZ, W.A., PHILLIPS, O.L., SHVIDENKO, A., LEWIS, S.L., CANADELL, J.G., CIAIS, P., JACKSON, R.B., PACALA, S.W., MCGUIRE, A.D., PIAO, S., RAUTIAINEN, A., SITCH, S., and HAYES, D. 2011. A large and persistent carbon sink in the world’s forests. *Science* **333**(6045): 988–993.
- PINHEIRO, T.F., PINTO, J.F.S.K.C., de CARVALHO, M.A., SESTINI, M.F., PETTINATI, D.R., SANTOS, J.O., dos SANTOS, B.F., de SOUZA SOLER, L., SCHEIDE, A.D., MESSÍAS, C.G., ALMEIDA, C.A., AMARAL, S., MOREIRA, T.A., DOUSSEAU, S.L., da CUNHA MORAES, D., da SILVA COSTA, J., da SILVA COSTA, J., and NISIMURA, T.D.M. 2024. Uncovering Patterns: Data Mining the Deforestation Frontier in Brazilian Cerrado. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **48**: 401–406.
- PRZEWORSKI, A., and TEUNE, H. 1970. The logic of comparative social inquiry. Wiley.
- PUETTMANN, K.J. 2021. Extreme events: Managing forests when expecting the unexpected. *Journal of Forestry* **119**(4): 422–431.
- PUETTMANN, K.J., D’AMATO, A.W., DOCKRY, M., FORTIN, M.J., HIMES, A., PALIK, B., WARING, K., and WINDMULLER, M. 2025. Silviculture – More Complex Than Ever. *Journal of Forestry* **123**: 133–160. <https://doi.org/10.1007/s44392-025-00015-2>
- PUETTMANN, K.J., WILSON, S.M., BAKER, S.C., DONOSO, P.J., DRÖSSLER, L., AMENTE, G., HARVEY, B.D., KNOKE, T., LU, Y., NOCENTINI, S., PUTZ, F.E., YOSHIDA, T., and BAUHUS, J. 2015. Silvicultural alternatives to conventional even-aged forest management—what limits global adoption?. *Forest Ecosystems* **2**(1): 8.
- SANDSTRÖM, C., LINDAHL, K.B., and STÉNS, A. 2017. Comparing forest governance models. *Forest Policy and Economics* **77**: 1–5.
- SEAWRIGHT, J., and GERRING, J. 2008. Case selection techniques in case study research: A menu of qualitative and quantitative options. *Political Research Quarterly* **61**(2): 294–308.
- SIRY, J.P., CUBBAGE, F.W., and AHMED, M.R. 2005. Sustainable forest management: global trends and opportunities. *Forest policy and Economics* **7**(4): 551–561.
- SKOGSSTYRELSEN. 2022. Fördjupad utvärdering av miljömålet Levande skogar. Swedish Forest Agency.
- TAB. 2024. Transformation requirements for German forests by 2050. Technical Assessment Bureau. Berlin.
- THONFELD, F., GESSNER, U., HOLZWARTH, S., KRIESE, J., DA PONTE, E., HUTH, J., and KUENZER, C. 2022. A first assessment of canopy cover loss in Germany’s forests after the 2018–2020 drought years. *Remote Sensing* **14**(3): 562.
- TOLUNAY, D. 2021. Türkiye’de ekosistem tahribat faktörü olarak habitat ve arazi kullanım değişiklikleri. *Memleket Siyaset Yönetim* **16**(36): 279–304.
- UBONI, A., ÅHMAN, B., and MOEN, J. 2020. Can management buffer pasture loss and fragmentation for Sami reindeer herding in Sweden?. *Pastoralism* **10**(1): 23.
- VIÑUALES, J.E. 2024. Comparing environmental law systems. *International and Comparative Law Quarterly* **73**(1): 247–258.

WINKEL, G. 2014. When the pendulum doesn't find its center: Environmental narratives, strategies, and forest policy change in the US Pacific Northwest. *Global Environmental Change* **27**: 84–95.

YILDIRIM, H., and AYANOĞLU, S. 2014. 6292 sayılı yasa hakkında düşünceler. *Journal of the Faculty of Forestry Istanbul University* **64**(1): 1–11.

ZABEL, A., AFRIYIE-KRAFT, L., AVANA-TIENTCHEU, M.L., BANTIDER, A., BREU, T., BÜRGI BONANOMI, E., ECKERT, S., IVANOVA, Y., MONTOYA-ZUMAETA, J.G., MUSSELLI, I., OBERLACK, C., PROVIDOLI, I., SOLAR, J., SONDEREGGER, G., and ZELEKE, G. 2025. Time for change: Recommendations for action during the proposed EUDR postponement. *Ambio* **54**: 740–744. <https://doi.org/10.1007/s13280-024-02127-z>.

# An assessment of export-import performances of Nepal's wood sector: market landscape and trade indices analysis

R.B. DANGI

*Nepal Forest Service (Retired)*

Email: reshamdangi@gmail.com

---

## HIGHLIGHTS

- Forest regulations, trade policies, tariff, and trade agreements regulate the wood trade.
- Nepal has transitioned from a net importer to a net exporter for the wood sector.
- Sawn and carpentry woods have no competitive advantage, leading to a net importation.
- Ply and carved wood benefit from clustering and integration with the furniture sector.
- Existing policies should be revised to enhance wood supply, support technology transfer and create market demand for domestic timber.

## SUMMARY

The prevailing gap in knowledge surrounding to the export-import performance of Nepal's forestry sector limits the ability to properly understand the sector in general, and particularly the competitive position of the wood sector. Adopting four assessment tools: RCA, RTA, TCI, and MSI, the export-import performance of six selected wood products were evaluated. Recognizing the uniqueness and non-substitutability features of carved wood products, the paper proposes targeting an international niche market and adopting a product differentiation strategy. The paper concludes by proposing recommendations for revisiting policies to enhance access to input products for domestic industries, support technology transfer, and create market demand for domestic timber, at least in public-financed construction works.

Keywords: wood sector, trade performance, competitiveness, product-differentiation, export duty, cost disadvantage

---

## INTRODUCTION

Nepal is divided into five physiographic regions: Terai (plain), Churia (Siwalik/foot-hills), Middle Mountains, High Mountains, and High Himalaya sharing 14.4%, 12.7%, 29.5%, 19.7% and 23.7% landmass, respectively (DFRS 2015). Moreover, the country exhibits all major climate types due to elevation gradients (Peel *et al.* 2007). The southern plains and mid-hills fall under the Indomalayan realm and the northern part falls under the Palearctic realm representing it as a biographical transition zone (Olson *et al.* 2001). The Census administered by the National Statistics Office (NSO) recorded a total population of 29,192,480, which is shared by the Terai, Hills, and Mountains at 53.7%, 40.3%, and 6%, respectively (NSO 2021). The southern plain is highly populated due to suitable land for intensive farming, and holds almost 55% of the total cultivated lands, whereas Hills and Mountains share 35% and 10%, respectively (Timilsina *et al.* 2019). Since the Terai has improved access to public infrastructures, this region is host to agro-based processing industries which export surplus production. With improved road access, the urban cities of the Terai and hills expanded manufacturing industrial estates, targeting the input products and labor availability.

Approximately 44% of Nepal is under forest cover with a further 2.7% classified as other wooded land (FRTC 2024).

Forest distribution pattern, accessibility status, and the commercial potential of existing forest varies throughout the five physiographic regions of the country, as shown in Table 1.

The Terai is highly fertile, densely populated, and recognized as the country's food basket and hub of the manufacturing industry. As a consequence, there is pressure on forests to extract from them high-value tropical hardwoods, expand agricultural land, and develop industrial estates. The Churia forests are also a potential source of tropical hardwoods, however, the government has enforced stringent harvesting standards for commercial timber harvesting in forests above 19-degree slopes to protect fragile watersheds (GoN 2017). The forests in the mid-hills are fragmented and managed by local communities as Community Forests (CF). These Mid-hill CF are underutilized due to rapid outmigration and increased access to wood substitutes for household energy and building materials. As a result, CF contributed to the restoration of degraded forests in the Mid-hills. The mountain forests are in remote topography, where population density and transportation facilities are poor which makes these forests expensive for timber production. However, High Mountain forests are valued for hosting high-value and low-volume medicinal herbs and extracts. Due to less human pressure, forests have low extractive potential, leading the High-mountain and the High Himalaya to be relatively intact.

TABLE 1 A snapshot of Nepal's forests and their extractive potential (DFRS 2015)

Region	Forest Cover	Stem Vol. (m <sup>3</sup> ha <sup>-1</sup> )	≥50 cm DBH stems/ha	Forest type	Extractive potential
Terai (plain)	6.9%	161.66	35.61	Tropical/Sub-tropical broadleaved forests	High due to road access to tropical hardwood forests & clustered wood industries.
Churia (foot-hill)	23.0%	147.49	48.79	Sub-tropical broadleaved/ conifer	Moderate due to fragile ecosystem.
Mid-hill	37.8%	124.26	39.32	Sub-tropical broadleaved/ conifer & Temperate broadleaved	Forests are fragmented and mostly managed by the local communities, as Community Forests (CF). They have low potential due to high extraction and delivery costs.
High-Mountains	32.3%	225.24	53.18	Sub-alpine conifer forest	The remote location and difficult terrain makes them less accessible. Forests have lower commercial value due to excessive extraction and delivery costs.
High-Himalaya				Montana grasslands & shrub lands	

The Constitution empowers the government to adopt policies relating to the protection, promotion, and use of natural resources (MoLJPA 2020), and the federal parliament legitimizes legal frameworks to govern natural resources, including the forests. The Ministry of Forests and Environment (MoFE) is empowered by the Government of Nepal (GoN) to regulate all types of forests and environment-related issues in the country. Forests are regulated by two federal Acts, the National Parks and Wildlife Conservation Act 1973 (MoLJPA 2025<sup>1</sup>) and the Forest Act 2019 (MoLJPA 2025<sup>2</sup>), and their respective Bylaws, guidelines, and directives.

The Forest Act governs all types of forests, outside the Protected Area (PA), which is known as the National Forest (NF). The NF accounts for almost 82.7% of forests, and the PA accounts for 17.3% (DFRS 2015). The NF generally refers to the natural forests managed by the state and non-state agencies. The Forest Research and Training Centre (FRTC), under the Ministry of Forests and Environment (MoFE), periodically updates the forest area by using remote sensing images supplemented with field verification in predetermined permanent sample plots. Since images cannot distinguish between forests that are either privately or publicly owned, there is doubt about including both under the category of forests. Therefore, while analyzing the NF data sets, such limitations need to be considered.

The state-managed NF includes two regimes: protected and managed forests. The protected forests do not contribute to the domestic timber market due to restrictive harvesting standards, but the government-managed forests (GMF) do. Similarly, the NF managed by non-state actors adopts four different management modalities based on the rights and concessions in management contracts: Community Forests (CF), Collaborative Forests (CoF), Religious Forests, and Leasehold Forests. The CF and CoF, collectively named Community-Based Forest Management (CBFM), contribute to the domestic timber market. Whereas the religious and leasehold forests do not. Therefore, the term forest refers to all types of forests in this paper, but economic potential of each forest types is determined by its property rights arrangement, harvesting standards, and market access.

In domestic timber market, the GMF and CBFM are two important sources of hardwood timber for the construction and manufacturing sectors. In this paper, the term hardwoods refers to the hard, heavy, and durable timber produced from broadleaved forests, used as building construction materials. Similarly, plantation forests are recognized as industrial plantation forests (IPFs), which contribute to supplying softwoods for the local veneer, plywood, and furniture-making industry.

The escalated migration of the working population from rural to urban areas has elevated labor costs, making agro-activity less attractive, and farm lands are abandoned as underutilized lands (UUL). The expansion of UUL has led farmers towards less labor-intensive agro-forest activities, one of which is tree planting to maintain private ownership in those UULs. The expansion of forests and shrub lands aligns with the agriculture sector census, which reveals that agricultural land has decreased by 0.3 million hectares from the 2.52 million hectares reported in 2011/12 (NSO 2023).

Private forests consist of numerous small farmers who dominate the input product market for veneer sheets, plywood, and the furniture industry. Furthermore, the wood carving industry also relies on private forests for input products.

## OBJECTIVE

A systematic literature review confirmed that trade-related systematic data for the wood sector were available for 2013 onwards. A comprehensive study on export-import performance of the wood sector was lacking, which limited the ability to properly understand the competitive position of this sector. Acknowledging such limitations, there was justification for a national-level performance assessment of this sector to contribute to enhancing its competitive position. Therefore, the objective of this paper is to assess the competitiveness of the wood sector through market landscape analysis and trade performance indicators in order to propose recommended strategies for enhancing the forestry sector performance and its export potential.

## RESEARCH METHODS

## Methods and Tools

A hybrid approach was adopted, combining qualitative and quantitative analysis, to evaluate external and internal drivers, focusing on the market landscape and competitiveness of Nepal's wood sector. Integration of both contributed to understanding the wood sector's competitive position, strategic advantage, and empirical validation of wood products.

The market landscape analysis included drivers influencing the domestic timber market and visualized cost-driving forces to highlight strategic leverage. To evaluate competitiveness, four assessment tools were used: Revealed Comparative Advantage (RCA), Relative Trade Advantage (RTA), Trade Competitiveness (TC) Index, and Market Share Index (MSI), most of which were already adopted in the wood sector (Thamiam 2011). The assessment results are presented in Table 2, sourcing from various authors (Tyzynski 1951, Richardson 1971, Fagerberg and Solie 1987, Cooper *et al.* 1988, Danna-Buitrago and Stellian 2022).

## Data sources

The raw timber production-related annual data were extracted from two secondary sources – MoFE (2024) and Dangi (2024). The national-level annual export-import data were sourced from the Customs Department's official website for six years (DoC 2019/20, 2020/21, 2021/22, 2022/23, 2023/24, 2024/25). Similarly, global-level export-import data were extracted from the UN website for the year 2024/25 (United Nations 2024, 2025).

The trade-related databases are maintained in a standard, universally accepted system known as the Harmonized System (Harmonized System n.d.) which is adopted for many other purposes, including trade policies and taxes, and it uses 6-digit numbers. The first two digits designate the chapter, the second two digits designate the heading, and the last two digits designate the subheading. Following this system, the wood sector-level analysis included products listed under HS-Codes 440111 to 442199. For product-level assessment,

six products were selected from the following 4-digit numbers: 4403, 4407, 4408, 4412, 4418, and 4420. The first two digits 44 refer to Chapter 44, which includes raw and manufactured wood products. The next two digits specify the type of woods, such as 03 referring to round timber and 07 to sawn timber. The detailed features of selected wood products are shown in Table 3.

The export-import performance assessment used six year data (July 2019 to June 2025). Two products were considered as key substitutes for wood materials. The selected substitutes included the Poly Vinyl Chloride (PVC) and Aluminum products, listed in the HS-code 39252000 to 39259090 and 76042100 to 76042900, respectively. However, Aluminum-based wires, foils, PVC-based reservoirs, and tanks were excluded as non-substitutes. The import trends of these substitutes were considered while analyzing the timber export and import trends in the domestic market.

## Limitations

The significance of multiyear data in evaluating the competitiveness of the wood sector is acknowledged. However, due to resource constraints, this study utilized single year data for assessing competitiveness of six wood products.

## RESULTS

## Market landscape analysis

A clear understanding of external and internal forces helps in framing the prevailing issues and developing evidence-based production strategies. Considering the prevailing slackness in the national economy, particularly timber users such as the construction and manufacturing sectors, there is a need to evaluate the strengths, weaknesses, opportunities, and threats (SWOT) in the domestic timber industry to mitigate business risk. A critical review of the timber supply chain, exporting competitive products, advancing technology, and influencing policy instruments is considered useful in developing production strategies and scoping the market.

TABLE 2 General features of tools used in measuring competitiveness of wood products

Tools	Formula	Variables	Interpretation
$RCA_i$	$RCA_i^a = (X_i^a / X^a) / (X_i^w / X^w)$	$X_i^a$ = export of commodity $i$ by country $a$ $X^a$ = total exports of country $a$ ; $X_i^w$ = global exports of commodity $i$ ; $X^w$ = total global exports	score > 1 means $i$ is competitive; but < 1 non-competitive
$MSI_i$	$MSI_i = X_i^a / X_i^w$	$X_i^a$ = export of commodity $i$ by country $a$ $X_i^w$ = global exports of commodity $i$ ;	% contribution of a country in world export of $i$ ( $X_i^a$ )
$RTA_i$	$RCA_i^a - ((M_i^a / M^a) / (M_i^w / M^w))$	$M_i^a$ = imports of $i$ by country $a$ ; $M^a$ = total imports of country $a$ ; $M_i^w$ = global imports of commodity $i$ ; and $M^w$ = total global imports;	> 0 hints at $i$ is competitive; < 0 hints disadvantage
$TCI_i$	$((X_i^a - M_i^a) / (X_i^a + M_i^a))$	$X_i^a$ = export of commodity $i$ by country $a$ ; $M_i^a$ = imports of $i$ by country $a$ ;	> 0 hints at $i$ is competitive; and < 0 is disadvantage

TABLE 3 Selected wood-based commodities, and their respective codes

SN	Features of Wood-based product segments	HS-Codes
1	wood in the rough, whether or not stripped of bark or sap wood or roughly squared	4403
2	sawn wood of thickness exceeding 6mm	4407
3	veneering for plywood/ laminated wood, and sawn lengthwise of thickness < 6mm.	4408
4	plywood, veneered panels and similar laminated woods	4412
5	Builders joinery and carpentry of woods, including wood panel/flooring panels	4418
6	Wood marquetry, carved decorative wood, statuettes, ornaments, art and craft objects	4420

*Timber supply trend:* The national-level forest inventory indicates an average growing stock of 164.76 M<sup>3</sup>/ha in 4.93 million ha of NF (DFRS 2015). Since no survey-based estimate is available for private forests, a conservative assumption of 15 percent of the NF is estimated to be 0.74 million ha (Dangi 2024). There is a gap between the projected and actual timber supply in the domestic market (DoF 2015, MoF, 2024, MoFE, 2024, 2025). Figure 1 below illustrates that domestic market supply trends are generally increasing, although significant fluctuations are evident. Administrative barriers and unpredictable natural disasters have disrupted the timber production and supply chains. The administrative barriers have particularly impacted CBFM regimes, while natural disasters, earthquakes, and the COVID-19 outbreak have impacted across all forest regimes.

Nepal experienced a devastating earthquake on 15 April 2015, of magnitude 7.8, which damaged over 100 000 private houses in Kathmandu alone (Kadel *et al.* 2023). The round timber required for the reconstruction of damaged houses in 40 district was estimated at 1.48 million m<sup>3</sup> (MoFSC 2015). Furthermore, the report acknowledged that the short supply of domestic timber will create space for the market to manage demand through imports of construction wood and substitutes. The construction activities were at a high pace during the reconstruction phase (2016–2021), and the country experienced a shortage of wood-based construction materials in the domestic market. Since timber supply from domestic sources

was less than demand, the market responded by increasing imports of construction wood and substitutes, as shown in Figure 2 below.

As the reconstruction phase approached exit, the country was hit by the COVID-19 outbreak in 2020, which caused stagnation in economic activities across all sectors. As a result, there was a reduced demand for hardwoods in the construction sector and softwoods in the manufacturing sector during the post-COVID-19 period. By amending the Forest regulation, GoN lifted the export ban on timber (GoN 2022) and reduced its export duty by quadruple (DoC 2024). The foreign trade statistics (FTS) confirmed that both policies positively contributed to enhancing exports of wood products and reducing imports of construction timber and substitutes, as shown in Figure 2. The increased export aligns with the trends of raw timber supply in Figure 1 above.

Softwood timber supply from private forests escalated after the Fifth Amendment in the Forest Regulation 1995 (GoN 2015). The deregulated harvesting and transport permits have contributed to pushing timber supply in the domestic market, as shown in Figure 1. Despite the revision in export duty, hardwood supply from GMF and CBFM did not improve as expected. Both sources underperformed due to stringent harvesting standards and administrative hurdles. Therefore, an uncertain and unpredictable supply chain increases transaction costs and risks of losing competitiveness in the market.

FIGURE 1 Raw timber supply trends in the market (Source: MoF 2024, MoFE 2024, 2025)

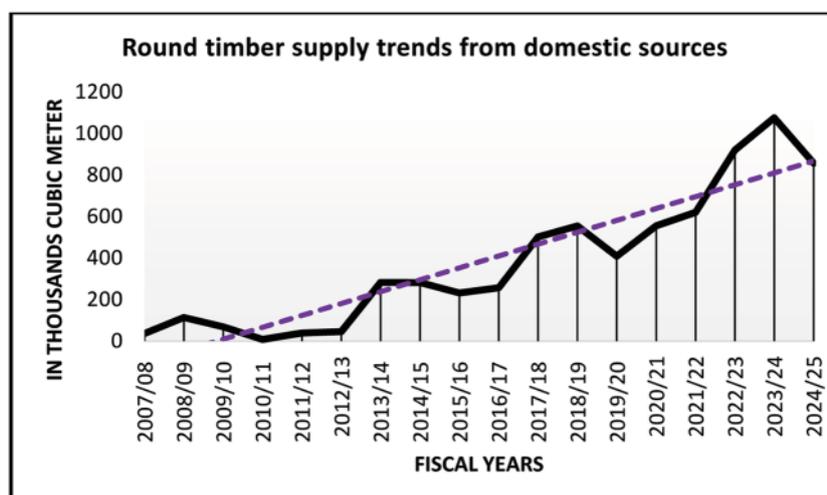
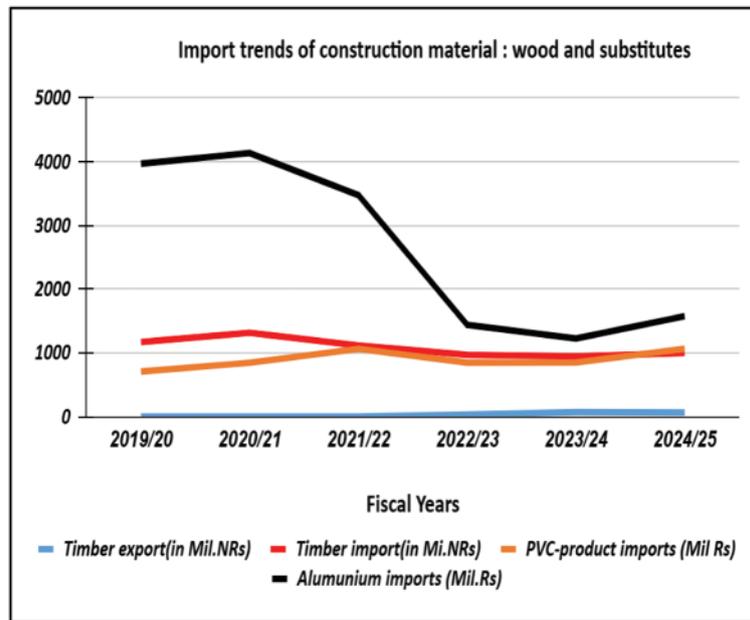


FIGURE 2 COVID-19 impacts in the trade pattern of timber and substitutes (FTS 2019–2025)



*Revealed competitiveness:* The industrial survey highlights that furniture making represents approximately 85% shares of the domestic wood-based industry (NSO 2022), which requires two input products: plywood and small-sized sawn softwoods. It is noted that the plywood market flourished during the post-earthquake reconstruction phase for its reasonable costs, durability, workability, and availability in the domestic market. As a consequence of increasing demand from the construction sector, the veneer and furniture-making sectors had opportunities to grow.

The plywood industry required peeled veneer sheets, which fueled the expansion of the veneer industry. Since the veneer industry required less skilled labor, they concentrated in the locations where softwoods were available. In contrast, plywood makers required skilled labor, and they concentrated in the urban areas of the Terai to ease exports. The veneer producers targeted accessible Mid-hills and the Terai to secure the required softwood logs. However, the required sawn timber for the furniture sectors was produced from local small and medium-sized sawmills.

There are 80 plywood-producing firms that have established 100 veneer-sheet producing units to supply 80 percent of their demand for the Veneer-sheets (TRN 2024). It shows that the remaining 20 percent of demand is met from imports. Nepal also exports veneer sheets to India (Plyreporter 2024). Therefore, the veneer industry has the potential to substitute imports by enhancing production capacity and reducing the cost, and export the domestic surplus.

The input products required by the furniture-makers are price-sensitive due to the availability of various categories of similar products in the market. Similarly, required hardwoods for the construction sector are supplied by sawmills concentrated in the Terai region. Moreover, sawn hardwood is also price-sensitive due to the availability of alternative materials in the market. The export performance shown in Figure 3

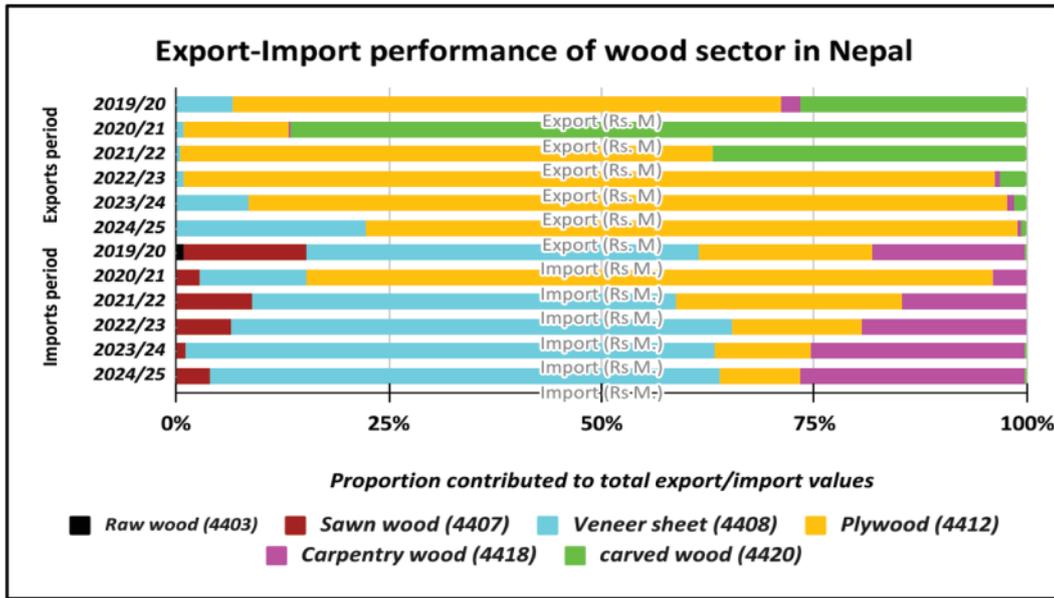
confirms that plywood reveals strong competitiveness due to its low cost advantage in conifer and tropical plywood. Since FTS indicates imports of cheap plywood, this suggests adopting a cost-focused strategy targeting the niche market for sub-tropical plywood to increase the cost of switching to imports for the furniture industry.

Terai-based sawmills supply timber to the construction sector, which includes so-called branded hardwoods, such as *Shorea robusta* and *Terminalia tomentosa*. Due to the under-supply of hardwoods, their export base is small, as shown in Figure 3. Moreover, they supply high-quality furniture-making sawn woods, such as *Dalbergia sissoo*, *Dalbergia latifolia*, and *Tectona grandis*. Since these hardwoods are available in tropical and subtropical forests, they influence the input product market of the construction sectors.

The import trends of carpentry wood products exhibit an increasing trend, positioning Nepal as a net importer. The export value of carved wood products outweighs the total imports of similar products, justifying its competitiveness. However, firms producing carved wood products face supply constraints for input products and skilled labor, which limit their production capacity and marketplace. Therefore, it positions Nepal as a net exporter in the international niche market.

*Advancing technology:* Products lose their competitiveness when close substitutes improve their costs and performance. The immediate substitutes of plywood include fiberboards and particle boards in the furniture-making sector. The construction sector uses polyvinyl chloride (PVC) and aluminum products as alternative building materials for timber. Similarly, wood-plastic composites and high-tech engineered woods are considered potential future substitutes for plywood. Therefore, the revealed competitiveness of plywood will be eroded when cutting-edge technology reduces its cost and improves the performance of alternatives, leading plywood products into a volatile market.

FIGURE 3 Export-Import performance of six wood products (FTS of July 2019 to June 2025)



Nepal stands among the highest remittance-receiving countries, roughly one-third of GDP, which has pushed up the marginal cost of labor relative to capital. As a result, labor-intensive activities, such as harvesting, sectioning, log delivery, veneer sheet drying, sheet sorting and stacking, and trimming, are becoming expensive. The low interest rate in the domestic financial market and lower acquisition cost for forest operation machines indicate that the user cost of capital is moderate. Since capital and labor are highly substitutable, the credit constraint is moderate to accessing capital for automation.

Since hardwood forests are limited, the timber supply is a binding constraint, and capital investment in this segment may increase the capital-labor ratio but may not increase output, as expected. Therefore, sawn timber producers targeting the construction sector may consider switching from cost-minimization (factor substitution) to value appreciation production strategy in order to enhance efficiency per unit volume. With that background, hardwood products must focus on investing capital for efficiency improvement and adopt strategic targets for the local market.

Unlike hardwoods, the softwood supply chain is relatively smooth due to the overwhelming share of private sources in the domestic market. Moreover, the elasticity of labor substitutions is high, indicating that softwood processing firms can reasonably substitute labor with capital invested in machines. The veneer and plywood maker may consider investing capital in the automated peeling, drying, and pressing machines. Therefore, veneer and plywood products need to adhere to the strategic advantage of low cost and broader markets.

Certain products require skilled labor, where the elasticity of substitution is low. In such products, the anticipated negative effect of remit-driven wages must be addressed by adopting labor productivity enhancement and product differentiation strategies. Carved wooden products are one of such segments which, due to their unique features created by

highly skilled labor using a special type of raw timber, are export competitive and capable of capturing premium prices. The limited market supply enables the carved wood industry to sell its products in the international market. Therefore, despite limited export volumes, they are competitive due to quality differentiation and strong cultural foundations. At the outset, this industry may consider focusing on product differentiation targeting niche international markets.

*Policy influence:* The GoN enforced a high export duty on raw products when domestic industries were in their infancy. Now, the GoN has lifted export bans and reduced export duty. The weak export performance in raw and sawn timber indicates their cost disadvantages, while steady growth in the veneer and plywood sectors reflects their advantages. Therefore, export duty of NRs 6/kg for veneer sheet (MoICS 2018, p.163) enabled a competitive position. Similarly, the export duties of NRs 15/m<sup>3</sup> on plywood and NRs 15/kg on carpentry woods (NBSM 2022, p.126) were supportive in positioning both products competitively. It implies that a high export duty functions as a trade barrier, and a fair duty facilitates exports.

The export performance of raw and sawn timber was lower due to the high export duty. The GoN reduced the duty by quadruple to respond to the contracted domestic demand. The recent export performance reveals that it contributed positively, but insignificantly. The customs duty has been increased to 100% from 50% (NBSM 2025) although the implications are yet to be studied.

It is worth noting that the export performance of plywood and veneer sheets increased after being listed as export preferential commodities (DoI 2022, 2023). Therefore, such trade-friendly policy measures positively contribute to boosting exports. Moreover, automation reduces risks for supply shocks and foreign exchange fluctuations. The GoN may consider adopting an industrial policy to incentivize processing industries to cluster in spatial locations where backward and forward functional linkages are well established and potential

TABLE 4 Business strategies for wood products in domestic timber industry in Nepal

Strategic Targets	Strategic advantages	
	Lower cost	Differentiation
<b>International Market</b>	Cost effective production of veneer sheets for plywoods responding to prevailing contractionary economy aiming to transition towards product differentiation strategy, when economy resumes back.	Overall differentiation of Pine made plywood (limited resource but unique features), unique carved wood products of Nepal listed under HS-Code 4418, and carved wood marquetry products under HS-Code 4420 targeting international niche market to capture premium prices for their nonsubstitutability nature.
<b>Domestic Market</b>	Low cost focussed production of branded hardwoods, such as <i>Shorea robusta</i> listed under HS-Code 4407 to off-set imports of similar items.	Focus on differentiation of wooden kitchen wares listed in HS-Code 4419 to enhance their competitive position in the domestic market to reduce imports.
<b>Source of competitive advantages</b>		

for reinforcement. Based on the above analysis, production strategies for six wood products are presented in Table 4.

### Trade competitiveness assessment

The export–import performance of selected wood products were evaluated using four assessment tools. Their results are outlined below.

*Revealed Comparative Advantages index:* The RCA was introduced to measure the export performance of the country for a specified product relative to the global average, and it is used to identify competitiveness based on the trade data of the respective country (Balassa 1965). It expresses the relative competitiveness of a specific sector or product segment, and benchmarks competitiveness based on export performance. Adopting Balassa equation (1) below.

$$RCA_i^n = ((X_i^n / X^n) / (X_i^w / X^w)) \quad (1)$$

The numerator  $X_i^n / X^n$  refers to the ratio of export of commodity  $i$  to total exports of Nepal. Similarly, the denominator  $X_i^w / X^w$  refers to the ratio of global exports of commodity  $i$  to total global exports. The  $X_i^n$ ,  $X^n$  values were extracted from the FTS (DoC 2024, 2025) and  $X_i^w$ ,  $X^w$  values were extracted for the period July 2024–Jun 2025 from the UN-website (United Nations 2024, 2025), and result presented in Table 5. However, RCA is considered as a first-level diagnostic tool

due to remit-driven wage inflations and further validated with additional tools to draw on corrective measures.

*Relative Trade Advantage (RTA) index:* This was introduced by Vollrath, to address asymmetry issues of export-focussed analysis and combines relative export advantage and relative import penetration into a single index (Vollrath 1991), as shown in equation (2) below.

$$RTA_i^n = RCA_i^n - ((M_i^n / M^n) / (M_i^w / M^w)) \quad (2)$$

In this equation, the first part refers to the RCA of six commodities, and the remaining part refers to the relative import penetration of them. The  $M_i^n$  and  $M^n$  denote the imports of six commodities and total imports of Nepal, respectively. The  $M_i^w$  and  $M^w$  denote the global imports of six wood products and total global imports, respectively. The required data for  $M_i^n / M^n$  value extracted from FTS (DoC 2024, 2025) and  $M_i^w$  and  $M^w$  from the UN-website (United Nations 2024, 2025). These data were used in equation (2), and the assessment result is given in Table 6.

From the above table, carved wood, veneer and plywood hold strong competitive advantages, and raw timber has weak advantages. However, the sawn timber and carpentry wood have disadvantages due to domination of imported commodities in the domestic market. However,

*Trade Competitiveness (TC) index:* This tool enables to explain the country's status on foreign trade balance and

TABLE 5 Revealed competitive advantage assessment of six wood products

Commodities	$X_i^n$ in \$	$X^n$ in \$	$X_i^w$ in \$	$X^w$ in \$	RCA	Interpretation
Raw timber	89467	1980663127	1982536985	16731484142027	0.38	non-competitive
Sawn timber	729		28486001357		0.0002	non-competitive
veneer sheet	14749950		2610938939		47.72	competitive
Plywood	50713220		9423269642		45.46	competitive
Carpentry wood	360874		11119119426		0.274	non-competitive
Carved wood	1683463.2		1325584810		10.73	competitive

(Note: Exchange rate for 1 \$= NPR 139.87. Adopted Hinloopen and Van Marrewijk (2001) to interpret as follows:  $0 < RCA < 0.8$  for non-competitive,  $0.8–1.25$  for neutral,  $1.25–2.5$  for weak trade advantage, and  $>2.5$  for strong advantage)

TABLE 6 Relative trade advantage assessment for six wood products of Nepal

Commodities	RCA <sub>i</sub> <sup>n</sup>	M <sub>i</sub> <sup>n</sup> (\$)	M <sup>n</sup> (\$)	M <sub>i</sub> <sup>w</sup> (\$)	M <sup>w</sup> (\$)	RTA <sub>i</sub> <sup>n</sup>	Interpretation
Raw timber	0.38	13884.7	12,898,807,944	8,758,156,764	18,265,533,650,676	0.38	competitive
Sawn timber	0.0002	93810.3		29,879,051,970		-0.004	non-competitive
Veneer sheet	47.72	14,243,340		3,383,305,335		41.81	competitive
Plywood	45.46	2,290,570		13,383,161,312		43.06	competitive
Carpentry wood	0.274	6,195,053.31		14,749,539,742		-0.727	non-competitive
Carved wood	10.73	1,683,463		1,811,633,229		9.41	competitive

(Note: Exchange rate for 1 \$ = NPR 139.87)

reflects the role of foreign trade in the domestic economy (Vu *et al.* 2019). Comparing domestic trade to global trade, using required data from Table 5 and Table 6 above in equation (3) below, the competitiveness of six wood products are presented in Table 7.

$$TCI_i^n = ((X_i^n - M_i^n) / (X_i^n + M_i^n)) \quad (3)$$

*Market share (MS) Index:* This tool was introduced by the League of Nations and GATT (Tyszynski 1951). Adopting equation 4 below and employing data from above Table 5, the results for six wood products are given in Table 8 below.

$$MSI_i^n = (X_i^n / X_i^w) * 100 \quad (4)$$

The  $X_i^n / X_i^w$  ratio refers to export of commodity  $i$  from Nepal to global export of commodity  $i$ . The result expresses the percentage share of Nepal in the global exports for commodity  $i$ . The higher value is interpreted as the absolute presence of commodity  $i$  in the global market. The required values for  $X_i^n$  were extracted from FTS (DoC 2024, 2025) and  $X_i^w$  from the UN Comtrade (UN 2024, 2025). Since Nepal

cannot be key players in the global market due to its small economy and limited capacity to modernize its production technology. Therefore, the result of  $MSI_i^n$  is paired with  $RCA_i^n$  and proposed three products competitive and the rest not.

Table 8 shows that the position of plywood holds strong competitive advantages, veneer has a fragile advantage, and round wood has a small export base due to surplus products because of stagnated economic activities. Moreover, carpentry and sawn timber are considered non-competitive products due to strong competition with rivals in the domestic market. However, carved wood has export potential, but in limited volume to capture a premium price from a secured niche market.

## DISCUSSION

Many countries, including Nepal, enforced raw log export bans and adopted strict regulation against trans-boundary trade in order to foster their domestic industries to capture

TABLE 7 Trade competitiveness assessment for six wood products of Nepal

Commodities	X <sub>i</sub> <sup>n</sup> (\$)	M <sub>i</sub> <sup>n</sup> (\$)	TCI <sub>i</sub> <sup>n</sup>	Interpretation
Raw timber	89467	13884.7	0.73	Competitive advantages, but doubtful
Sawn timber	729	93810.3	-0.98	Net importer due to strong competition
Veneer sheet	14749950	14,243,340	0.02	Fragile and less export advantages
Plywood	50713220	2,290,570	0.91	Outstanding export competitive advantages
Carpentry wood	360874	6,195,053.31	-0.89	Net importer due to strong competition
Carved wood	1683463.2	1,683,463	0.000001	Competitive advantages in niche market

(Note: Adopting Vu and *et al.* (2019),  $0.8 < TCI_i^n \leq 1$  value for outstanding competitive advantage,  $0.5 < TCI_i^n \leq 0.8$ , for higher advantages, and  $0 < TCI_i^n \leq 0.5$  for no advantages)

TABLE 8 Summary of trade competitiveness assessment results of six wood products

HS-Code	Commodities	RCA	RTA	TCI	MSI	Result interpretation
4403	Raw timber	0.38	0.38	0.73	0.005	Small export base due to surplus
4407	Sawn timber	0.0002	-0.004	-0.98	0.000003	Net importer due to competing rivals
4408	Veneer sheet	47.72	41.81	0.02	0.56	Fragile net exporter due to rivals
4412	Plywood	45.46	43.06	0.91	0.54	Net exporter with trade advantages
4418	Carpentry wood	0.274	-0.727	-0.89	0.0032	Net importer due to competing rivals
4420	Carved wood	10.73	9.41	0.000001	0.127	Net exporter in secure niche market

revenue from value-additions (SPFP 2016, Mariya-Sube and Woodgate 2019, Apeti and N'Doua 2023). The export bans caused market distortions in Southern Thailand, Viet Nam, and the Philippines (Muhamad 2000, Lakanavichian 2001, Tuynh and Phuong 2021, Guiang 2001) and countries such as Indonesia and Malaysia, adopted raw log export bans and enhanced their domestic earnings by exporting processed products (Lakanavichian 2001, Hyde 2003, Islam *et al.* 2010).

Bhutan and India extended forest cover by enforcing export bans and strict regulations, respectively (Namgyal 2025, Ghosh and Sinha, 2016). Sri Lanka reduced timber price and illegal logging by enforcing reduced import tariffs (Weerahewa and Gunatilake 2010). Nepal enhanced exports of processed products by adopting a modest export duty. Generally, labor-abundant nations earn by trading labor-intensive products and capital-abundant countries earn by capital-intensive products. Nepal used to be a labor-abundant country, but rapid outmigration has eroded its comparative advantages on labor-intensive productions.

The concentrated sawmills and plywood in the Terai region where cross-border labor mobility is high, challenges classical comparative advantage theories. Heckscher-Ohlin and Factor Price Equalization (Balassa 1965, Leamer 1995, Samuelson 1948). Labor mobility is stimulating the clustering of wood industries, which indicates labor endowments alone cannot lock-in the comparative advantages for Nepal. This implies that impediments in trade stimulate factor movements and factor mobility barriers stimulate trade in goods, indicating scope of factor substitution (Mundell 1957). Ghimire *et al.* (2021) claim that capital-intensive production decisions depend on community infrastructure, which hints at alternative approaches that can internalize spatial and agglomeration dynamics in order to enhance competitiveness.

As a consequence, existing wood industries in the Indo-Nepal border cities offer empirical evidence that the factor

proportion theory (H-O model) provides a necessary baseline to understand potential comparative advantages, but not sufficient to conclude competitiveness. The core-periphery and industrial clustering model of Krugman (1991) suggests that underlying forces for agglomeration reduce cost and create a self-reinforcing loop by developing a thick labor market in the core area. Therefore, the clustering in the Indo-Nepal border is justified for prevailing infrastructures, labor mobility, and producer-buyer networks, and forest-rich hills and mountains are left behind as periphery due to weak infrastructures.

Referring to the Krugman-model, Venables (1996, 2000) considered that linkages between the raw product suppliers (backward linkages) and processed product suppliers and vice-versa reduced delivery cost to market (forward linkage). Since concentrated industries have the opportunity of taking advantage from knowledge spillovers and mutual learning, the veneer producers target softwood forests (backward linkages), and plywood clusters in Indo-Nepal border targeting the domestic and global market (forward linkage). Similarly the hardwood sawn timber producers target hardwood forests (backward linkages) and they are clustered in the Terai regions targeting the domestic market and exports (forward linkage).

The industry owners producing plywood and veneer products have the advantages of clustering and integrating with the furniture-making industries to benefit from cross-sectorial knowledge, technology, and skill transfers. Moreover, the raw log and sawn timber industry segments indicate that they are facing cost disadvantages due to inefficient production and trade barriers. Drawing results from Tables 4 to 8, Table 9 presents the competitiveness in the global market and required policy interventions to enhance the competitiveness of respective products.

TABLE 9 *Nepal's trade performance in wood sector and recommended policy intervention*

Products	Country position	Strategic target	Policy intervention
Raw logs	Non-specialized net exporter	Strategic advantage in reducing costs and targeting the domestic market.	Reduce import tariff on tools to reduce production loss. Revise royalty rate & Export duty to reduce cost.
Sawn timber	Non-specialized net importer	Strategic advantage in reducing costs and targeting domestic markets.	Reduce export duty and list it under export preferential commodities. Make timber use mandatory in public works to boost demand.
Veneer sheet	Specialized but fragile net exporter	Strategic advantage in reducing costs and targeting international markets.	Enhance softwood supply from GMF, CBFM and deregulation in private forests. Credit facility for investment in automation.
Plywood	Specialized net exporter	Strategic advantage in reducing costs and targeting international markets.	Selfreliant in domestic supply of input products (veneer sheets)
Carpentry wood (aggregate)	Non-specialized net importer	Strategic advantage in differentiation and targeting domestic markets	Policies for raw logs and sawn timber will substitute imports by domestic woods
Carved wood products	Niche market exporter for carved wood	Strategic advantage in product differentiation and targeting international niche markets.	Support exports organizing trade fairs linking with tourism. Encourage product branding and certification.

## CONCLUSIONS

The timber trade in Nepal has been strictly regulated, with export restrictions and a heavy export duty imposed to foster domestic industries. After adopting liberal trade policies, export restrictions were lifted, and export duties on raw and sawn timber were reduced. Despite that effort, export performance did not improve due to labor migration-induced wage inflation. In contrast, the export performance of veneer, plywood, carpentry and carved woods performed well due to a modest export duty. Combining the results from quantitative indices with a strategic framework constructed from qualitative analysis, Nepal's position with its trade partners is proposed, as follows:

- 1) *Specialized exporter*: plywood is proposed in this category due to high index values for RCA, RTA, MSI, and TCI tools.
- 2) *Specialized but limited and fragile exporters*: veneer products are included here due to high indices for RCA, RTA, and MSI, but low in TCI which indicates that it has limited net export strength due to imports of similar products.
- 3) *Non-specialized net exporter*: raw log products are included for moderate TCI, and lower values for others. It has a minimal export base due to a contracted domestic market and reduced export duty in 2024, but recently increased duty raises doubts about its competitiveness in the future.
- 4) *Non-specialized net importer*: Sawn timber and carpentry woods are included in this category due to their negative RTA and TCI, positioning Nepal as a net importer due to cost disadvantage.

Credit should go to the plywood and veneer industry for a successful transition from a net importer to a net exporter, despite a 20% stake of imported veneer as input products in domestic plywood manufacturing. Noting market volatility in the plywood products due to improved performance of direct substitutes, plywood is proposed as a specialized export product.

Recognizing wood carving as competitive and sustainable, it is proposed that consideration is given to this niche market with focus on product differentiation to capture premium prices.

Plywood and carved wood should be considered as advantageous products of clustering and integration with furniture-making industries, and authorities should ensure access to input products, technology transfer, and enforce timber material standards to expand demand, at least in public-financed construction works.

## ACKNOWLEDGEMENT

The author has not received external financial support to prepare this manuscript and sincerely appreciates comments shared by three anonymous reviewers.

## DECLARATION OF INTEREST

The author reports no conflict of interest and is solely responsible for the analysis and conclusions, which do not represent the author's previous professional engagements.

## REFERENCES

- APETI, ABLAM, E., and N'DOUA, BOSSOMA, D. 2023. The impact of timber regulations on timber and timber product trade. *Ecological Economics* **213**(2023): Article 107943. <https://doi.org/10.1016/j.ecolecon.2023.107943>
- BALASSA, B. 1965. Trade liberalization and "revealed" comparative advantage. *The Manchester School* **33**(2): 99–123. Retrieved on 9 August 2025 from following link: <https://sci-hub.se/10.1111/j.1467-9957.1965.tb00050.x>
- BALASSA, B. 1989. Revealed Comparative Advantage in Japan and the United States. *Journal of International Economic Integration* **4**(2): 8–22. <https://www.e-jei.org/upload/1w100053.pdf>
- COOPER, L., and NAKANISHI, M. 1988. Market Share Analysis: Evaluating Competitive Marketing Effectiveness. In (Eds.) Eliashberg, J. *International Series in Quantitative Marketing*. Kluwer Academic Publishers, USA. [https://www.researchgate.net/publication/259583948\\_Market\\_Share\\_Analysis\\_Evaluating\\_Competitive\\_Marketing\\_Effectiveness](https://www.researchgate.net/publication/259583948_Market_Share_Analysis_Evaluating_Competitive_Marketing_Effectiveness)
- DANNA-BUITRAGO, J.P., and STELLIAN, R.A. 2022. New Class of Revealed Comparative Advantage Indexes. *Open Econ Rev* **33**: 477–503. <https://doi.org/10.1007/s11079-021-09636-4>
- DANGI, R.B. 2024. Timber Production Potentials in Nepal: A Critical Review on Projected Estimates. *Journal of Forest and Livelihood* **24**(1): 62–76. [https://forestaction.org/wp-content/uploads/2024/10/4\\_Dangi.pdf](https://forestaction.org/wp-content/uploads/2024/10/4_Dangi.pdf)
- DFRS. 2015. *State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal*, Department of Forest Research and Survey (DFRS). Kathmandu, Nepal. [https://frtc.gov.np/downloadfiles/StateofNepalsForestsDFRS\\_1457599484-1729667336.pdf](https://frtc.gov.np/downloadfiles/StateofNepalsForestsDFRS_1457599484-1729667336.pdf)
- DoC. 2020. *Foreign trade statistics of Nepal of Fiscal years 2019/20*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/53/a-v-208-06/>
- DoC. 2021. *Foreign trade statistics of Nepal of Fiscal years 2020/21*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/54/a-v-204-06/>
- DoC. 2022. *Foreign trade statistics of Nepal of Fiscal years 2021/22*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/55/a-v-204-049/>
- DoC. 2023. *Foreign trade statistics of Nepal of Fiscal years 2022/23*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/56/a-v-2089-060/>
- DoC. 2024. *Foreign trade statistics of Nepal of Fiscal years 2023/24*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/45/a-v-2080-041/>

- DoC. 2025. *Foreign trade statistics of Nepal of Fiscal years 2023/24*. Department of Customs (DoC), Kathmandu, Nepal. <https://customs.gov.np/content/10/statistics-a--and-2081-82/>
- DoF. 2015. *National Production plan of timber and fuel-wood for fiscal year 2072/73*. Plan submitted by the department of Forests to the Ministry of Forests and Environment (unpublished). Department of Forest (DoF), Kathmandu, Nepal. (unpublished)
- DoI. 2022. *Industrial statistics of fiscal year 2022/23*. Department of Industry (DoI), Kathmandu, Nepal. <https://doind.gov.np/detail/3f961e8b-99aa-4816-bf6d-bf416247ccfa>
- DoI. 2023. *Industrial statistics of fiscal year 2023/24*. Department of Industry (DoI), Kathmandu, Nepal. <https://doind.gov.np/detail/98c5403c-5c1c-4702-94f6-cebac5cc7938>
- DoI. 2024. *Industrial statistics of fiscal year 2024/25*. Department of Industry (DoI), Kathmandu. <https://doind.gov.np/industrial-statistics>
- FRTC. 2024. *National land cover monitoring system of Nepal, 2020–2022*. Forest Research and Training Centre (FRTC). Babarmahal, Kathmandu, Nepal. [https://frtc.gov.np/uploads/files/NLCMS\\_Report\\_Final.pdf](https://frtc.gov.np/uploads/files/NLCMS_Report_Final.pdf)
- GEOGRAPHY OF NEPAL. (n.d.). *Wikipedia*. Retrieved on 18 November 2025, from <https://en.wikipedia.org/wiki/Nepal#Geography>
- GHIMIRE, D.J., AXINN, W.G., and BHANDARI, P. 2021. Social Change, Out-migration, and Exit from Farming in Nepal. *Population and Environment* **42**(3): 302–324. <https://doi.org/10.1007/s11111-020-00363-5>
- FAGERBERG, J., and SOLLIE, G. 1987. The method of constant market shares analysis reconsidered. *Applied Economics* **19**(12): 1571–1583. <https://doi.org/10.1080/00036848700000064>
- GHOSH, M., and SINHA, B. 2016. Impact of forest policies on timber production in India: a review. *Natural Resources Forum* **40**(2016): 62–76. <https://doi.org/10.1111/1477-8947.12094>
- GoN. 2010. *Trade policy 2010 (BS 2067)*. Ministry of Trade, Commerce and Industry, Kathmandu, Nepal. <https://moics.gov.np/content/9189/9189-industrial-policy-2067/>
- GoN. 2015. Forest Rules, 2051 (1995). In Compilation of Forest, National park, soil conservation and environment related few acts, regulation and directives. *Law Book Management Board* (2015): 167–243.
- GoN. 2017. *President Chure –Terai Madhesh Conservation and Management Master Plan*. President Chure-Terai Madhesh Conservation Development Board, Kathmandu, Nepal.
- GoN. 2022. *Forest Regulation 2022*. Government of Nepal (GoN). <https://lawcommission.gov.np/content/12938/12938-forest-regulation-2079/>
- GUIANG, E.S. 2001. Impacts and effectiveness of logging bans in natural forests: Philippines. In Dust, P.B., Waggoner, T.R., Enters, T. and Cheng, T.L. (Eds.) *Forests Out of Bounds: Impacts and Effectiveness of Logging Bans in Natural Forests in Asia-Pacific*. FAO Regional Office for Asia and the Pacific, 2001. Available at: <https://portals.iucn.org/library/node/26177>
- HARMONIZED SYSTEM (n.d.). *Wikipedia*. Retrieved on 18 November 2025, from [https://en.wikipedia.org/wiki/Harmonized\\_System](https://en.wikipedia.org/wiki/Harmonized_System)
- HINLOOPEN, J., and VAN MARREWIK, C. 2001. *On the empirical distribution of the Balassa index*. *Weltwirtschaftliches Archive*, **137**(1): 1–35. <https://doi.org/10.1007/BF02707598>
- HYDE, W.F. 2003. Economic considerations on instruments and institutions. In Y. Dube and F. Schmithusen (Eds.), *Cross-sectoral Policy Impacts between Forestry and other Sectors*. *FAO Forestry Paper No.142*: 37–52. <https://www.fao.org/4/y4653e/y4653e06.htm>
- ISLAM, R., ISMAIL, S.M., and SIWAR, C. 2010. Analyzing of Trade Barriers to Timber Trade Policy. *American Journal of Environmental Sciences* **6**(1): 95–102. <https://www.thescipub.com/pdf/ajessp.2010.95.102.pdf>
- KADEL, R., and KADEL, R. 2023. Post-Earthquake Reconstruction in Kathmandu Valley: Progress and Challenges. *Journey for Sustainable Development and Peace Journal* **1**(2): 177–197. Accessible at: <https://doi.org/10.3126/jdsdpj.v1i02.58274>
- KRUGMAN, P. 1991. Increasing returns and economic geography. *Journal of Political Economy* **99**(3): 483–499. <https://doi.org/10.1086/261763>
- LEAMER, E.E. 1995. *The Heckscher–Ohlin model in theory and practice* (Princeton Studies in International Finance, No. 77). Princeton University, International Finance Section. <https://ies.princeton.edu/pdf/S77.pdf>
- LAKANAVICHIAN, S. 2001. Impacts and effectiveness of logging bans in natural forests: Thailand. In Dust, P.B., Waggoner, T.R., Enters, T. and Cheng, T.L. (Eds.). *Forests Out of Bounds: Impacts and Effectiveness of Logging Bans in Natural Forests in Asia-Pacific*. Asia-Pacific Forestry Commission, RAP PUBLICATION 2001/08. <https://www.fao.org/4/X6967E/x6967e09.htm#bm9>
- MARIA-SUBE, E., and WOODGATE, G. 2019. Analysis of the India-Myanmar timber trade. *Asian Journal of Forestry* **3**(1): 1–9. <https://doi.org/10.13057/ASIANJFOR/R030101>
- MoF. 2024. *Economic Survey 2021/22. Annex 7.22: Status of Forest Product Collection*, pp. 119. <https://mof.gov.np/content/281/economic-survey-2023-24/>
- MoFE. 2024. *Annual Progress Report for the year 2023/2024*. Published by Ministry of Forests and Environment (MoFE), Singhadarbar, Kathmandu, Nepal. <https://www.mofe.gov.np/uploads/documents/annual-report-208081pdf-6786-852-1740046582.pdf>
- MoFE. 2025. *Annual Progress Report for the year 2024/2025*. Published by Ministry of Forests and Environment (MoFE), Singhadarbar, Kathmandu, Nepal. <https://mofe.gov.np/content/308/annual-progress-report-2081-82/>
- MoFSC. 2015. *A study report on enhancing timber and fuel wood supply in the earth quake affected districts*. Report submitted to the Ministry of Forests and Soil Conservation (MoFSC) by the working group led by Mr. Resham Bd. Dangi, Joint Secretary, MoFSC (Unpublished)

- MoICS. 2018. *Nepal trade policy review 2018*. Ministry of Industry and Commerce (MoIC). [https://giwmscdntwo.gov.np/media/app/public/6/posts/1712503644\\_72.pdf](https://giwmscdntwo.gov.np/media/app/public/6/posts/1712503644_72.pdf)
- MoLJPA. 2020. *The constitution of Nepal, 2015*. Ministry of Law, Justice, and Parliamentary Affairs (MoLJPA). <https://www.moljpa.gov.np/public/uploads/238f7219-492b-40af-a919-c94c35f9c269.pdf>
- MoLJPA. 2025<sup>11</sup>. *National parks and wildlife conservation act, 1973*. Amendment updated until mid-February, 2025. Ministry of Law, Justice, and Parliamentary Affairs (MoLJPA). <https://www.moljpa.gov.np/public/uploads/287a7b77-b686-4fea-83db-87513f669cb6.pdf>
- MoLJPA. 2025<sup>22</sup>. *Forest act, 2019*. Amendment updated until mid-February, 2025. Ministry of Law, Justice, and Parliamentary Affairs (MoLJPA). <https://www.moljpa.gov.np/public/uploads/c87668b1-3d60-4849-8e71-2bd1e2500cd2.pdf>
- MUHAMAD, B. 2000. *Timber trade policy and industrialization: Implication for forest harvest and environment in Malaysia* (Doctoral thesis, University of York). Retrieved from <https://etheses.whiterose.ac.uk/14037/>
- MUNDELL, R.A. 1957. *International trade and factor mobility*. *American Economic Review* **47**(3): 321–335.
- MYREPUBLICA. 2024. Nepal has 45.31 percent forest cover. *Republica Daily*. Published on May 27, 2024. Retrieved 30 October, 2025 from <https://myrepublica.nagariknetwork.com/news/nepal-has-45-31-percent-forest-cover>
- NBSM. 2022. *Nepal Budget 2022–23: Nepal Budget (2022–23): highlights from tax perspective*. NBSM and Associates, Chartered Accountants, Narayan Chaur, Naxal, Kathmandu, Nepal. <https://nbsm.com.np/uploads/large/1654255224368473.pdf>
- NBSM. 2025. *Nepal Budget 2025–26: Nepal Budget (2025–26): Highlights from tax perspective*. NBSM and Associates, Chartered Accountants, Narayan Chaur, Naxal, Kathmandu, Nepal. <https://www.nbsm.com.np/uploads/large/1749024881547448.pdf>
- NAMGYAL, T. 2025. *Bhutan's forests: Vast green wealth, modest economic returns*. Business Bhutan, published on 2 June 2025. [https://businessbhutan.bt/bhutans-forests-vast-green-wealth-modest-economic-returns/?utm\\_source=chatgpt.com](https://businessbhutan.bt/bhutans-forests-vast-green-wealth-modest-economic-returns/?utm_source=chatgpt.com)
- NSO. 2021. *National population and housing census 2021: preliminary report*. National Statistics Office (NSO), Nepal. <https://nsonepal.gov.np/content/7252/7252-preliminary-report-of-national/>
- NSO. 2022. *National industrial survey (2019/20): National Report*. National Statistics Office (NSO), Nepal. <https://data.nsonepal.gov.np/organization/manufacturing-industry>
- NSO. 2023. *National sample census of agriculture 2021/22: National Report*. National Statistics Office (NSO), Nepal. [https://giwmscdntwo.gov.np/media/app/public/36/posts/1695554836\\_25.pdf](https://giwmscdntwo.gov.np/media/app/public/36/posts/1695554836_25.pdf)
- OLSON, D., DINERSTEIN, E., WIKRAMANAYAKE, E., BURGESS, N., POWELL, G., UNDERWOOD, E., D'AMICO, J., ITOUA, I., STRAND, H., MORRISON, J., LOUCKS, C., ALLNUTT, T., RICKETTS, T., KURA, Y., LAMOREUX, J., WETTENGEL, W., HEDAO, P., and KASSEM, K. 2001. Terrestrial Eco regions of the World: A New Map of Life on Earth. *Bioscience* **51**(11): 933–938. Retrieved 30 October 2025 from: 10.1641/0006-3568(2001)051
- PEEL, M.C., FINLAYSON, B.L., and MCMAHON, T.A. 2007. Updated world map of the Köppen-Geiger climate classification, *Hydrology and Earth System Sciences* **11**: 1633–1644. <https://doi.org/10.5194/hess-11-1633-2007>
- PLYREPORTER. 2024. *Increasing Core veneer Import from Nepal and Vietnam*. Ply Reporter, Tuesday, 12 March 2024. Retrieved from: <https://www.plyreporter.com/article/153812/increasing-core-veneer-import-from-nepal-vietnam#:~:text=plywood%20import%20fear%20has%20been,implementation%20dates%20remain%20the%20same.>
- RICHARDSON, J.D. 1971. Constant-market-shares analysis of export growth. *Journal of International Economics* **1**(2): 227–239. [https://doi.org/10.1016/0022-1996\(71\)90058-4](https://doi.org/10.1016/0022-1996(71)90058-4)
- SAMUELSON, P.A. 1948. International trade and the equalization of factor prices. *Economic Journal* **58**(230): 163–184. <https://doi.org/10.2307/2225933>
- SPFP. 2016. *Sustainable procurement of forest products*, In Table 4. Logging and export bans: Pp. 6–9. <https://sustainableforestproducts.org/Introduction>
- THAMIEM, S., WEERAHEWA, J., PUSHPAKUMARA, D.K.N.G., and SINGH, V.P. 2011. Trade Competitiveness of Agroforestry Crop Sector in Sri Lanka. *Tropical Agricultural Research* **22**(4): 338–347. DOI: 10.4038/tar.v22i4.3784
- TIMILSINA, R.H., OJHA, G.P., NEPALI, P.B., and TIWARI, U. 2019. Review Article Agriculture land in Nepal: Prospects and impacts on food security. *Journal of Agriculture and Forestry University* **3**: 1–9. Retrieved from: [https://www.researchgate.net/publication/342672699\\_Review\\_Article\\_AGRICULTURE\\_LAND\\_USE\\_IN\\_NEPAL\\_PROSPECTS\\_AND\\_IMPACTS\\_ON\\_FOOD\\_SECURITY](https://www.researchgate.net/publication/342672699_Review_Article_AGRICULTURE_LAND_USE_IN_NEPAL_PROSPECTS_AND_IMPACTS_ON_FOOD_SECURITY)
- TRN. 2024. *veneer and ply board worth Rs 5 billion exported from eastern border customs point*. The Rising Nepal (TRN). Published on Wed, 13 November 2024. Retrieved from: <https://risingnepaldaily.com/news/51863?utm>
- TUYNH, V.H., and PHUONG, P.X. 2001. Impacts and effectiveness of logging bans in natural forests. In Dust, P.B., Waggoner, T.R., Enters, T. and Cheng, T.L. (Eds.). *Forests Out of Bounds: Impacts and Effectiveness of Logging Bans in Natural Forests in Asia-Pacific*. Asia-Pacific Forestry Commission, RAP PUBLICATION 2001/08. <https://www.fao.org/4/X6967E/x6967e0a.htm#bm10>
- TYSZYNSKI, H. 1951. World trade in manufactured commodities, 1899–1950. *The Manchester School* **19**(3): 272–304. <https://doi.org/10.1111/j.1467-9957.1951.tb00012.x>
- UNITED NATIONS. 2024. *UN-Comtrade Database of period July–December, 2024*. Retrieved from following link: <https://comtradeplus.un.org/TradeFlow>
- UNITED NATIONS. 2025. *UN-Comtrade Database of period January–June, 2025*. Retrieved from following link: <https://comtradeplus.un.org/TradeFlow>

- VENABLES, A.J. 1996. Equilibrium locations of vertically linked industries. *International Economic Review* **37**(2): 341–359. <https://doi.org/10.2307/2527329>
- VOLLRATH, T.L. 1991. A theoretical evaluation of alternative trade intensity measures of revealed comparative advantage. *Weltwirtschaftliches Archiv* **127**(2): 265–280. <https://doi.org/10.1007/BF02707986>
- VU, T.T.H., TIAN, G., KHAN, N., ZADA, M., ZHANG, B., and NGUYEN, T.V. 2019. Evaluating the International Competitiveness of Vietnam Wood Processing Industry by Combining the Variation Coefficient and the Entropy Method. *Forests* **10**(10): 901. <https://doi.org/10.3390/f10100901>
- WEERAHEWA, J., and GUNATILAKE, H.M. 2010. Timber Market Liberalization in Sri Lanka: Implications for Forest Conservation. *Sri Lankan Journal of Agricultural Economics* **8**(2006): 1–20. <https://doi.org/10.4038/SJAE.V8I0.1826>

# Energy forests on small rural properties in the semi-arid region of Brazil

D.C. GAMA<sup>a</sup>, D.A. DEUS<sup>b</sup>, T.A.S. FREITAS<sup>a</sup>, F.F. OLIVEIRA<sup>c</sup>, M.D.S. FONSECA<sup>d</sup> and A.C.P. SANTOS<sup>a</sup>

<sup>a</sup>Center for Agricultural, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia. Rui Barbosa Street, 710. Zip Code 44.380-000, Cruz das Almas, BA, Brazil

<sup>b</sup>Institute of Agricultural Sciences, Federal Rural University of the Amazon. Avenue Tancredo Neves, 2501. Terra Firme. Zip Code 66.077-830. Belém, PA, Brazil

<sup>c</sup>Laboratory of Bionomy, Biogeography and Insect Systematics. Institute of Biology, Federal University of Bahia. Barão de Jeremoabo Street, 668. Zip Code 40.170-115. Salvador, BA, Brazil

<sup>d</sup>Department of Forestry and Wood Sciences, Federal University of Espírito Santo. Avenue Gov. Lindemberg, 316. Zip Code 29.550-000. Jerônimo Monteiro, ES, Brazil

Email: drauziogama@hotmail.com, deiseamaral.ufra@gmail.com, teresa@ufrb.edu.br, favosgyrl@gmail.com, duarte.123@hotmail.com, carolpereiraa@aluno.ufrb.edu.br

## HIGHLIGHTS

- Small rural properties in the semi-arid region of Northeast of Brazil are underutilized due to low levels of support and technology.
- The volume of wood production from sustainably managed forests in the Caatinga is not sufficient to meet the energy consumption needs of the industrial sector.
- The wood production from planted eucalyptus forests in already degraded areas is an important option for generating additional household income.
- Systems associated with eucalyptus forestry (agriculture, beekeeping, forage production, etc.) consolidate alternatives for semi-arid farmers.
- *Eucalyptus camaldulensis*, *E. crebra* e *E. tereticornis* are suitable for planting in the semi-arid region for the production of firewood and charcoal.

## SUMMARY

This study aimed to analyze the importance of implementing *Eucalyptus* L'Heritier silviculture in the formation of energy forests in small rural properties in the semi-arid ecoregion of Brazil known as Caatinga. To this end, a bibliographic review was carried out based on the technical-scientific literature related to the topic, available in official databases, journals and research platforms. The energy matrix (the type of energy source available to commercial, industrial and domestic sectors) of the region still consumes a large volume of native wood in the Caatinga ecoregion, largely extracted illegally. Alternative sources are crucial for conserving this already impacted ecosystem. Due to eco-physiological characteristics, some eucalyptus species tolerate the soil and climatic conditions of the Brazilian semi-arid and have properties suitable for energy production. It is concluded that wood production from planted eucalyptus forests, implemented in already degraded areas on small rural properties in the semi-arid region of Brazil for energy purposes, is an important opportunity to establish a clean and renewable, socioeconomic development system within the broader context of environmental conservation.

Keywords: Caatinga, *Eucalyptus*, sustainable development, energy production, conservation

## INTRODUCTION

Although much has been written about the natural management of forests, and the commercial improvement of trees and systems analogous to forests (Puettmann *et al.* 2015, Arts and Koning 2017, Franklin *et al.* 2018, McEwan *et al.* 2020, Betts *et al.* 2021), little attention has been paid to establishing planted eucalyptus forests in the semi-arid region of Northeast Brazil as an alternative for socioeconomic development in the region. This is particularly the case when considering the interaction of rural inhabitants with tree species in agricultural landscapes as an economic and energy alternative, in

order to contribute to sustainable development, as occurs in regions in arid and semi-arid regions of Africa (Ndegwa *et al.* 2011, Eijck *et al.* 2012, Karlberg *et al.* 2015, Miller *et al.* 2016, Kuyah *et al.* 2016, Njenga *et al.* 2019).

Energy forests have been defined as planted forests of fast-growing species of tree or woody shrub, grown specifically to produce energy (woodfuels), in order to provide biomass or biofuel for heating or other domestic or industry uses (coal, firewood, and other products) (Mead 2005, Lauri *et al.* 2014, Lavoranti *et al.* 2021). In Brazil, from the perspective of energy matrices, woody biomass is a major source of energy production for commercial, industrial, and agroindustrial

purposes, as well as for domestic purposes. In the Northeast Region, where the woody species used as energy resources originate almost entirely from native forests, (97% of consumption) and where 80% of energy resources (firewood and charcoal) are illegally extracted from the Caatinga (Riegelhaupt and Pareyn 2010, Silva 2016, Gioda 2019), it is especially important that alternative forms of renewable energy are identified and utilized.

From the point of view of plant energy resources, firewood alone represents around 60% of all energy used for cooking in the region, in addition to its use in small local enterprises, such as artisanal ceramic production, for example (Gioda 2019).

The estimated demand for firewood and charcoal in Northeast Brazil in 2015 was approximately 60 million m<sup>3</sup>/year. Projections for 2030 indicate stability or a slight increase in the demand for wood for energy from the industrial and commercial sectors of the Northeast, along with stagnation or a reduction in the demand for firewood and charcoal from the residential sector (Pareyn et al. 2024). However, of the volume of firewood consumed in the geographic region of Northeast Brazil, only about 5% comes from Sustainable Forest Management Plans (SFMPs), with the majority coming from illegal extraction of the different Caatinga vegetation physiognomies (Riegelhaupt and Pareyn 2010, Moreira 2011, Silva 2016, Coelho Júnior et al. 2019, Gama 2021). Therefore, considering the growing demand for this natural resource in various consumer sectors, the volume produced can be considered very low. This is due to factors such as the population density of woody species, which varies greatly between different environments, and differences in the age of harvesting, in addition to the low Mean Annual Increment (MAI), which is around 5 m<sup>3</sup>/ha/year, although it can vary from 0.3 to 10.9 m<sup>3</sup>/ha/year depending on the heterogeneity of this vegetation in the Caatinga (Riegelhaupt et al. 2010, Alves et al. 2011).

In terms of production volume, wood production in the Caatinga can vary between 40.29 to 60.88 m<sup>3</sup>/ha, as observed in regions of Rio Grande do Norte (Santos et al. 2020a), with an average of 86.1 m<sup>3</sup>/ha observed in Pernambuco (Almeida et al. 2023). It can, therefore, be concluded that the woody material available in the natural stocks of Caatinga vegetation is insufficient for a growing and constant local energy demand.

Given these challenges some consideration has been given to the implementation of planted forests with species of the genus *Eucalyptus* L'Heritier (Myrtaceae) due to its high annual productivity in other areas in Brazil (Rodigheri et al. 2007, Santarosa et al. 2014).

The agricultural and forestry economic sectors in countries facing edaphoclimatic problems frequently resort to genetic materials that can tolerate abiotic stresses, such as heat, salinity, floods, diseases, and drought (Acevedo et al. 2020). Specifically with silviculture for agroforestry, there is a growing need to seek the performance of tree species in terms of faster growth rates and improved products with higher yield and wood quality (Simons and Leakey 2004, Gumucio et al. 2018, Corona et al. 2016, Udawatta et al. 2019). Notably, this becomes necessary in semi-arid regions

that have a history of large environmental impacts and low human development, such as in the Cerrado and Caatinga biomes (Miccolis et al. 2019, Melo et al. 2024).

In this aspect, the development of research on management and technological improvement of wood properties can generate information and technologies that increase the capacity of plantations to establish a sufficient wood stock to regularly supply the energy phytomass needed by consumer sectors, with quality, added value, and in the shortest possible time due to short rotations (Alves et al. 2011).

In particular, the use of eucalyptus species (*Eucalyptus* spp.) has been identified as an important option for socioeconomic development and environmental protection in semi-arid regions (Gama et al. 2025a), and as an alternative to meet the demand for wood for fuel. This is pertinent given that in the last 10 years the production of firewood and charcoal from native forests in the semi-arid region of the Northeast has been drastically reduced (Gama et al. 2025b), with a large part of this decrease caused by the reduction of natural wood stocks in the native forests of the Caatinga (Travassos and Souza 2014, Santos et al. 2023).

On the other hand, according to Simmons et al. (2002), although natural regeneration allows for timber production, it is not a recommended system from an economic standpoint. This is because, in addition to the lack of selection of individuals in terms of physiological quality, as occurs in seedling production, it is a system that does not guarantee productivity on an economic scale. Therefore, planted *Eucalyptus* spp. forests in semi-arid regions of northeastern Brazil are a logical option to meet the demand for timber resources and the possibility of regional development mainly by establishing eucalyptus energy forests on small rural properties, where, according to Gama et al. (2025a), forest formations are still scarce in semi-arid regions. According to Santarosa et al. (2014), eucalyptus species may be preferred by small properties due to their rapid growth, adaptability to diverse ecological regions, and the economic potential provided by the various applications of their wood.

According to Eisfeld et al. (2017), forestry implemented in these regions with a low Human Development Index (HDI) and where agriculture is unfeasible, generates positive economic impacts, providing opportunities for social and economic advancement. In addition, Eisfeld et al. (2017) observed that silviculture implemented has a low environmental impact, as the wood from silviculture contributes to the conservation of native forests. Thus, the use of eucalyptus species in silviculture in the region may be opportune, covering social, economic, and environmental aspects.

Given this context, a literature review was conducted with the objective of analyzing the characteristics and importance of implementing eucalyptus (*Eucalyptus* L'Heritier) cultivation forests for the production of wood for fuel – woodfuels – (firewood and charcoal) – also known as ‘energy forests’ – on small rural properties in semi-arid regions of Brazil. Structurally, as a narrative review, it was constructed with stages organized as follows: identification of the topics covered, selection of specialized technical-scientific literature,

of relevant legislation and official data, and with the presentation of the review topics systematized into defining topics, based on Pautasso (2019).

The metadata collected on the subject were gathered from academic and institutional platforms, as well as from national and international journals. The bibliographic search in the databases (Science Direct, Web of Science, Scopus, Scielo and Google Scholar) and the official platform of the Brazilian government was carried out using keywords related to the topics of interest: the semi-arid region of Brazil (economic, socio-environmental aspects and human development), eucalyptus silviculture (cultivation systems, phenotypic plasticity in the region, productive potential and alternative uses of the wood) and small rural properties (integration of eucalyptus, maximization of land use and optimization of economic capacity), without applying any temporal cut-off line.

After the collection, screening, qualification and selection phase of the studies, the final organization was carried out, with the studies being aligned according to the objective of this study. The results of the studies were synthesized and presented according to the themes encompassed in their respective subjects.

### Semi-arid region of Brazil

Ranging between the parallels 3°–18° South Latitude and 35°–46° West Longitude, the current Brazilian semi-arid climate region has a total extension of 1 182 697 km<sup>2</sup>, distributed across 1 262 municipalities between the North-eastern states and the northern region of Minas Gerais. The population in this region is estimated at 27 830 765 inhabitants, distributed as approximately 63% in urban areas and 37% in rural areas (Brazil 2017, 2019a). Originally, the semi-arid region was occupied by 808 357 5 km<sup>2</sup> of Caatinga (Santos *et al.* 2020b), which corresponds to 79.35% of the region's vegetation (Figure 1).

The semi-arid region is characterized by a climate with an average precipitation of 800 mm/year, average temperature ranging from 20 to 28 °C/year, with a low temperature range varying from 5°C to less than 2°C, low aridity index ( $\leq 0.5$ ), ratio of average annual precipitation to average annual potential evapotranspiration), 60% risk of drought, and daily percentage of water deficit equal to or greater than 60% (Zanella 2014, Brazil 2017, Silva and Bezerra 2020).

The soils forming the region comprise a mosaic with various classes distributed throughout the extension, including shallow soils of crystalline origin or deep soils with sedimentary soils, sometimes with rocky outcrops, low water retention capacity, low nutrient and organic matter content, with predominance of Latosols and Ultisols soil types (Marques *et al.* 2014, Gama and Jesus 2020).

The Caatinga vegetation in the region is of the hyperxerophilic type, occupying more than 50% of the areas in the driest, with rainfall below 500 mm, and hypoxerophilic Caatingas occurring in wetter zones (Santos *et al.* 2011). Savannah typology enclaves in the Caatinga are composed of a mixed flora with elements typical of two biomes, the Cerrado and the Caatinga itself (Nepomuceno *et al.* 2021).

From a socio-economic perspective, both the Human Development Index (HDI) and the Firjan Municipal Development Index (FMDI) are low to moderate (between 0.4 and 0.6) for most semi-arid municipalities (61%). The HDI in this region is below the national average of 0.75 (Freitas 2009, Buainain and Garcia 2013, Silva and Bezerra 2020). From an economic standpoint, the semi-arid region has experienced low development and widespread poverty, with direct transfers from Social Security (retirement and pensions) and income transfer programs representing the most important sources of income for most families, with family agricultural production largely restricted to local and regional economies (Buainain and Garcia 2013, Mattos *et al.* 2021, Sabourin 2021).

In general, deforestation of the Caatinga (loss of forest cover) practiced for the purpose of agricultural land use has not translated into human development in most municipalities of the semi-arid region, according to data from Alencar *et al.* (2024). Furthermore, according to the authors, based on cycles of expansion and contraction in different agricultural frontiers, there has been no reduction in poverty, income inequality, infant mortality, or increased longevity.

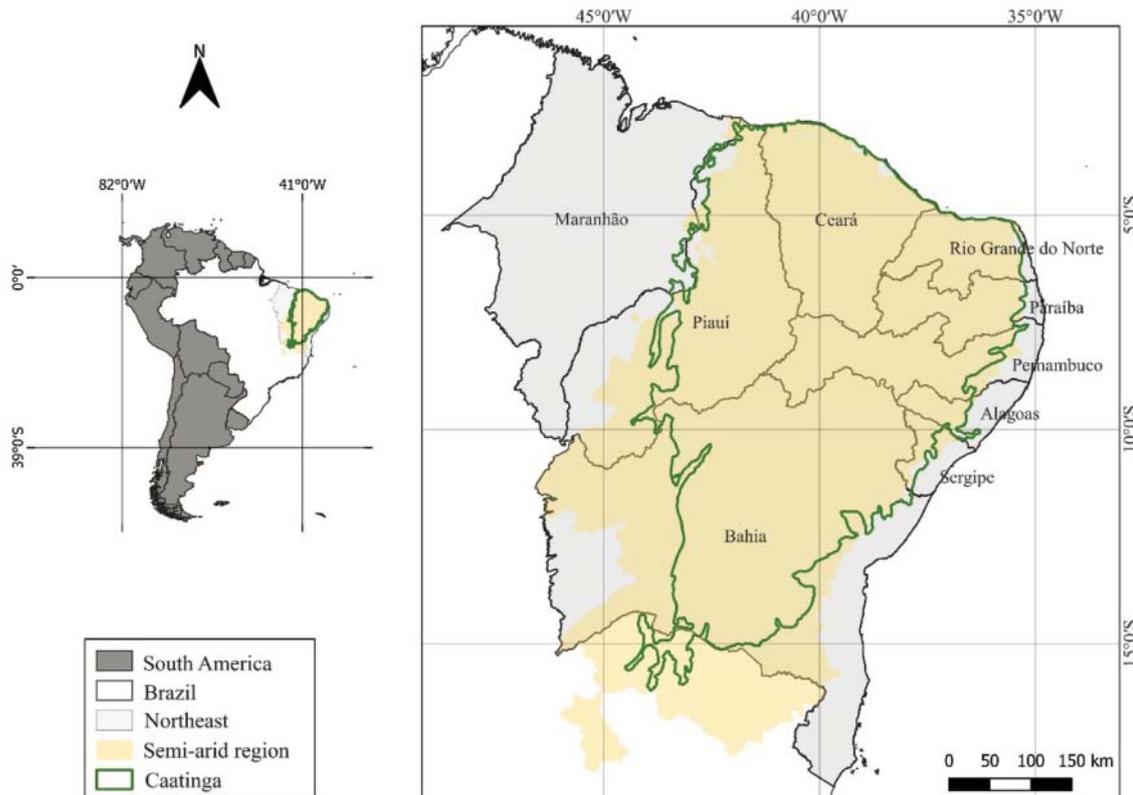
In the semi-arid region, rural occupation reflects two sets of factors: dominant low-productivity, labor-intensive production systems and structural variables, particularly the importance of smallholdings, which serve as units for subsistence and housing for the poorer rural population who have no alternatives for survival in other activities (Buainain and Garcia 2013). Furthermore, as observed by Alencar *et al.* (2024), the exploitation of natural resources alone, when it occurs, is insufficient to achieve sustainable progress in the development of this region.

About the smallholdings, despite totalling approximately one million establishments, they represent insufficient economic units for ensuring sustainability in a broad sense in the conditions of the semi-arid environment, as they contribute with only 31% of the total value of agricultural production in the semi-arid region (Buainain and Garcia 2013). However, according to Buainain and Garcia (2013), the agricultural sector is still the backbone of rural society and the main economic activity in most small municipalities in terms of population.

On the other hand, although the rural population is significant, there has been a pronounced population displacement (forced migration) from rural areas to local, small, and medium-sized cities, due to the lack of opportunities in rural areas (Gonçalves 2001, Buainain and Garcia 2013, Oliveira *et al.* 2019). Rural families, for the most part, only produce enough for their own consumption, and therefore, the scenario of prolonged droughts in the semi-arid region presents a permanent risk to food and nutritional security (Mattos *et al.* 2021). There is also a portion of the population that ends up migrating to other regions of the country in search of better living conditions, a phenomenon more evident during periods of drought (Freitas 2009, Tavares *et al.* 2019).

A particular effect of the fragility of these populations' quality of life may be reflected in environmental degradation

FIGURE 1 Geographic delimitation of the Caatinga biome and the semi-arid climate region in Brazil. Scale: 1:250 000, Brazilian Geodetic System DATUM Sirgas 2000. Source: (Brazil 2019b)



through the suppression of Caatinga vegetation as an alternative for employment and income (Tavares *et al.* 2019). This can be evidenced by the fact that pastures occupy more than 40% of the area of rural establishments in the semi-arid region, which is more concerning in some municipalities in Bahia, such as the microregion of Itapetinga, where more than 70% of its territory is comprised of pastures (Santos *et al.* 2011). Another example in Bahia is the microregion of Ribeira do Pombal, which presents a very high level of degradation, with about 90% of its area susceptible to desertification, and only 35% of its territory containing areas of original vegetation cover (Gama *et al.* 2022). Habitat loss is a real situation in the Caatinga, where, of the original vegetation cover that occupied an area of 40 582 671 ha (Sanquetta *et al.* 2018), there was a total loss of 6 076 939 ha of its original vegetation in 17 years (from 2002 to 2018) (Santos *et al.* 2020a).

The loss of forest remnants tends to bring drastic changes in regional climate and hydrology, where conservation efforts would be more effective with an increased awareness of the urgency of this problem at a larger spatial scale (Watson *et al.* 2018, Betts *et al.* 2021). This is a recurring problem in the Caatinga, where changes in land use impact the eco-hydrological dynamics, especially where pastures replacing native forests degrade due to inadequate management under adverse climatic conditions (Souza *et al.* 2016, Ribeiro *et al.* 2019, Silva *et al.* 2025).

The economic, social, and environmental problems generated by habitat loss in the semi-arid region of Brazil highlight

the urgent need for the development and consolidation of public policies whose aim is coexistence with the semi-arid region and restoring the environment in areas prone to desertification (Freitas 2009). In view of this, it is noted that although numerous non-governmental organizations focus on ecological restoration, few encourage the planting of fast-growing species on smallholdings, whether for commercial purposes or for self-consumption, which could be a good initiative to alleviate pressure on remaining native forests (Simmons *et al.* 2002).

Therefore, for strategies to be effective and habitat loss to be contained, local populations must be involved as active participants in the process of acquiring knowledge and using natural resources, rather than mere passive spectators (Núñez-Cruz *et al.* 2018). This is necessary because the lack of knowledge and encouragement of forest management practices, and unfamiliarity with the values of trees and wood yields, severely limit the development of silviculture in local agricultural systems, notably hampering any projects in this direction (Arnold and Dewees 1998, Simons and Leakey 2004).

### Eucalyptus silviculture in small rural properties

To illustrate the high impact of eucalyptus wood productivity compared to native species, the study by Gadelha *et al.* (2015) estimated a consumption of firewood from the Caatinga of 1.91 million m<sup>3</sup> (with the exploitation of 25 489 ha/year of woody vegetation). Converting energy efficiency to eucalyptus wood use, this volume would fall to 1.58 million m<sup>3</sup> of

firewood, exploiting only an area of 8,346.51 ha/year. In that case, considering only the gypsum sector of Araripe in Pernambuco (encompassing the municipalities of Araripina, Ipubi, Trindade, Bodocó and Ouricuri).

It can also be noted that, in addition to the productivity gains from timber production, planted forests allow for the direct protection of just over 17,140 hectares of remaining native Caatinga vegetation (Gadelha *et al.* 2015). Thus, the use of renewable energy, combined with advanced and efficient silvicultural production technologies, contributes, as emphasized by Bichel and Telles (2021), to reducing the suppression of native vegetation. In this way, planted forests can act as mitigators of environmental degradation in the semi-arid region, since the removal of native vegetation in this region occurs beyond its natural regeneration capacity (Alves *et al.* 2011, Gadelha *et al.* 2015). As such, planted forests promote the conservation of remaining Caatinga areas. Kremen and Merenlender (2018) classified this as 'productive landscapes,' in which, while meeting human needs (in this case, timber from planted forests), they conserve biodiversity and maintain ecosystem services (of native forests).

From a practical and labour standpoint, energy forests represent a type of plantation that requires few silvicultural treatments, allowing for short-term harvesting in strip systems without occupying large areas of the property and thus avoiding compromising agricultural production, nor requiring exclusive dedication, allowing owners to engage in other activities. However, in semi-arid environments, more intensive silvicultural interventions may occur during the planting phase, from which the plant acquires the ability to adapt to the edaphoclimatic conditions of the environment during the initial stage of development and growth, such as in planting systems in pits with different depths, with cultural treatments in growth management, with alternative hydrogel systems to reduce water stress and ensure the survival of seedlings (Noulèkoun *et al.* 2017, Jo and Park 2017, Crous 2017), and after establishment, considering that it is an intensive forestry system for firewood production, pre-commercial thinning (non-extractive thinning) or pruning to obtain clean wood is not necessary. This is because, in addition to the objective of planting not being the production of sawn timber, the effects of pruning are not significant for the growth of unthinned stands (Montagu *et al.* 2003, Forrester and Baker 2012, West 2014). As such, this is ideal for the production of biomass for renewable energy with low maintenance costs for small rural landowners.

In this context, energy forest formations composed of *Eucalyptus* spp. plantations stand out for having rapid growth, environmental plasticity, and ease of resprouting and propagation (Alves *et al.* 2011).

It is worth noting that, due to the examples of significant economic return and thanks to the availability of selected material for various regions and commercial purposes, combined with competitive costs, areas planted with *Eucalyptus* spp., especially clones, are constantly expanding throughout the Brazilian territory (Xavier and Silva 2010), although the most common practice has been for the owner to lease their land for eucalyptus forestry as a viable alternative to ensure

long-term security and appreciation of their property (Valverde *et al.* 2004, Soares *et al.* 2010). However, for semi-arid regions, characterized by a predominantly small-scale agrarian structure and distant from the main consumer centers, forest formation on small properties by the landowners themselves in these regions is more advantageous, both for supplying the regionally closest consumer sectors and for the timber use itself.

In other words, producing timber large enough to supply specialized industries such as pulp and paper or steel is practically unfeasible, for technical, logistical, and economic reasons, without the necessary support for forestry activities suited to semi-arid conditions, which would encompass a wider range of operations in the forestry sector. Furthermore, according to Valverde *et al.* (2004), this would meet the needs of a more dynamic forestry policy, adapted to new trends and markets.

An alternative to conventional pure *Eucalyptus* spp. plantations in high forest monocultures or coppices, is to adopt strategies of mixed intercropping in Agroforestry Systems (AFS) or Integrated Crop-Livestock-Forest Integration (ICLF) systems (Kleinpaul *et al.* 2010, Lima and Gama 2018). These systems have the capacity for multiple uses and alternative benefits, providing indirect gains, in addition to the productive potential of wood biomass. For example, flowering can serve as pasture for bees (beekeeping and stingless beekeeping), destined for the production of honey and other bee products (such as propolis and bee pollen), enhanced by the broader seasonal phenology due to the diversity of eucalyptus species and other plants in the consortium, allowing combinations at different times of the year, even when natural floral sources are scarce (Wolff and Schuhli 2021). In the semi-arid regions, this occurs more intensely due to prolonged droughts, causing the characteristic dry spells in the region (Tavares *et al.* 2019, Mattos *et al.* 2021). Another source of income could be the extraction of essential oil from eucalyptus leaves (Vitti and Brito 2003), before obtaining wood as the final product.

In terms of the efficiency of agrosilvopastoral systems, Ferreira *et al.* (2024), in a study conducted in Pernambuco on intercropping tree species with foraging crops, observed that the hybrid eucalyptus (*E. urophylla* x *E. tereticornis*) presented average production values of 164.43 ton/ha, higher than the 47.1 ton/ha of native species such as angico (*Anadenanthera colubrina* var. Cebil – Fabaceae) and aroeira (*Myracrodruon urundeuva* Allemão – Anacardiaceae), after 10 years of planting. Thus, systems associated with eucalyptus forestry (agriculture, beekeeping, stingless beekeeping, forage, etc.) can provide alternatives for semi-arid farmers, generating diversified and rotational economic returns throughout the year, according to the production of the employed crop or associated cattle farming (forage), in addition to the gains from wood production.

It is worth noting that among the possible market opportunities, there is also the carbon credit market, which permits the addition of value to forest resources (Jacovine *et al.* 2008) as a potential generator of capital flow, offering conditions for carbon offsetting through the Clean Development Mechanism (CDM), not only with the establishment of planted forests but

also through the conservation of native forests (Jacovine *et al.* 2008).

In the case of planted forests, however, as observed by Núñez-Cruz *et al.* (2018), before any decision, it is important to know the species from which one intends to obtain results via commercial planting, since insufficient knowledge about eco-physiological conditions and propagation methods, coupled with inadequate silvicultural practices for the planted species, can lead to losses due to low survival and productivity, especially when local soil and climatic factors are disregarded. Other important factors to consider, before any initial planning, are the necessary conservation strategies, in addition to the levels and types of possible impacts on planned forest areas, aiming for the least possible pressure on local biodiversity and other forest resources (Medeiros *et al.* 2011, Betts *et al.* 2021).

Due to their aforementioned characteristics and high adaptability to arid environments, *Eucalyptus* spp. stand out as the best economic option for energy demand (Gadelha *et al.* 2015) in the semi-arid region of Brazil. In Africa, for example, in environments with a tropical climate similar to the Brazilian semi-arid region, *Eucalyptus* spp. have already been cultivated in broad ecological zones and poor environments, resisting certain diseases and environmental stresses, generating substantial incomes for rural and urban families (Daba 2016, Alemayehu and Melka 2022, Getnet *et al.* 2022). Emphasis should be placed by environmentalists, researchers, and policymakers on supporting users, managers, and producers of *Eucalyptus* spp. wood in the proper selection of species according to the chosen purpose and management strategy, with the choice of the appropriate planting site, so that environmental impacts are minimized and economic benefits are optimized (Daba 2016, Betts *et al.* 2021).

Scientific research on *Eucalyptus* spp. aiming for their adaptation to the tropical climate in the semi-arid regions of Northeast Brazil has been conducted since the 1970s through Embrapa Semiárido (Brazilian Agricultural Research Corporation of the semi-arid region), headquartered in the municipality of Petrolina-PE. These studies have been based on the use of some species of this genus in agroforestry systems in areas with rainfall below 600 mm/year. From the perspective of production value and adaptability to environmental conditions similar to those of the Caatinga, scientific research has indicated that species such as *Eucalyptus crebra*, *E. camaldulensis*, *E. tereticornis*, *E. pellita* F. Muell, *E. brassiana* S.T. Blake, *E. exserta* F. Muell, *E. tessellaris* (F. Muell) KD Hill & LAS Johnson (*Corymbia tessellaris* KD Hill & LAS Johnson), and *Eucalyptus alba* Reinw (ex Bl) are the most suitable for wood production in the semi-arid region, especially due to their resistance to local conditions of low rainfall (Drumond *et al.* 2004, Alves *et al.* 2011, Santos *et al.* 2011, Gadelha *et al.* 2012, Gadelha *et al.* 2015, Gonçalves *et al.* 2017). According to these studies, species like *Eucalyptus crebra* F. Muell., *E. tereticornis* Sm, *Eucalyptus grandis* W. Hill ex Maiden, and *E. camaldulensis* Dehnh showed the best results in terms of biomass volume produced, in addition to the high survival rates observed, comparable only to species native to the semi-arid region of the Caatinga

(Drumond *et al.* 2004, Alves *et al.* 2011, Santos and Santos 2012, Gadelha *et al.* 2015).

Furthermore, some species with medium tolerance to semi-arid conditions, such as *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson (previously called *Eucalyptus citriodora*), *Corymbia torelliana* (F.Muell.) K.D.Hill & L.A.S.Johnson (previously called *Eucalyptus torelliana*), *Eucalyptus grandis*, and *Eucalyptus urophylla* S.T.Blake, can also be indicated as alternative species to be planted for energy purposes (Gonçalves *et al.* 2017).

Among the most tolerant species, *E. crebra*, *E. camaldulensis*, and *E. tereticornis* have shown resistance to rainfall limits at least 600 mm/year, where *E. camaldulensis*, in some regions, resisted at least 500 mm/year (Drumond *et al.* 2004), which is considered an unviable precipitation range for many agricultural and forage crops (Santos *et al.* 2011). The drought resistance exhibited by *E. camaldulensis* is mainly due to its faster, deeper, and more branched root system, as well as its behavior of exploiting a larger volume of soil for water absorption (Gonçalves and Passos 2000). Taking into account its fast growth and high ecological plasticity, species of this genus can present an Annual Increment of Merchantable Area (IMA) of 20 to 45 m<sup>3</sup>/ha/year in rotations of six to eight years (Gonçalves *et al.* 2017). Some clones have achieved significant results, such as the hybrid of *Eucalyptus urophylla* x *E. tereticornis* x *E. pellita*, with an average production of 90 t/ha or 94.7 m<sup>3</sup>/ha, considered a density of 95% (0.95 g/cm<sup>3</sup>) at 4.5 years, studied in the Araripe region in Pernambuco and subjected to an average precipitation of 650 mm/year (Alves *et al.* 2011). Still on the topic of pure hybrids, the result from the crossing of *E. brassiana* and *E. urophylla* has also shown good results under the same environmental conditions (Gadelha *et al.* 2015).

In terms of accumulated energy, the highest amount of energy stored per m<sup>3</sup> in *Eucalyptus* spp. wood occurs between five and seven years of age, on average. Additionally, age also influences the basic density, which has been recorded on average from 0.6 to 0.7 g/cm<sup>3</sup>, depending on the species. For example, the species *E. camaldulensis* presented an average of 4,649.0 kcal/kg at seven and a half years of age (Costa *et al.* 2017).

Deep soils are the most suitable, especially due to their water retention capacity at depths greater than ten meters, which is an important criterion for selecting the most suitable for afforestation and for improving biomass production predictions (Laclau *et al.* 2013). Regarding the soil conditions in the semi-arid region, no problems related to this species have been reported, since the predominant soils in the region, mainly Latosols and Argisols, have characteristics that are favourable for the silviculture of *Eucalyptus* spp. As a consequence, 82% of forest plantations with species of this genus in this region are on these two types of soils (Gonçalves *et al.* 2016, Gama and Jesus 2020).

As discussed by Simmons *et al.* (2002), the decision to plant trees is essentially an economic decision to incorporate trees into an agricultural system, which is relatively uncommon among small producers in Brazil, mainly due to the absence of government incentives, through subsidies or legal requirements.

The participation of public and private sectors in promoting and fostering silvicultural activity for wood purposes on small rural properties becomes an important economic development strategy. In many underdeveloped countries, eucalyptus cultivation has been adopted as a source of income in areas with poor quality soils, where certain crops would not develop without intensive soil management, unlike eucalyptus (Daba 2016). Furthermore, in densely populated rural areas of Africa and Asia, for example, forest plantations have been expanding more rapidly, mainly due to government policies promoting reforestation (Mcewan *et al.* 2020).

Due to the technological, social, economic, and environmental benefits that the silviculture of *Eucalyptus* spp. can generate in semi-arid regions, mainly due to its adaptation to low rainfall (largely a limiting factor for many agricultural crops), the lack of policies and incentives for the implementation of planted forests with species of this genus on small rural properties in the semi-arid region of Brazil is not justified. The outcome is that the semi-arid region of Brazil represents one of the largest silvicultural voids of *Eucalyptus* spp. in the country.

Researchers including Arnold and Dewees (1998), Pandey *et al.* (2016), Miller *et al.* (2016), Duguma *et al.* (2019) and Sheppard *et al.* (2020), highlight the danger represented by the lack of government incentives for farmers' access to forest product markets, which can inadvertently interfere with and harm subsistence economies and their conversion to market economies. Although less extensive than reforestation, due to succession, tree planting reduces the demand to open up virgin lands, minimizes the degree of ecological disturbance on farm sites, and provides a means of increasing land value, in addition to the recovery of abandoned agricultural lands (Simmons *et al.* 2002, Brancalion and Holl 2020, Lohd *et al.* 2025).

Furthermore, the sectors (commerce and industry) that consume *Eucalyptus* spp. woody biomass in the Northeast can be a factor in the decentralization of the forestry sector in relation to the rest of Brazil, notably through the production of firewood and charcoal (Soares *et al.* 2010). Consequently, this allows for greater added value to timber products generated in the region, especially because eucalyptus wood is a renewable energy product.

As noted by Santarosa *et al.* (2014), when planned and managed properly, forest planting of eucalyptus species in small and medium-sized rural properties contributes to diversifying production and income. This is also of public interest, as it prevents a rural exodus and unemployment, ensuring an additional source of income for farmers, concurrently with other agricultural activities, and primarily helps to reduce pressure on the deforestation of remaining natural forests. In many locations, wood production from native forests has been replaced by reforestation wood, where the genus *Eucalyptus* spp. represents the most cultivated genus for this purpose (Santos *et al.* 2017, Gama *et al.* 2023). If there is a focus on planting energy forests in already deforested, abandoned, and degraded areas in semi-arid regions of the Northeast (Gama *et al.* 2022), it is possible to achieve an additional source of planned and low-impact income, which can help contain the

deforestation of the preserved remaining native forests on rural properties.

Therefore, it is important to correctly identify the species that can be used, adapting to the local environment, and generating the desired results satisfactorily, primarily because it is a highly restricted semi-arid climate environment. Authors such as Simons and Leakey (2004), Akinyele (2019), Khasa and Atangana (2019), Nair *et al.* (2021), Sax *et al.* (2022) and Varghese *et al.* (2024) have highlighted that this is possible through the 'domestication' of species, whereby scientists, authorities, commercial companies, forest inhabitants, or farmers select, manage, and propagate trees for the purpose of providing both products (wood, fruit, fodder, etc.) and services (protection of water sources, soil improvement, erosion control, etc.).

In view of this, an important strategy is the use of species with efficiently improved genotypes, adapted to local climatic conditions, and which are managed using appropriate management practices, allowing for an increase in productivity and ensuring constant production (Gonçalves *et al.* 2017).

Other factors that may contribute to tree planting, besides economic motivation and species knowledge, according to Simmons *et al.* (2002), Smith *et al.* (2016), Lawry *et al.* (2017), Brancalion and Holl (2020) and Rakotonarivo *et al.* (2023), are tree and land tenure security as without this security, small farmers will hesitate to invest time and money in tree planting efforts.

Notwithstanding, while eucalyptus forests are the most viable alternative for improving the quality of life for populations for small rural properties in the semi-arid region, we cannot fail to highlight the need for incentives for research in forestry engineering, so that native species of the region can be studied with the aim of establishing more energy plantation. Studies that identify native species with high calorific potential and capable to rapid growth.

## FINAL CONSIDERATIONS

Energy forest formations with species of the genus *Eucalyptus* L'Heritier on small rural properties in the semi-arid region of Brazil represent a viable opportunity to establish a clean and renewable energy matrix, serving local and regional commercial, industrial, and residential sectors.

Silvicultural activity on small rural properties in the Brazilian semi-arid region is a fixed asset that generates income for local families and contributes to the permanence of small producers on the property, reducing turnover and migratory flow.

Planted forests of *Eucalyptus* spp. for the purpose of renewable biomass energy production drastically contributes to reducing the extraction of native wood from the region, which is often carried out illegally or without due care.

Promoting eucalyptus cultivation in the semi-arid region, whether in combination with other methods or planted alone, is an alternative for sustainable socioeconomic development and mitigation of degradation in this region, as it reconciles energy production with the conservation of remaining native vegetation and associated biodiversity.

## ACKNOWLEDGEMENTS

The authors thank the contributions of referees assigned by the International Forestry Review for their suggestions and constructive comments, which greatly improved a lot this paper.

## DECLARATION OF INTEREST

The authors declare no conflict of interest.

## DECLARATION AND USE OF GENERATIVE AI

During the preparation of this manuscript, the authors did not use any AI tools.

## REFERENCES

- ACEVEDO, M., PIXLEY, K., ZINYENGERE, N., MENG, S., TUFAN, H., CICHY, K., BIZIKOVA, L., ISAACS, K., GHEZZI-KOPEL, K., and PORCIELLO, J. 2020. A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nature Plants* **6**(10): 1231–1241. <https://doi.org/10.1038/s41477-020-00783-z>
- AKINYELE, A.O. 2019. Achieving sustainable development through silviculture: focus on tree domestication. Ibadan University Press Publishing: House University of Ibadan-Nigeria, 87p.
- ALEMAYEHU, A., and MELKA, Y. 2022. Small scale *Eucalyptus* cultivation and its socioeconomic impacts in Ethiopia: A review of practices and conditions. *Trees, Forests and People* **8**: 100269. <https://doi.org/10.1016/j.tfp.2022.100269>
- ALENCAR, L., PARRY, L., and MELO, F. 2024. Deforestation and human development in the Brazilian tropical dry forest. Research Square, p. 1–22. <https://doi.org/10.21203/rs.3.rs-4441251/v1>
- ALMEIDA, A.C.S., LOPES, G.M.B.L.M., FORMIGA, S.A., MEDEIROS, M.S., and ALMEIDA, F.C.P. 2023. Viabilidade econômica de produção de bioenergia em áreas de assentamentos de reforma agrária no Nordeste Semiárido, PE, Brasil. *Pesquisa Agropecuária Pernambucana* **28**(1): e2812822023. <https://doi.org/10.12661/pap.2022.008>
- ALVES, A.M.C., SILVA, J.A.A.D., FERREIRA, R.L.C., and BARRETO, L.P. 2011. Quantificação da produção de biomassa em clones de eucaliptos com 4, 5 anos, no polo gesseiro do Araripe-PE. *Revista de Ciências Agrárias* **48**(1): 161–174.
- ARNOLD, J.E., and DEWEES, P.A. 1998. Rethinking approaches to tree management by farmers. *Natural Resources Perspectives* **26**: 1–14.
- ARTS, B., and KONING, J.D. 2017. Community forest management: An assessment and explanation of its performance through QCA. *World Development* **96**: 315–325. <https://doi.org/10.1016/j.worlddev.2017.03.014>
- BETTS, M.G., PHALAN, B.T., WOLF, C., BAKER, S.C., MESSIER, C., PUETTMANN, K.J., VERDE, R., HARRIS, S.H., EDWARDS, D.P., LINDENMAYER, D.B., and BALMFORD, A. 2021. Produzindo madeira ao menor custo para a biodiversidade: integrando a tríade e abordagens de compartilhamento para informar o manejo da paisagem florestal. *Biological Reviews* **96**(4): 1301–1317. <https://doi.org/10.1111/brv.12703>
- BICHEL, A., and TELLES, T.S. 2021. Spatial dynamics of firewood and charcoal production in Brazil. *Journal of Cleaner Production* **313**: 127714. <https://doi.org/10.1016/j.jclepro.2021.127714>
- BRANCALION, P.H., and HOLL, K.D. 2020. Guidance for successful tree planting initiatives. *Journal of Applied Ecology* **57**(12): 2349–2361. <https://doi.org/10.1111/1365-2664.13725>
- BRASIL. 2017. Delimitação do Semiárido. Superintendência do Desenvolvimento do Nordeste-SUDENE. Retrieved 12 January 2022. <https://www.gov.br/sudene/pt-br/assuntos/delimitacao-do-semiarido>
- BRASIL. 2019a. O Semiárido Brasileiro. Instituto Nacional do Semiárido – INSA. Retrieved 23 May 2023. <https://www.gov.br/insa/pt-br/semiario-brasileiro#:~:text=O%20Semi%C3%A1rido%20Brasileiro%20se%20estende,semi%C3%A1ridos%20mais%20povoados%20do%20mundo>
- BRASIL. 2019b. Biomass e Sistemas Costeiros do Brasil. Geociências – Instituto Brasileiro de Geografia e Estatística – IBGE. Retrieved 18 September 2023. <https://www.ibge.gov.br/geociencias/informacoes-ambientais/estudos-ambientais/15842-biomass.html>
- BUAINAIN, A.M., and GARCIA, J.R. 2013. Desenvolvimento rural do semiárido brasileiro: transformações recentes, desafios e perspectivas. *Confins. Revue franco-brésilienne de géographie/Revista franco-brasileira de geografia* **19**: 1–24. <https://doi.org/10.4000/confins.8633>
- CARNEIRO, A. DE C.O., CASTRO, A.F.N.M., CASTRO, R.V.O., SANTOS, R.C. DOS., LUMMA, P.F., DAMÁSIO, R.A.P., and ROCHA VITAL, B.R. 2014. Potencial energético da madeira de *Eucalyptus* sp. em função da idade e de diferentes materiais genéticos. *Revista Árvore* **38**(2): 375–381. <https://doi.org/10.1590/S0100-67622014000200019>
- COELHO JÚNIOR, L.M., BURGOS, M.C., SANTOS JÚNIOR, E.P., and PINTO, P.A.L.A. 2019. Regional concentration of the gross production value of firewood in Paraíba. *Floresta e Ambiente* **26**: e20170887. <https://doi.org/10.1590/2179-8087.088717>
- CORONA, P., CUTINI, A., CHIAVETTA, U., and PAOLETTI, E. 2016. Forest-food nexus: A topical opportunity for human well-being and silviculture. *Annals of Silvicultural Research* **40**(1): 1–10. <https://doi.org/10.12899/asr-1181>
- COSTA, A.C.S., LEAL, C.S., SANTOS, L.C., CARVALHO, A.M.M.L., OLIVEIRA, A.C., and PEREIRA, B.L.C. 2017. Propriedades da madeira de cerne e alborno de *Eucalyptus camaldulensis*. *Revista Ciência da Madeira* **8**(1): 10–20. <https://doi.org/10.12953/2177-6830/rcm.v8n1p10-20>

- CROUS, J.W. 2017. Use of hydrogels in the planting of industrial wood plantations. *Southern Forests: a Journal of Forest Science* **79**(3): 197–213. <https://doi.org/10.2989/20702620.2016.1221698>
- DABA, M. 2016. The *Eucalyptus* dilemma: the pursuit for socio-economic benefit versus environmental impacts of *Eucalyptus* in Ethiopia. *Journal of natural Sciences Research* **6**(19): 127–136.
- DRUMOND, M.A., MORGADO, L.B., RIBASKI, J., ALBUQUERQUE, S.D., and CARVALHO FILHO, O.D. 2004. Contribuição da Embrapa Semiárido para o desenvolvimento dos sistemas agroflorestais no Semiárido brasileiro. *Agrossilvicultura* **1**(2): 145–153.
- DUGUMA, L.A., ATELA, J., MINANG, P.A., AYANA, A.N., GIZACHEW, B., NZYOKA, J.M., and BERNARD, F. 2019. Deforestation and forest degradation as an environmental behavior: unpacking realities shaping community actions. *Land* **8**(2): 26. <https://doi.org/10.3390/land8020026>
- EIJCK, V.J., SMEETS, E., and FAAIJ, A. 2012. The economic performance of jatropha, cassava and Eucalyptus production systems for energy in an East African smallholder setting. *GCB Bioenergy* **4**(6): 828–845. <https://doi.org/10.1111/j.1757-1707.2012.01179.x>
- EISFELD, R. de L., SOCHER, L.G., and RIBEIRO, C.C. 2017. Modelo de fomento florestal nas instituições estaduais nos estados do Sul, São Paulo e Minas Gerais. *BIOFIX Scientific Journal* **2**(2): 1–9. <http://dx.doi.org/10.5380/biofix.v2i2.53230>
- FERREIRA, J.C.S., SILVA, J.A.A. da., and FERREIRA, R.L.C. 2024. Viabilidade econômica de um sistema silvipastoril com e sem a inclusão de crédito de carbono. *Revista Caatinga* **37**: e11721–e11721. <https://doi.org/10.1590/1983-21252024v37i11721rc>
- FORRESTER, D.I., and BAKER, T.G. 2012. Growth responses to thinning and pruning in *Eucalyptus globulus*, *Eucalyptus nitens*, and *Eucalyptus grandis* plantations in southeastern Australia. *Canadian Journal of Forest Research* **42**(1): 75–87. <https://doi.org/10.1139/x11-146>
- FRANKLIN, J.F., JOHNSON, K.N., and JOHNSON, D.L. 2018. Ecological forest management. Waveland Press. 646p.
- FREITAS, N.B. 2009. Dinâmica territorial e populacional no semi-árido brasileiro: índice de desenvolvimento humano (IDH) das áreas propensas à desertificação. *Observatório Geográfico da América Latina* **1**: 1–14. Retrieved 8 February 2024. <http://observatorioriogeograficoamericalatina.org.mx/egal12/Geografiasocioeconomica/Geografiadeltransporte/03.pdf>
- GADELHA, F.H.D.L., SILVA, J.A.A.D., FERREIRA, R.L.C., MELO, I.V.D., JORGE, D.L., TAVARES, J.A., and SILVA, S.P.R.D. 2012. Rendimento volumétrico e energético de clones de híbridos de *Eucalyptus* sp. no Polo Gesseiro do Araripe, PE. *Ciência Florestal* **22**(2): 331–341. <https://doi.org/10.5902/198050985740>
- GADELHA, F.H.D.L., SILVA, J.A.A.D., FERREIRA, R.L.C., SANTOS, R.C.D., and TAVARES, J.A.D. 2015. Produtividade de clones de eucaliptos em diferentes sistemas de manejo para fins energéticos. *Pesquisa Florestal Brasileira* **35**(83): 263–270. <https://doi.org/10.4336/2015.pfb.35.83.827>
- GAMA, D.C. 2021. Manejo florestal sustentado da Caatinga: aspecto legal e técnico-científico. *Advances in Forestry Science* **8**(1): 1363–1376. <https://doi.org/10.34062/afs.v8i1.10844>
- GAMA, D.C., and JESUS, J.B.D. 2020. Principais solos da região Semiárida do Brasil favoráveis ao cultivo do *Eucalyptus* L'Heritier. *BIOFIX Scientific Journal* **5**(2): 214–221. <http://dx.doi.org/10.5380/biofix.v5i2.70968>
- GAMA, D.C., DEUS, D.A.D., CHAMBÓ, E.D., and OLIVEIRA, F.F.D. 2025b. Firewood and charcoal production in northeastern of Brazil. *Cerne* **31**: e-103405. <https://doi.org/10.1590/01047760202531013405>
- GAMA, D.C., FREITAS, T.A.S. de., MARTINS, M. de. S., VIDAL, R.B.M., VIDAL, C.B.M., FONSECA, M.D.S., PEREIRA, E.G., SANTOS NETO, J.C. dos., VIEIRA, J.M.O. do. N. 2025a. Forestry products and *Eucalyptus* L'heritier plantations in northeast Brazil. *Scientia Agraria* **21**(1): 2–8. <https://doi.org/10.5380/sa.v21i1.99164>
- GAMA, D.C., OLIVEIRA, F.F. de., JESUS, J.B. de., and NASCIMENTO JÚNIOR, J.M.D. 2022. Susceptibilidade à desertificação em uma microrregião semiárida do Brasil. *Revista de Geociências do Nordeste* **8**(1): 160–174. <https://doi.org/10.21680/2447-3359.2022v8n1ID21732>
- GAMA, D.C., SANTOS NETO, J.C.D., RIBEIRO, N.M.A.R., and SANTOS, J.C. 2023. Caracterização do consumo de lenha em pizzarias e panificadoras em Vitória da Conquista-Bahia. *BIOFIX Scientific Journal* **8**(2): 1–7. <http://dx.doi.org/10.5380/biofix.v8i2.86701>
- GETNET, M.T., KETEMA, M., ALEMU, B., and DEMILEW, G. 2022. An Assessment on socio-economic impacts of smallholder *Eucalyptus* tree plantation in the case of Northwest Ethiopia. *European Online Journal of Natural and Social Sciences* **11**(1): 250–262.
- GIODA, A. 2019. Características e procedência da lenha usada na cocção no Brasil. *Estudos Avançados* **33**: 133–150. <https://doi.org/10.1590/s0103-4014.2019.3395.0009>
- GONÇALVES, A.J. 2001. Migrações Internas: evoluções e desafios. *Estudos Avançados* **15**(43): 173–184. <https://doi.org/10.1590/S0103-40142001000300014>
- GONÇALVES, J.L.D.M., ALVARES, C.A., SOUZA, A.H.B.N., and ARTHUR JUNIOR, J.C. 2016. Caracterização edafoclimática e manejo de solos das áreas com plantações de eucalipto. **4**: 111–153. In.: *Silvicultura do Eucalipto no Brasil*. (Org.) SCHUMACHER, M.V., and VIEIRA, M. Santa Maria-RS. Editora: UFSM, 208p.
- GONÇALVES, J.L.M., ALVARES, C.A., ROCHA, J.H., BRANDANI, C.B., and HAKAMADA, R. 2017. *Eucalyptus* plantation management in regions with water stress. *Southern Forests: a Journal of Forest Science* **79**(3): 169–183. <https://doi.org/10.2989/20702620.2016.1255415>
- GONÇALVES, M.R., and PASSOS, C.A.M. 2000. Crescimento de cinco espécies de eucalipto submetidas a déficit hídrico em dois níveis de fósforo. *Ciência Florestal* **10**(2): 145–161.
- GUMUCIO, T., ALVES, M.D.A., ORENTLICHER, N., and CEBALLOS, M.C.H. 2018. Analysis of gender research

- on forest, tree and agroforestry value chains in Latin America. *Forests, Trees and Livelihoods* **27**(2): 69–85. <https://doi.org/10.1080/14728028.2017.1417921>
- JACOVINE, L.A.G., SOARES, C.P.B., RIBEIRO, S.C., SILVA, R.D., and PAIXÃO, F.A. 2008. Sequestro de carbono em povoamentos florestais de eucalipto e a geração de créditos de carbono. *Informe Agropecuário* **29**(242): 90–104.
- JO, H.K., and PARK, H.M. 2017. Effects of pit plantings on tree growth in semi-arid environments. *Forest Science and Technology* **13**(2): 66–70. <https://doi.org/10.1080/21580103.2017.1312559>
- KARLBERG, L., HOFF, H., FLORES-LÓPEZ, F., GÖTZ, A., and MATUSCHKE, I. 2015. Tackling biomass scarcity – from vicious to virtuous cycles in sub-Saharan Africa. *Current Opinion in Environmental Sustainability* **15**: 1–8. <https://doi.org/10.1016/j.cosust.2015.07.011>
- KHASA, D., and ATANGANA, A. 2019. Tropical tree domestication in agroforestry. In *Agroforestry for sustainable agriculture*. Burleigh Dodds Science Publishing, p. 439–466.
- KLEINPAUL, I.S., SCHUMACHER, M.V., VIERA, M., and NAVROSKI, M.C. 2010. Plantio misto de *Eucalyptus urograndis* e *Acacia mearnsii* em sistema agroflorestal: produção de biomassa. *Ciência Florestal* **20**(4): 621–627.
- KREMEN, C., and MERENLENDER, A.M. 2018. Landscapes that work for biodiversity and people. *Science* **362**(6412): 6020. <https://doi.org/10.1126/science.aau6020>
- KUYAH, S., ÖBORN, I., JONSSON, M., DAHLIN, A.S., BARRIOS, E., MUTHURI, C., MALMER, A., NYAGA, J., MAGAJU, C., NAMIREMBE, S., NYBERG, Y., and SINCLAIR, F.L. 2016. Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. *International Journal of Biodiversity Science, Ecosystem Services & Management* **12**(4): 255–273. <https://doi.org/10.1080/21513732.2016.1214178>
- LACLAU, J.P., SILVA, E.A.D., RODRIGUES LAMBAIS, G., BERNOUX, M., L.E., MAIRE, G., STAPE, J.L., BOUILLET, J.-P., GONÇALVES, J.L.D.M., JOURDAN, C., and NOUVELLON, Y. 2013. Dynamics of soil exploration by fine roots down to a depth of 10 m throughout the entire rotation in *Eucalyptus grandis* plantations. *Frontiers in Plant Science* **4**(243): 1–12. <https://doi.org/10.3389/fpls.2013.00243>
- LAURI, P., HAVLÍK, P., KINDERMANN, G., FORSELL, N., BÖTTCHER, H., and OBERSTEINER, M. 2014. Woody biomass energy potential in 2050. *Energy Policy* **66**: 19–31. <https://doi.org/10.1016/j.enpol.2013.11.033>
- LAVORANTI, O.J., BELLOTE, A.F.J., BUSCHINELLI, C.D.A., SIMIONI, F.J., ANDRADE, G.D.C., SILVA, H.D.D., BRITO, J.O., RIBASKI, J., DAMASO, M.C.T., SANTOS, P.E.T.D., and COURI, S. 2021. Florestas energéticas. **26**: 941–980. In: OLIVEIRA, E.B.D., PINTO JÚNIOR, J.E. (Ed.). *O eucalipto e a Embrapa: quatro décadas de pesquisa e desenvolvimento*. Brasília, DF: Embrapa, 1160p.
- LAWRY, S., SAMIL, C., HALL, R., LEOPOLD, A., HORNBY, D., and MTERO, F. 2017. The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *Journal of Development Effectiveness* **9**(1): 61–81. <https://doi.org/10.1080/19439342.2016.1160947>
- LIMA, M.C.D. DE., and GAMA, D.C. 2018. O sistema de integração lavoura-pecuária-floresta no Brasil: conceitos, desafios e novas perspectivas. *Agroforestalis News* **3**(1): 31–51.
- LODH, U.K., CHAUHAN, V., VERMA, S., and CHAND, K. 2025. Plantation Forestry. In: Mandal, A.K., Nicodemus, A. (eds) *Textbook of Forest Science*. Springer, Singapore, p. 495–504. [https://doi.org/10.1007/978-981-97-8289-5\\_22](https://doi.org/10.1007/978-981-97-8289-5_22)
- MARQUES, F.A., NASCIMENTO, A.F.D., ARAUJO FILHO, J.C.D., and SILVA, A.B.D. 2014. Solos do Nordeste. Embrapa Solos: Recife-PE, 8p.
- MATTOS, L.C., FERREIRA, A.P., and MAY, P.H. 2021. Seca e estiagem: dois sentidos para o mesmo fenômeno. **2**: 29–46. In: SABOURIN, E., RIBEIRO, O.L.M., GOULET, F., and MARTINS, E.S. (Eds). *A ação pública de adaptação da agricultura à mudança climática no Nordeste semiárido brasileiro*, 284p.
- MCEWAN, A., MARCHI, E., SPINELLI, R., and BRINK, M. 2020. Past, present and future of industrial plantation forestry and implication on future wood harvesting technology. *Journal of Forestry Research* **31**: 339–351. <https://doi.org/10.1007/s11676-019-01019-3>
- MEAD, D.J. 2005. Forests for Energy and the Role of Planted Trees. *Critical Reviews in Plant Sciences* **24**(5–6): 407–421. <https://doi.org/10.1080/07352680500316391>
- MEAD, D.J. 2007. Forests for energy and the role of planted trees. *BPTS* **24**(5–6): 407–421. <https://doi.org/10.1080/07352680500316391>
- MEDEIROS, P.M.D., ALMEIDA, A.L.S.D., SILVA, T.C.D., and ALBUQUERQUE, U.P.D. 2011. Pressure indicators of wood resource use in an Atlantic Forest area, northeastern Brazil. *Environmental Management* **47**: 410–424.
- MICCOLIS, A., PENEIREIRO, F.M., VIEIRA, D.L.M., MARQUES, H.R., and HOFFMANN, M.R.M. 2019. Restoration through agroforestry: options for reconciling livelihoods with conservation in the Cerrado and Caatinga biomes in Brazil. *Experimental Agriculture* **55**(S1): 208–225. <https://doi.org/10.1017/S0014479717000138>
- MILLER, D., MUÑOZ-MORA, J., CHRISTIAENSEN, L., MILLER, D.C., and MUNOZ MORA, J.C.M. 2016. Prevalence, economic contribution, and determinants of trees on farms across Sub-Saharan Africa. *World Bank Policy Research Working Paper* **7802**: 1–39.
- MONTAGU, K.D., KEARNEY, D.E., and SMITH, R.G.B. 2003. The biology and silviculture of pruning planted eucalypts for clear wood production – a review. *Forest Ecology and Management* **179**(1–3): 1–13. [https://doi.org/10.1016/S0378-1127\(02\)00579-0](https://doi.org/10.1016/S0378-1127(02)00579-0)
- MOREIRA, J.M.M.Á.P. 2011. Potencial e participação das florestas na matriz energética. *Pesquisa Florestal Brasileira* **31**(68): 363–363. <https://doi.org/10.4336/2011.pfb.31.68.363>
- NAIR, P.R., KUMAR, B.M., NAIR, V.D., NAIR, P.R., KUMAR, B.M., and NAIR, V.D. 2021. Multipurpose trees (MPTs) and other agroforestry species. An Introduction to Agroforestry: Four Decades of Scientific Developments, p. 281–351.

- NDEGWA, G., BREUER, T., and HAMHABER, J. 2011. Woodfuels in Kenya and Rwanda: powering and driving the economy of the rural areas. *Rural* **45**(2): 26–30.
- NEPOMUCENO, I.V., SOUZA, E.B.D., ZAPPI, D.C., MOREIRA, M.C., NEPOMUCENO, F.A.A., and MORO, M.F. 2021. Savannas of the Brazilian semiarid region: what do we learn from floristics? *Acta Botanica Brasílica* **35**(3): 361–380. <https://doi.org/10.1590/0102-33062020abb0259>
- NJENGA, M., GITAU, J.K., IIYAMA, M., JAMNADASSA, R., MAHMOUD, Y., and KARANJA, N. 2019. Innovative biomass cooking approaches for sub-Saharan Africa. *African Journal of Food, Agriculture, Nutrition and Development* **19**(1): 14066–14087. <https://doi.org/10.18697/ajfand.84.BLFB1031>
- NOULÈKOUN, F., KHAMZINA, A., NAAB, J.B., and LAMERS, J.P. 2017. Biomass allocation in five semi-arid afforestation species is driven mainly by ontogeny rather than resource availability. *Annals of Forest Science* **74**(78): 2–12. <https://doi.org/10.1007/s13595-017-0676-4>
- NÚÑEZ-CRUZ, A., MEAVE, J.A., and BONFIL, C. 2018. Reproductive phenology and seed germination in eight tree species from a seasonally dry tropical forest of Morelos, Mexico: Implications for Community-Oriented Restoration and Conservation. *Tropical Conservation Science* **11**: 1–14. <https://doi.org/10.1177/1940082917749946>
- OLIVEIRA, H.C.G.D., COSTA, J.V., and OJIMA, R. 2019. Migração de retorno para a região do semiárido setentrional brasileiro. *Mercator* **18**(e18023): 1–13. <https://doi.org/10.4215/rm2019.e18023>
- PANDEY, A.K., TRIPATHI, Y.C., and KUMAR, A. 2016. Non wood forest products (NTFPs) for sustained livelihood: Challenges and strategies. *Research Journal of Forestry* **10**(1): 1–7. <https://doi.org/10.3923/rjf.2016>
- PAREYN, F.G.C., RIEGELHAUPT, E.M., GARLET, A., GARIGLIO, M.A. Manejo florestal na caatinga: 40 anos de experimentação, Brasília/DF, MMA, 2024, 458p.
- PAUTASSO, M. 2019. The structure and conduct of a narrative literature review. A guide to the scientific career: Virtues, communication, research and academic writing, **31**: 299–310. <https://doi.org/10.1002/9781118907283.ch31>
- PUETTSMANN, K.J., WILSON, S.M., BAKER, S.C., DONOSO, P.J., DRÖSSLER, L., AMENTE, G., HARVEY, B.D., KNOKE, T., LU, Y., NOCENTINI, S., PUTZ, F.E., YOSHIDA, T., and BAUHUS, J. 2015. Silvicultural alternatives to conventional even-aged forest management—what limits global adoption?. *Forest Ecosystems* **2**(8): 1–16. <https://doi.org/10.1186/s40663-015-0031-x>
- RAKOTONARIVO, O.S., RAKOTOARISOA, M., RAJANARIVELO, H.M., RAHARIJAONA, S., JONES, J.P., and HOCKLEY, N. 2023. Resolving land tenure security is essential to deliver forest restoration. *Communications Earth & Environment* **4**(1): 179. <https://doi.org/10.1038/s43247-023-00847-w>
- RIBEIRO, F.L., GUEVARA, M., VÁZQUEZ-LULE, A., CUNHA, A.P., ZERI, M., and VARGAS, R. 2021. The impact of drought on soil moisture trends across Brazilian biomes. *Natural Hazards and Earth System Sciences* **21**(3): 879–892. <https://doi.org/10.5194/nhess-21-879-2021,2021>
- RIEGELHAUPT, E.M., and PAREYN, F.G.C. 2010. A questão energética, 65–75. In.: GARIGLIO, M.A., SAMPAIO, E.V. DE. S.B., CESTARO, L.A., and KAGEYAMA, P.Y. (Org.). *Uso Sustentável e Conservação dos Recursos Florestais da Caatinga*. Brasília-DF: Serviço Florestal Brasileiro, 368p.
- RIEGELHAUPT, E.M., PAREYN, F.G.C., and BACALINI, P. 2010. O manejo florestal na Caatinga: resultados da experimentação, 256–275. In.: GARIGLIO, M.A., SAMPAIO, E.V. DE. S.B., CESTARO, L.A., and KAGEYAMA, P.Y. (Org.). *Uso Sustentável e Conservação dos Recursos Florestais da Caatinga*. Brasília-DF: Serviço Florestal Brasileiro, 368p.
- RODIGHERI, H.R., da SILVA, H.D., and TUSSOLINI, E.L. 2007. Indicadores de custos, produtividade e renda de plantios de eucaliptos para energia na região de Guarapuava, PR. Colombo-PR: Embrapa, 7p.
- SABOURIN, E. 2021. Implementação da ação pública de adaptação às secas no Nordeste Semiárido. **1**: 9–27. In.: SABOURIN, E., RIBEIRO, O.L.M., GOULET, F., and MARTINS, E.S. (Org.). *A ação pública de adaptação da agricultura à mudança climática no Nordeste semiárido brasileiro*, 284p.
- SANQUETTA, C.R., DALLA CORTE, A.P., PELISSARI, A.L., TOMÉ, M., MAAS, G.C.B., and SANQUETTA, M.N.I. 2018. Dinâmica em superfície, volume, biomassa e carbono nas florestas nativas brasileiras: 1990–2015. *Biofix Scientific Journal* **1**(1): 193–198. <http://dx.doi.org/10.5380/biofix.v3i1.58384>
- SANTAROSA, E., PENTEADO JÚNIOR, J.F., and GOU-LART, I.C.G.D.R. 2014. Transferência de tecnologia florestal – cultivo de eucalipto em propriedades rurais: diversificação da produção e renda. Brasília-DF: Embrapa, 140p.
- SANTOS, C.A.G., NASCIMENTO, T.V.M.D., and SILVA, R.M.D. 2020a. Analysis of forest cover changes and trends in the Brazilian semiarid region between 2000 and 2018. *Environmental Earth Sciences* **79**(418): 1–20. <https://doi.org/10.1007/s12665-020-09158-1>
- SANTOS, C.P.S., SANTOS, R.C., CARVALHO, A.J.E., CASTRO, R.V.O., COSTA, S.E.L., LOPES, L.I., PAREYN, F.G.C., DIAS JÚNIOR, A.F., TRUGILHO, P.F., CARVALHO, N.F.O., and MAGALHÃES, M.A. 2020b. Estoque de energia da madeira em áreas sob manejo florestal no Rio Grande do Norte. *Scientia Forestalis* **48**(126): e3080. <https://doi.org/10.18671/scifor.v48n126.06>
- SANTOS, F.R., and SANTOS, M.J.C. 2012. Avaliação do desenvolvimento inicial de espécies florestais de uso múltiplo no semiárido Sergipano. *Scientia Plena* **8**(4): e047301-1.
- SANTOS, G.H.F., NASCIMENTO, R.S.D., and ALVES, G.M. 2017. Biomassa como energia renovável no Brasil. *Uningá Review* **29**(2): 6–13.

- SANTOS, J.P.D.O., ABREU, K.G., ARAÚJO, J.R.E.S., SOUSA, V.F.D.S., MACÊDO, M.L.A.D., and TORRES, E.D.N. 2023. Pressões antrópicas em Floresta Tropical Sazonalmente Seca em área suscetível a desertificação no Nordeste do Brasil. *Revista em Agronegócio e Meio Ambiente* **16**(3): 1–14. <https://doi.org/10.17765/2176-9168.2023v16n3e10535>
- SANTOS, P.M., VOLTOLINI, T.V., CAVALCANTE, A.C.R., PEZZOPANE, J.R.M., MOURA, M.S.B.D., SILVA, T.G.F.D., and CRUZ, P.G.D. 2011. Mudanças Climáticas Globais e a Pecuária: Cenários Futuros para o Semiárido Brasileiro. *Revista Brasileira de Geografia Física* **4**(6): 1176–1196.
- SAX, D.F., SCHLAEPFER, M.A., and OLDEN, J.D. 2022. Valuing the contributions of non-native species to people and nature. *Trends in Ecology & Evolution* **37**(12): 1058–1066.
- SHEPPARD, J.P., CHAMBERLAIN, J., AGÚNDEZ, D., BHATTACHARYA, P., CHIRWA, P.W., GONTCHAROV, A., SAGONA, W.C.J., SHEN, H.L., TADESSE, W., and MUTKE, S. 2020. Sustainable forest management beyond the wood-oriented status quo: transitioning to co-production of wood and non-wood forest products – a global perspective. *Current Forestry Reports* **6**(1): 26–40. <https://doi.org/10.1007/s40725-019-00107-1>
- SILVA, F.E.L.D., and BEZERRA, J.A. 2020. Região e Território: um breve olhar sobre a nova delimitação do Semiárido brasileiro. *Revista Homem, Espaço e Tempo* **14**(2): 66–82.
- SILVA, J.A.A.D. 2016. Potencialidades de Florestas Energéticas de Rápido Crescimento no Bioma Caatinga, p. 117–124. In: Anais do I Simpósio do Bioma Caatinga, Petrolina-PE: Embrapa Solos, p. 173.
- SILVA, J.R.I., SOUZA, R., SOUZA, E., BEZERRA, A.C., SAMPAIO, EVDSB, ORESKA, D., LIMA, J.R. DE. S., MENEZES, R.S.C., ANTONINO, A.C.D., MONTENEGRO, SMGL. 2025. Ecohydrological consequences of the replacement of Caatinga with pasture in the semiarid of Brazil. *Science of the Total Environment* **1002**: 180464. <https://doi.org/10.1016/j.scitotenv.2025.180464>
- SIMMONS, C.S., WALKER, R.T., and WOOD, C.H. 2002. Tree planting by small producers in the tropics: a comparative study of Brazil and Panama. *Agroforestry Systems* **56**: 89–105. <https://doi.org/10.1023/A:1021377231402>
- SIMONS, A.J., and LEAKEY, R.R.B. 2004. Tree domestication in tropical agroforestry. *Agroforestry Systems* **61**: 167–181. [https://doi.org/10.1007/978-94-017-2424-1\\_12](https://doi.org/10.1007/978-94-017-2424-1_12)
- SMITH, P., HOUSE, J.I., BUSTAMANTE, M., SOBOCKÁ, J., HARPER, R., PAN, G., WEST, P.C., CLARK, J.M., ADHYA, T., RUMPEL, C., PAUSTIAN, K., KUIKMAN, P., COTRUFO, F.M., ELIOTT, J.A., MCDOWELL, R., GRIFFITHS, R.I., ASAKAWA, S., BONDEAU, A., JAIN, A.K., MEERSMANS, J., and PUGH, T.A. 2016. Global change pressures on soils from land use and management. *Global Change Biology* **22**(3): 1008–1028. <https://doi.org/10.1111/gcb.13068>
- SOARES, N.S., SILVA, M.L.D., REZENDE, J.L.P.D., and GOMES, M.F.M. 2010. Competitividade da cadeia produtiva da madeira de eucalipto no Brasil. *Revista Árvore* **34**(5): 917–928. <https://doi.org/10.1590/S0100-67622010000500017>
- SOUZA, R., FENG, X., ANTONINO, A., MONTENEGRO, S., SOUZA, E., and PORPORATO, A. 2016. Vegetation response to rainfall seasonality and interannual variability in tropical dry forests. *Hydrological Processes* **30**(20): 3583–3595. <https://doi.org/10.1002/hyp.10953>
- TAVARES, V.C., ARRUDA, Í.R.P.D., and SILVA, D.G.D. 2019. Desertificação, mudanças climáticas e secas no semiárido brasileiro: uma revisão bibliográfica. *Geosul* **34**(70): 385–405. <https://doi.org/10.5007/2177-5230.2019v34n70p385>
- TRAVASSOS, I.S., and SOUZA, B.I. 2014. Os negócios da lenha: indústria, desmatamento e desertificação no Cariri paraibano. *Espaço e Tempo (Online)* **18**(2): 329–340. <https://doi.org/10.11606/issn.2179-0892.geosp.2014.84536>
- UDAWATTA, R.P., RANKOTH, L.M., and JOSE, S. 2019. Agroforestry and biodiversity. *Sustainability* **11**(10): 2879. <https://doi.org/10.3390/su11102879>
- VALVERDE, S.R., SOARES, N.S., SILVA, M.D., JACOVINE, L.A.G., and NEIVA, S.D.A. 2004. O comportamento do mercado da madeira de eucalipto no Brasil. *Biomassa & Energia* **1**(4): 393–403.
- VARGHESE, M., KAMALAKANNAN, R., and SURAJ, P.G. 2024. *Eucalyptus*: Taxonomy, Geographic Distribution, Domestication, Breeding, Ecology and Economic Importance. In *Economically Important Trees: Origin, Evolution, Genetic Diversity and Ecology*. Springer, Singapore, p. 81–128.
- VITTI, A.M.S., and BRITO, J.O. 2003. Óleo essencial de eucalipto. *Documentos Florestais* **17**(3): 1–26.
- WATSON, J.E., EVANS, T., VENTER, O., WILLIAMS, B., TULLOCH, A., STEWART, C., THOMPSON, I., RAY, J.C., MURRAY, K., SALAZAR, A., MCALPINE, C., POTAPOV, P., WALSTON, J., ROBINSON, J.G., PAINTER, M., WILKIE, D., FILARDI, C., LAURANCE, W.F., HOUGHTON, R.A., MAXWELL, S., GRANTHAM, H., SAMPER, C., WANG, S., LAESTADIUS, L., RUNTING, R.K., SILVA-CHÁVEZ, G.A., ERVIN, J., and LINDENMAYER, D. 2018. The exceptional value of intact forest ecosystems. *Nature Ecology & Evolution* **2**(4): 599–610. <https://doi.org/10.1038/s41559-018-0490-x>
- WEST, P.W. 2014. Pruning. In: *Growing Plantation Forests*. Springer, p. 131–146. [https://doi.org/10.1007/978-3-319-01827-0\\_9](https://doi.org/10.1007/978-3-319-01827-0_9)
- WOLFF, L.F., and SCHUHLI, G.S. 2021. Eucaliptos e abelhas, **16**: 687–699. In: OLIVEIRA, E.B.D., and PINTO JUNIOR, J.E. (Ed.). *O eucalipto e a Embrapa: quatro décadas de pesquisa e desenvolvimento*. Brasília, DF: Embrapa, 1160p.
- XAVIER, A., and SILVA, R.L.D. 2010. Evolução da silvicultura clonal de *Eucalyptus* no Brasil. *Agronomia Costarricense* **34**(1): 93–98.
- ZANELLA, M.E. 2014. Considerações sobre o clima e os recursos hídricos do semiárido nordestino. *Caderno Prudentino de Geografia* **1**(36): 126–142.

# Unlocking the potential of private forests for carbon storage, biodiversity conservation, and livelihoods in Nepal

R. JOSHI<sup>a,b</sup>, H. ZHANG<sup>a\*</sup>, T. MARASENI<sup>c\*</sup>, N. DHAKAL<sup>b</sup>, J. GAUTAM<sup>d</sup>, H. SINGH<sup>e</sup> and H. ADHIKARI<sup>f,g</sup>

<sup>a</sup>College of Economics and Management, Northwest A&F University, Yangling, Shaanxi 712100, China

<sup>b</sup>College of Natural Resource Management, Faculty of Forestry, Agriculture and Forestry University, Katari-56310, Udayapur, Nepal

<sup>c</sup>Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia

<sup>d</sup>Faculty of Forestry, Agriculture and Forestry University, Hetauda, Nepal

<sup>e</sup>ICFRE – Forest Research Institute, PO New Forest, Dehradun – 248006, Uttarakhand, India

<sup>f</sup>Department of Geosciences and Geography, University of Helsinki, P.O. Box 68, 00014 Helsinki, Finland

<sup>g</sup>Forest Nepal Oy, Vantaa, 01370, Uusima, Finland

\*Corresponding author: hanzhang@nwafu.edu.cn, tek.maraseni@usq.edu.au

Email: joshi.rajeev20@gmail.com, hanzhang@nwafu.edu.cn, tek.maraseni@usq.edu.au, nabindhakal789@gmail.com, jeetendra.gautam17@gmail.com, hukumsingh97@yahoo.com, hari.adhikari@helsinki.fi

---

## HIGHLIGHTS

- This study is the first to integratively quantify the significant potential of Nepal's private forests for carbon storage, biodiversity conservation, and livelihood support.
- Two distinct models are revealed: Terai forests are high-carbon-density systems (74.23 t C/ha), while Mid-Hill forests are high-diversity systems with more evenly distributed biomass.
- Ecological dominance is directly shaped by farmer preferences, high-value timber in the Terai and multipurpose species in the Mid-Hills proving management is a deliberate socio-economic strategy.
- The relationship between ecological importance (IVI) and biomass is strong in species-rich Mid-Hills forests ( $\rho = 0.78$ ) but weak in the Terai, showing fundamentally different mechanisms for carbon storage.
- Private forests are a major, underutilized asset for climate mitigation (e.g., REDD+). Our findings demand region-specific policies to unlock their full environmental and economic potential.

## SUMMARY

Globally, natural forests have declined since 1990, while planted and private forests have expanded by 123 million hectares. With careful species selection, private forests can offer significant environmental and financial benefits. This study collected and analyzed data from 28 private forests (PFs) across two distinct physiographic regions of Nepal, the Terai and Mid-Hills, assessing their ecological characteristics, carbon sequestration potential, and farmers' species preferences. Findings reveal contrasting ecological patterns: Mid-Hill Private Forests (MPF) exhibited higher species richness and more evenly distributed biomass, while Terai Private Forests (TPF) were dominated by a few high-biomass species such as *Shorea borneensis* and *Tectona grandis*, storing over three times more carbon per hectare than MPF. Farmers' preferences mirrored these contrasts, with multipurpose species favored in the Mid-Hills and high-value timber species in the Terai. Ecological dominance (IVI) strongly predicted aboveground biomass in MPF ( $\rho = 0.78$ ,  $p < 0.001$ ) but showed a weak association in TPF ( $\rho = 0.42$ ,  $p = 0.08$ ), highlighting divergent species roles in carbon storage. Our findings demonstrate that private forests hold untapped potential for carbon trading (REDD+), biodiversity conservation, and achieving the UN Sustainable Development Goals. This study provides vital information for evidence-based policy change and sustainable private forest management by integrating carbon sequestration, biodiversity indices, and farmer preferences across Nepal's physiographic gradients.

Keywords: carbon sequestration, comparative analysis, farmer preferences, private forestry, REDD+

---

## INTRODUCTION

Forests are the richest biological communities on earth and have been recognized to harbour a significant proportion of global biodiversity (Naidu *et al.* 2016). Globally, forests cover approximately 31% of the Earth's land surface, totaling 4.06 billion hectares (FAO 2020, 2022). Due to various national and international policy interventions, the global

annual deforestation rate declined from 16 million hectares in the 1990s to 10 million hectares between 2015 and 2020, although this decline remains concerning. Of the global forest area, 93% (3.75 billion ha) is naturally regenerating, while 7% (290 million ha) is planted forest. However, naturally regenerating forests have continuously declined since 1990, whereas planted forests expanded by 123 million ha despite the growth rate slowing over the last decade (FAO 2020).

Forests in Nepal play a vital role in environmental stability and livelihoods (Aryal *et al.* 2025). While community and national forests have received substantial attention in policy and research, private forests those owned and managed by individual farmers remain a largely untapped resource (Hirsch and Schmithüsen 2010). Despite recent policy reforms, including the Forest Act (2019) and the Forestry Sector Strategy 2016–2025, which acknowledge private forests' role in climate resilience and rural economies, their formal registration and integration into national climate strategies remain limited (CFD 2017, GoN 2015). This gap is especially pertinent given Nepal's REDD+ readiness and the potential for private forests to contribute significantly to carbon mitigation and rural prosperity (Bhattarai *et al.* 2023, Maraseni *et al.* 2020).

Forests are crucial for climate regulation, biodiversity preservation, and rural livelihoods, especially in forest-rich countries like Nepal (Dhakal *et al.* 2022). While community and national forests have garnered considerable attention in research and policy, private forests remain relatively overlooked despite their expanding area and potential (Tole 2010). These forests, owned and managed by individual farmers, could play an important role in carbon sequestration, biodiversity conservation, and income generation yet basic data on their structure, biomass, and carbon stocks are limited (Henry *et al.* 2009). Understanding their ecological and socio-economic aspects is essential, particularly across Nepal's varied physiographic regions where forest dynamics differ greatly (Pandey *et al.* 2023). This study addresses this global and national research gap by examining the ecological patterns and carbon potential of private forests in the Terai and Mid-Hills, thereby supporting evidence-based policies and management strategies. Private forests are still relatively understudied, despite growing research on forest carbon and biodiversity in Nepal, which has predominantly focused on community-managed forests (Joshi *et al.* 2021a,b, Joshi and Singh 2020) and specific national contexts (Joshi and Bhatta 2023). While a recent study assessed carbon in private forests across physiographic regions (Joshi *et al.* 2023a), there still remains a critical gap in integrated studies that simultaneously examine species diversity, biomass carbon, and farmer-driven species selection. This knowledge gap restricts our ability to comprehend how private woods in Nepal's Terai and mid-hill regions contribute to biodiversity conservation and climate mitigation. From a conceptual standpoint, private woods function within a unique socio-ecological framework where species composition, dominance, and related carbon storage capacity are directly influenced by the preferences of individual farmers. We hypothesize that the Terai and Mid-Hills have different private forest systems due to different environmental conditions and market access. In the fertile, market-connected Terai, private forests are likely dominated by high-value timber species, leading to relatively high carbon stocks with lower species diversity, while multipurpose species are expected to predominate in the more subsistence-oriented Mid-Hills, supporting higher biodiversity but more evenly distributed carbon stocks. Private forests differ from community or state-managed forests in this setting of individual-driven management, where collective governance systems frequently prioritize conservation goals in addition to livelihood benefits.

The aim of this study was to evaluate the ecological features, carbon sequestration capacity, and farmers' species preferences in private forests of Nepal's Terai and Mid-Hills regions. Specifically, we compared forest structure and diversity, estimated carbon stock density, analyzed ecological dominance (IVI)–carbon relationships, and assessed how farmers' species choices align with ecological functions. This research presents four key innovations: (1) it combines ecological data on species diversity, biomass, and carbon sequestration with socio-economic insights into farmers' preferences and management practices, offering a comprehensive understanding of how private forests support both environmental sustainability and local livelihoods; (2) it provides a new comparative analysis of private forests in two distinct physiographic regions, Terai and Mid-Hills, illustrating how different environmental conditions affect forest dynamics and carbon sequestration potential; (3) it investigates the feasibility of implementing REDD+ (Reducing Emissions from Deforestation and Forest Degradation) in privately owned forests, broadening REDD+'s scope beyond community and national forests to include private lands; and (4) the study's farmer-focused approach examines how economic incentives and regional environmental factors influence species preferences, further connecting private forest management with climate change mitigation and biodiversity conservation.

## MATERIALS AND METHODS

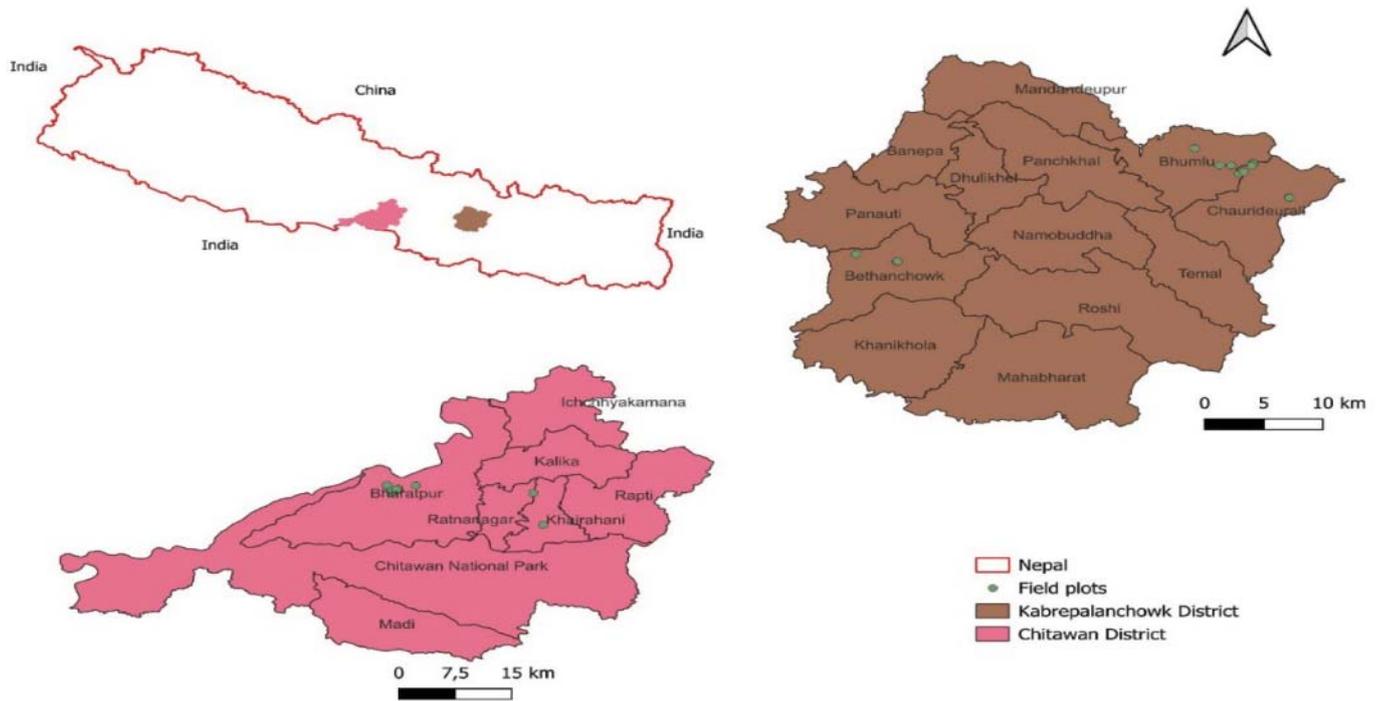
### Study area

This research was conducted in private forests located in two physiographic regions of Nepal: Chitwan district (Terai region-TPF) and Kavrepalanchok district (mid-hill region-MPF) within Bagmati Province (see Figure 1). Chitwan and Kavrepalanchok were purposefully selected because of their contrasting physiographic, ecological, and socio-economic conditions, which directly support the study's goals. Chitwan's private forests are dominated by high-value timber species with high carbon density, while Kavrepalanchok's forests contain multipurpose species that support diverse local livelihoods. These differences enable a strong comparison of species diversity, forest structure, and carbon storage potential, as well as an analysis of how farmer preferences shape forest management. For every district, a list of possible private forests was created. Forest sizes between 0.1 and 0.5 hectares were taken into account throughout the screening procedure. In the end, fourteen private forests were chosen from every region. In addition, two wards from various municipalities were selected at random within each district to identify the private forests while accounting for field data collection accessibility.

### Policy and Socio-economic Context

Private forestry in Nepal operates within a distinct historical and policy landscape. Early initiatives, such as the mandate

FIGURE 1 Selected districts for the study area and private forest distribution



by Prime Minister Juddha Sumsher requiring sapling planting before tree felling, reflected early recognition of sustainable use. However, the 1957 Private Forests Nationalization Act severely restricted private ownership and discouraged tree planting for decades (Dhakal *et al.* 2012). Recent legal reforms, particularly the Forest Act (2019) and the Forestry Sector Strategy 2016–2025, have begun to reverse this trend by formally acknowledging private forests' contributions to national forest cover, rural livelihoods, and climate objectives, including Nepal's Nationally Determined Contributions (NDC) (GoN 2015). Despite this, registration remains low, only 2,902 hectares were officially recorded across 62 districts as of 2017 (CFD 2017) indicating a significant implementation gap. This policy backdrop directly informs farmer decision-making and species selection, which we captured through semi-structured interviews to understand management rationales.

### Data Collection

Before field deployment, coordination meetings were held with the Division Forest Offices (DFOs) of Kavrepalanchok (MPF) and Chitwan (TPF) to obtain lists of registered private forests along with their contact information (Figure 2). The preliminary lists provided by the DFOs were subjected to a multi-stage screening process to ensure the selected private forests were representative and suitable for a robust comparative analysis. The screening was based on two primary criteria:

#### Forest Patch Size (0.1–0.5 hectares)

This specific size range was selected for critical methodological and ecological reasons. Firstly, it represents the most common landholding size for dedicated private woodlots in Nepal, ensuring our sample reflects the predominant

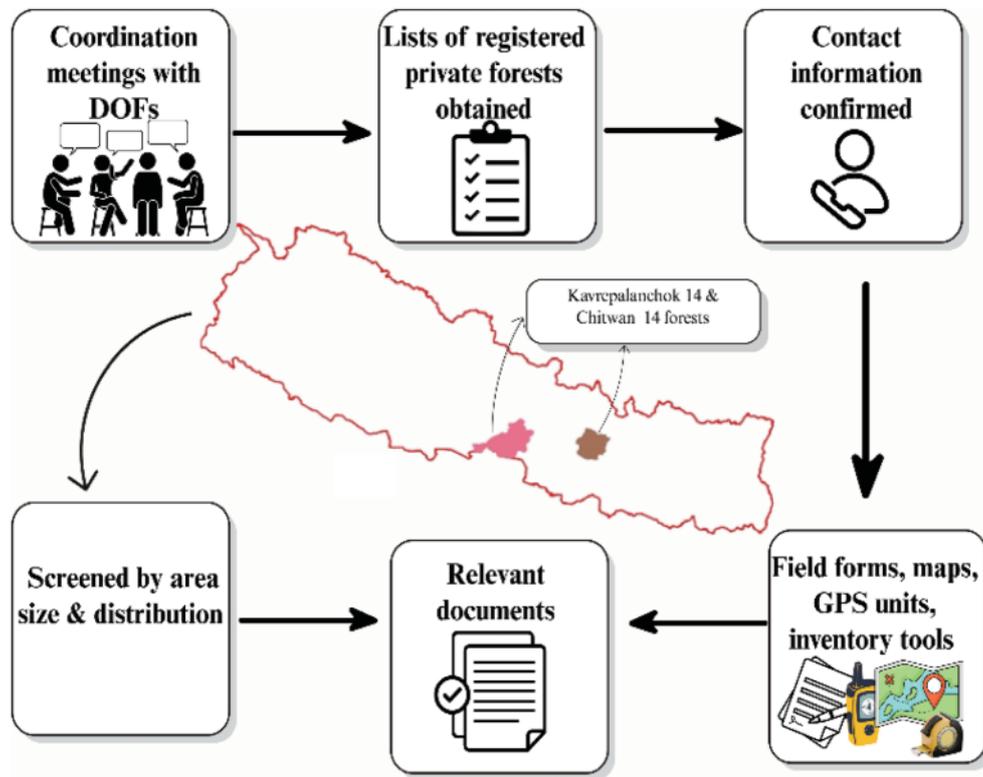
socio-ecological system of interest (CFD 2017). Secondly, and most importantly, standardizing the forest area was essential to control for the well-documented and confounding influence of patch size on forest structure, biomass, and biodiversity (e.g., Chave *et al.* 2005). By holding area relatively constant, we isolate the effects of our key independent variables, physiographic region and associated species composition on carbon stock and diversity metrics. This design allows for a more precise attribution of observed differences to regional and management factors rather than to area effects. Finally, this size range made the application of a total enumeration (100% census) method logistically feasible, ensuring high data integrity for each sampled unit.

#### Spatial Distribution

To capture the inherent environmental and socio-economic heterogeneity within each district and avoid spatial autocorrelation, we ensured the selected forests were distributed across multiple administrative units. Specifically, we selected two wards from different municipalities within each district. This stratified approach ensures that our sample is not clustered in a single micro-climate or market area, thereby increasing the external validity of our findings for the broader physiographic region. Following this rigorous screening, a final sample of 28 private forests (14 from each district) was selected for detailed inventory.

In parallel, relevant documents, including acts, policies, guidelines, and forest inventory strategies, were reviewed. These included publications from the Department of Forest Research and Survey (DFRS) and the Forest Resource Assessment (FRA) Final Report (2015). Before starting fieldwork, the team equipped themselves with field forms, topographic maps, GPS units, and necessary inventory tools.

FIGURE 2 Workflow for selecting and preparing private forests in Kavrepalanchok and Chitwan districts, Nepal, for field inventory and data collection



The field forms included essential details such as the owner's name, forest area, registration date, GPS coordinates, forest type, and forest condition, along with sections to record measurements of trees, poles, and saplings. Inventory equipment was inspected, and GPS coordinates for each site were preloaded. Similarly, during the forest inventory, informal discussions were held with each landowner to understand the history and management of their forest. We specifically inquired about the reasons for planting the dominant species observed. While not a formal structured survey, these conversations provided critical contextual data on farmer motivations, which we recorded as field notes. The reasons cited by farmers for species selection were later categorized and are reported here to ground our interpretation of the ecological data in local knowledge.

### Forest sampling design and measurement

The inventory of private forests employed a total enumeration method (Joshi *et al.* 2023a). Trees and poles with a diameter at breast height (DBH) greater than 10 cm were measured. DBH was estimated at 1.3 meters above ground using diameter tape, and tree height was measured with a Silva clinometer. The basal area (BA) was calculated ( $\text{m}^2/\text{ha}$ ) using DBH data and plot size (Figure 3).

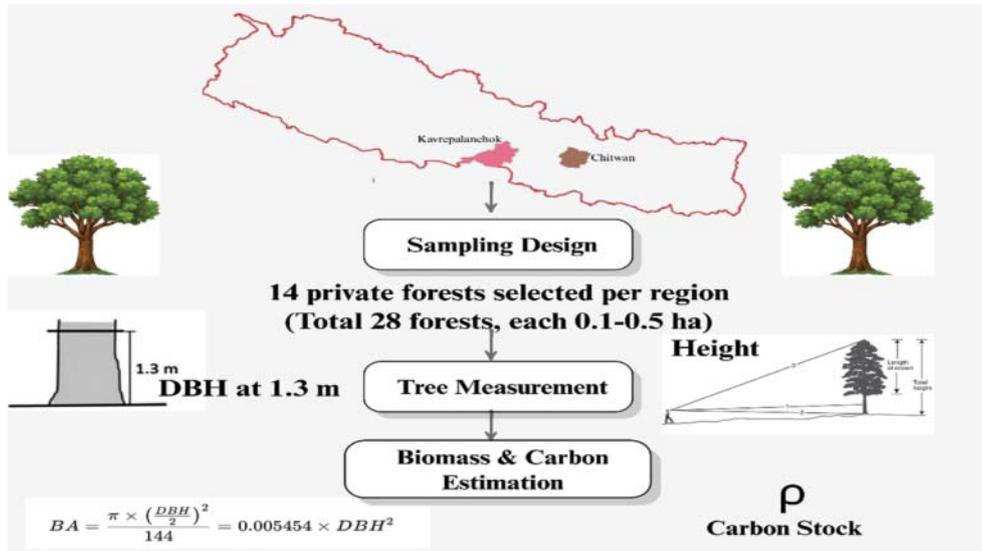
### Ecological and carbon assessment framework

Understanding the phytosociological information of specific tree species is crucial for a better grasp of their ecology

(Kharakwal 2009). Identifying plant communities allows us to gather data on habits, habitats, niches, vegetation structure, and various interactions among them (Khan *et al.* 2017). Similarly, recognizing patterns of vegetation and species diversity is essential for conserving natural areas, which has been a major focus of ecological research (Zhang *et al.* 2013). Analyzing the dynamic nature of vegetation in relation to particular eco-environmental conditions requires detailed information on plant diversity and distribution (Sorecha and Deriba 2017). Thus, vegetation analysis remains a critical tool for plant ecologists, applicable in range management and comparative studies (Tarin *et al.* 2017).

Estimating aboveground biomass (AGB) is a vital part of research on carbon stocks and the global carbon balance (Ketterings *et al.* 2001). While this study focuses on AGB, it is important to note that total biomass, including belowground biomass, can be calculated by using specific conversion factors for AGB, such as multiplying AGB by 1.24 for tropical forests (IPCC 2006). AGB remains a reliable metric for comparing the structural and functional features of forest ecosystems across different environments (Brown *et al.* 1999). Ecological studies have long used permanent sampling plots to measure biomass stocks (Brown 2002, Fearnside 1996). Tree AGB is closely linked to trunk diameter (Brown and Lugo 1992, Brown 1997), allowing researchers to use forest inventory data to estimate AGB stocks and their changes over time. Multiple studies have shown that diameter and height are dependable predictors for estimating AGB (Chave *et al.* 2001, Clark *et al.* 2001, DeWalt and Chave 2004). Environmental factors such as topography, hydrology, and soil properties can affect stand

FIGURE 3 Schematic diagram of the research methodology for estimating tree biomass and carbon stocks in private forests of Nepal's Terai and Mid-Hills regions



density and AGB (Clark and Clark 2000). Therefore, estimating AGB is essential for understanding ecosystem carbon storage and fluxes (Sun and Liu 2020).

#### Assessing farmer preferences and management rationale

To move beyond ecological inference and directly understand the socio-economic drivers behind species composition, we complemented the forest inventory with a survey of private forest owners. During the field visit to each of the 28 selected private forests, we conducted semi-structured interviews with the landowner or primary manager (n=28). The interviews were designed to elicit two key pieces of information:

##### Species preference ranking

Farmers were asked to rank the tree species on their land in order of importance/value to their household.

##### Planting and management rationale

For their top-ranked species, we asked open-ended questions to understand the primary reasons for planting and retaining them. The prompts included: “Why did you choose to plant [Species X]?” and “What are the main benefits you get from [Species X]?” Responses were recorded in field notebooks and later coded into thematic categories (e.g., ‘High timber value,’ ‘Fodder,’ ‘Soil fertility,’ ‘Fast growth,’ ‘Medicinal use’). This qualitative data provides the direct evidence linking the observed forest composition (IVI, biomass) to the underlying farmer motivations, allowing us to test the hypothesis that species selection is a deliberate process driven by socio-economic needs within environmental constraints.

#### Data analysis

##### Quantifying tree species diversity

We considered plants with a diameter of at least 10 cm at breast height as established plants and used them for diversity

estimation, for the quantitative data analysis frequency, density, basal area, abundance, and Importance Value Index (I.V.I) of tree species were calculated by using the method described by Zobel *et al.* (1987) with some modifications. We produced species accumulation curves using Kindt’s precise accumulator method (Ugland *et al.* 2003) and Chao2 richness estimator values (Magurran 2004) to compare and estimate the overall species number per management approach. Species richness, individual numbers, Simpson diversity index (1-D) (Simpson 1949), and Shannon diversity (Shannon 1948) were used to compare plant species diversity at both the plot and landscape levels.

##### Aboveground Biomass and Carbon Stock Estimation

The total stem volume of each tree species was calculated using the volume equation (Equation 1) developed by Sharma and Pukkala (1990).

$$\ln(V) = a + b \ln(\text{dbh}) + c \ln(\text{ht}) \quad (1)$$

where, V = total stem volume with bark (m<sup>3</sup>); dbh = diameter at breast height (m); ht = total tree height (m); and a, b, c = species-specific parameter estimates. The stem volume (m<sup>3</sup>) obtained from Equation (1) was divided by 1000 to obtain the cubic meter volume, and then the stem volume was multiplied by a species-specific dry wood density to obtain the oven-dry weight of stem biomass (Khanal *et al.* 2010, Subedi *et al.* 2010). Aboveground biomass (AGB) was estimated using species-specific allometric equations and wood density values, an approach consistently applied in our prior carbon stock assessments in various Nepalese forest systems (Joshi *et al.* 2020, Rauniyar *et al.* 2023). The Global Wood Density Database (Chave *et al.* 2009, Zanne *et al.* 2009) provided the wood density data, which were then augmented with references unique to Nepal (Sharma and Pukkala 1990).

Then, the biomass carbon content was calculated using an Equation 2 developed by IPCC (2006):

$$AGC = 0.47 \times AGB \quad (2)$$

Where, AGC=Aboveground Carbon (Mg) and AGB= Above-ground Biomass (Mg)

Finally, the aboveground carbon stock per hectare was calculated by dividing the total aboveground carbon stock by the total forest area (Equation 3), a widely applied method in carbon accounting following standard forestry and IPCC protocols (IPCC 2006, Subedi et al. 2010):

$$\text{Carbon (tonnes / ha)} = \frac{\text{Total Carbon (tonnes)}}{\text{Total Area (ha)}} \quad (3)$$

This study focuses on aboveground carbon (AGC) as the primary metric for carbon storage, aligning with IPCC Tier 1 reporting and practical forest inventory constraints. While belowground biomass is a significant carbon pool, it was accounted for using the IPCC (2006) default multiplier (AGB × 1.24) for tropical forests. Our AGC estimates thus provide a conservative, measurable, and policy-relevant baseline for assessing carbon sequestration potential in private forests.

### Statistical analysis

All statistical analyses were performed using R software (R Core Team 2024). Normality assumptions were tested using the Shapiro-Wilk test for all variables (diversity indices, IVI, and AGB), with  $p > 0.05$  indicating normality. Based on these results, Carbon stocks were compared using the Wilcoxon rank-sum test (non-parametric). Similarly, diversity indices (Shannon, Simpson, and Dominance) and other normally distributed parameters were compared using Welch’s t-test. The IVI-AGB relationship was analyzed using Spearman’s correlation ( $\rho$ ) due to non-normal distributions (Shapiro-Wilk:  $p < 0.05$  for both regions).

## RESULTS

### Distribution of diameter class

MPF showed a high concentration in the 10–19.9 cm diameter class, with 5 966 trees falling within this range. The number

of trees decreased significantly in subsequent diameter classes, with a minor peak of 78 trees in the 20–29.9 cm class. Similarly, the TPF group exhibited a higher concentration of trees in the 10–19.9 cm diameter class, with 3 351 trees. The TPF group, however, had a notable peak in the 30–39.9 cm diameter class, with 1 451 trees (Figure 4). The number of trees decreased significantly in the subsequent diameter classes.

The diameter distribution of tree stems revealed contrasting patterns between the two forest types (Figure 5). While both MPF and TPF exhibited the highest stem density in the 10–20 cm DBH class (347 individuals/ha and 547 individuals/ha, respectively), their distribution patterns diverged substantially in larger classes. TPF displayed a near-continuous reverse-J shaped distribution, with stem density gradually decreasing from 237 individuals/ha in the 20–29.9 cm class to 0 individuals/ha in the 40–≥70 cm class. In contrast, MPF showed an abrupt decline after the 10–20 cm class, with complete absence of trees in the 30–59.9 cm diameter range, followed by a minor resurgence of larger trees in the 60–69.9 cm (4 individuals/ha) and ≥70 cm (2 individuals/ha) classes. Overall, TPF maintained relatively higher stem densities across larger diameter classes compared to MPF, indicating a more balanced age structure.”

In the MPF, most tree species fall within the dbh≥10 cm class (19 species), with a significant drop in species numbers for larger dbh classes. Only 1 species is found in the dbh≥70 cm class, whereas the TPF forest type showed a more even distribution of species across dbh classes. It had the highest number of species in the dbh≥20 cm class (6 species), and the number gradually decreased for larger dbh classes. No species were found in the dbh≥70 cm class (Figure 6).

### Distribution of height class

MPF had a higher number of trees in the 0–9.9 m and 10–19.9 m height classes (3 050 and 2 798 trees, respectively), whereas TPF had a larger number of trees in the 20–29.9 m height class (3 549 trees). No trees exceeding 30 meters in height were recorded in either forest type, with the vast majority of individuals concentrated in the 0–29.9 m height classes (Figure 7).

FIGURE 4 No. of tree individual distribution with different DBH class

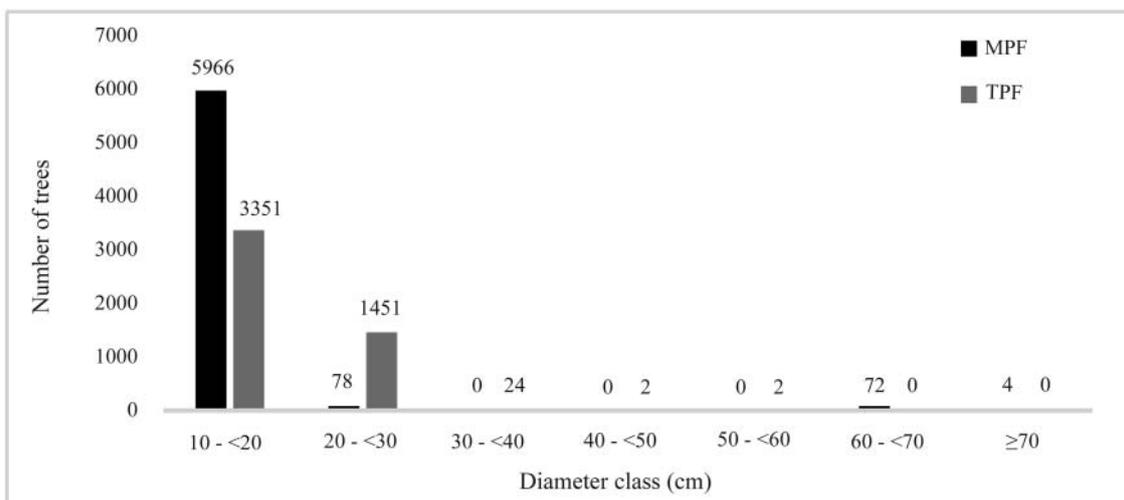


FIGURE 5 Diameter class distribution of tree individuals (density in ind./ha.) across MPF and TPF. The X-axis represents diameter at breast height (DBH) classes (cm), and the Y-axis represents tree density (no. of stems/ha)

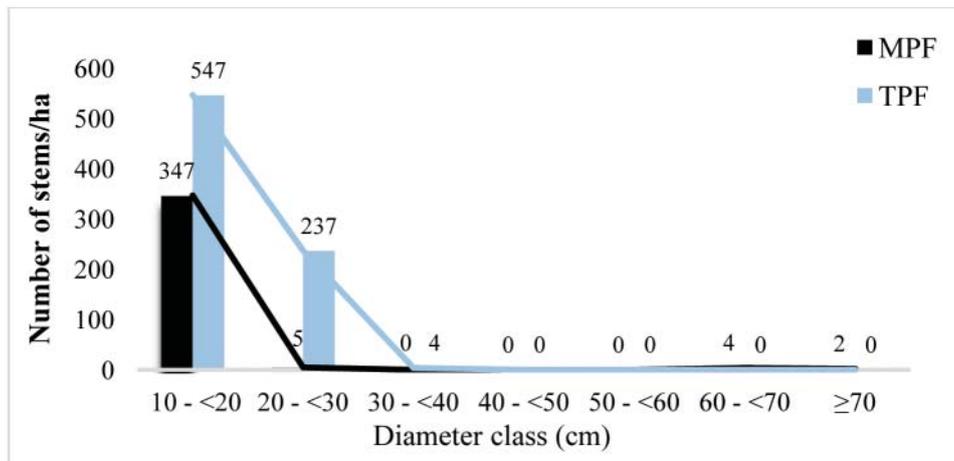


FIGURE 6 No. of tree species distribution with different DBH classes

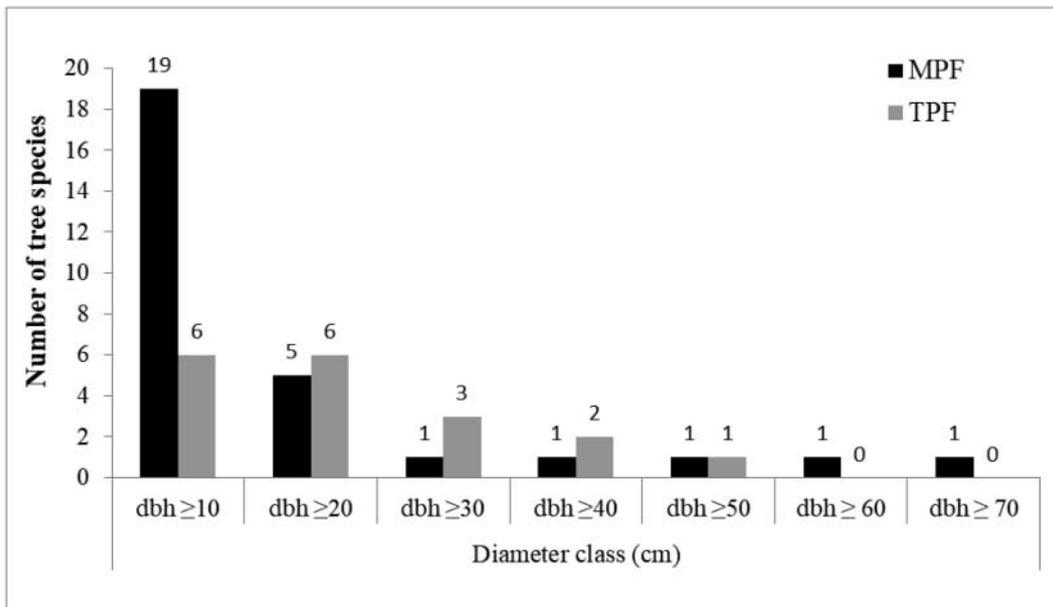
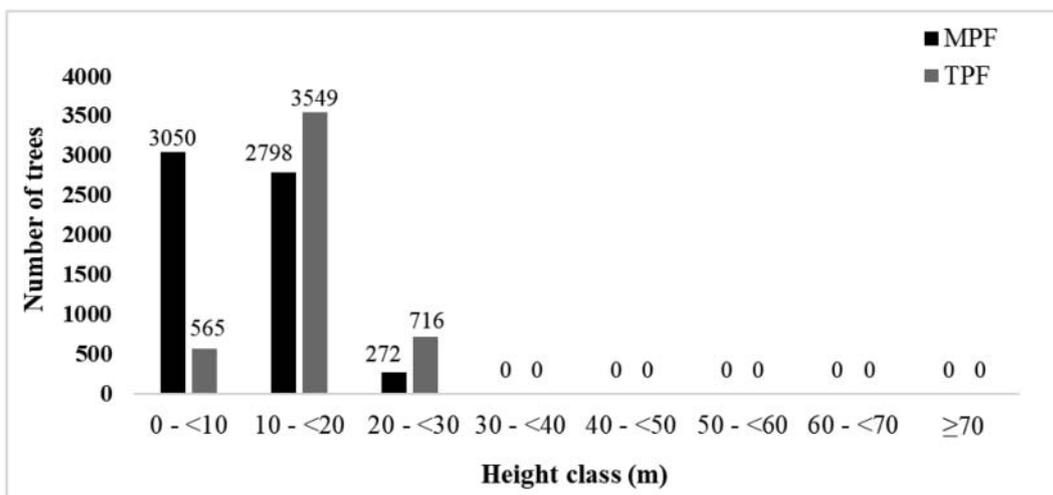


FIGURE 7 No. of tree individual distribution with different height class



### Contribution of tree species in carbon stock

In MPF, *Pinus patula* (37.73%) and *Choerospondias axillaris* (37.34%) were the most significant contributors to above-ground carbon (AGC), while in TPF, *S. borneensis* (68.79%) and *T. grandis* (19.66%) dominated carbon stocks. The Table 1 highlights the carbon storage potential (in tonnes) of various tree species within two forest types: MPF and TPF. Across MPF, carbon storage values exhibited a wide range, from minimal contributions by species such as *Abies pindrow* (0.00705 t) to significant contributions by *P. patula* (130.00858 t) and *C. axillaris* (128.65545 t). Similarly, TPF showed considerable variability, with *Bombax ceiba* contributing as little as 0.42864 t, while *S. borneensis* stands out with a remarkable 313.08956 t. Notable trends include the dominance of a few high-carbon species in each forest type, which significantly skew the averages. Most MPF species display moderate carbon storage values below 10 t, whereas TPF species like *T. grandis* and *Swietenia mahagoni* form a middle tier with values ranging from 26 to 89 t. The total aboveground carbon (AGC) stock was found to be 344.55 ± 9.18 tonnes in the MPF and 455.12 ± 49.18 tonnes in the TPF. These findings suggest distinct patterns of carbon sequestration across species

and forest types, highlighting the ecological and climatic importance of conserving specific high-carbon species (Table 1). While performing the Wilcoxon rank sum test, it indicated no statistically significant difference in carbon stock between the Terai and mid-hill regions ( $W=26$ ,  $p=0.052$ ), though the result was marginally non-significant. When normalized per unit area, the total AGC was estimated at  $20.01 \pm 0.53$  tonnes per hectare for MPF and  $74.23 \pm 8.02$  tonnes per hectare for TPF. These results reveal a significant contrast in carbon density between the two physiographic regions, with TPF exhibiting more than threefold higher carbon stock per hectare compared to MPF (Table 1).

### Forest Importance Value Index (IVI) and Aboveground Biomass (AGB) differentiation

The study of species composition, IVI and AGB in MPF and TPF revealed significant ecological differences between the two forest types in Nepal, as well as distinct patterns in the roles and contributions of individual species. In MPF, *P. patula* was the dominant species in both IVI (111.01) and AGB (276.61 Mg). However, *C. axillaris* displayed high AGB despite a lower IVI. This species contributed significantly to

TABLE 1 The percentage share of species contribution to the carbon stock of both PFs

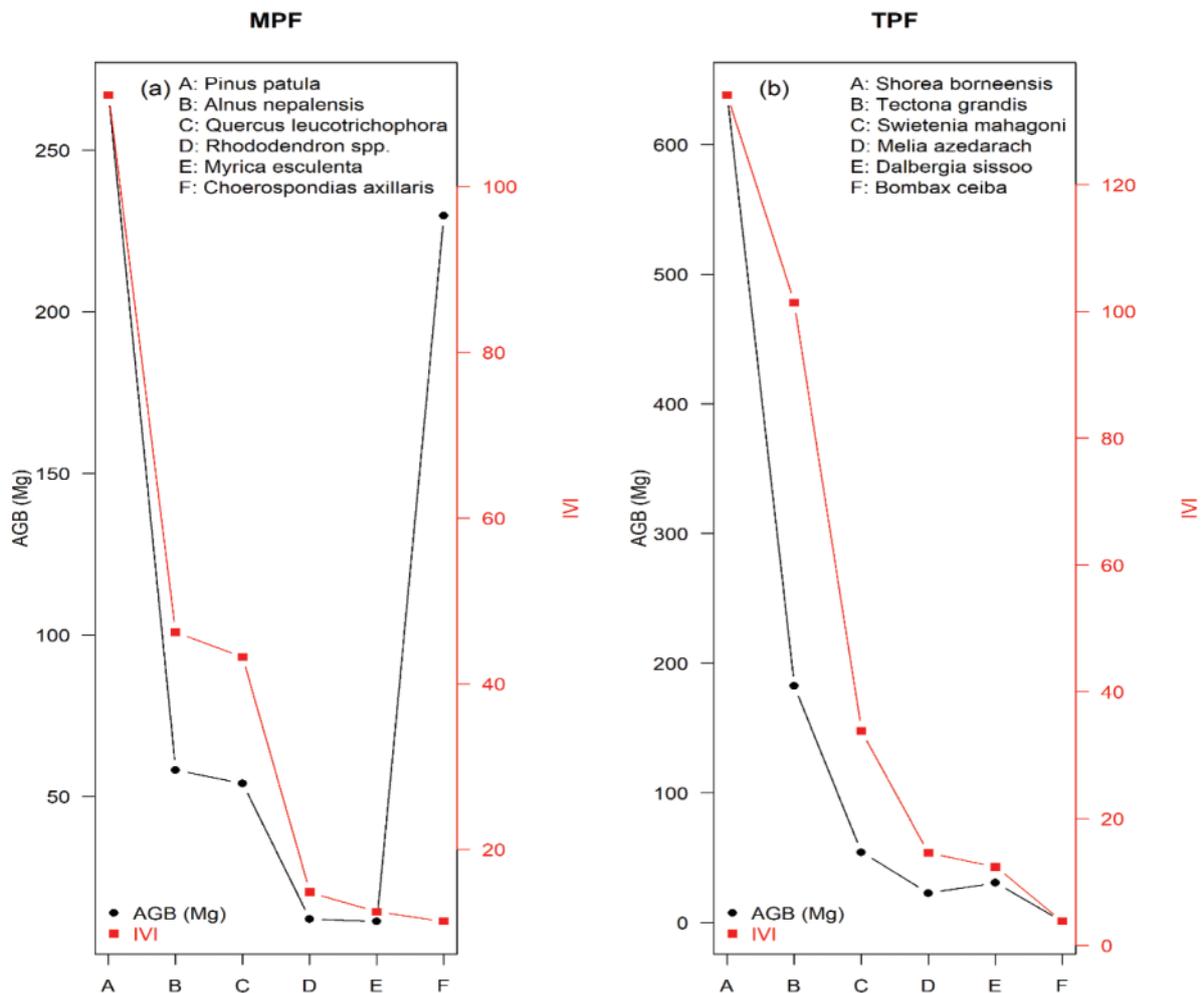
Rank	MPF			TPF		
	Species	AGC±SE (tonnes)	C (%)	Species	AGC±SE (tonnes)	C (%)
1	<i>Pinus patula</i>	130.01	37.73	<i>Shorea borneensis</i>	313.09	68.79
2	<i>Choerospondias axillaris</i>	128.66	37.34	<i>Tectona grandis</i>	89.49	19.66
3	<i>Alnus nepalensis</i>	27.90	8.10	<i>Swietenia mahagoni</i>	26.51	5.82
4	<i>Quercus leucotrichophora</i>	26.27	7.63	<i>Dalbergia sissoo</i>	14.43	3.17
5	<i>Pinus wallichiana</i>	7.36	2.14	<i>Melia azedarach</i>	11.17	2.45
6	<i>Rhododendron spp.</i>	5.93	1.72	<i>Bombax ceiba</i>	0.43	0.09
7	<i>Myrica esculenta</i>	5.54	1.61	-	-	-
8	<i>Castanopsis indica</i>	3.83	1.11	-	-	-
9	<i>Schima wallichii</i>	3.13	0.91	-	-	-
10	<i>Prunus cerasoides</i>	3.05	0.88	-	-	-
11	<i>Quercus semicarpifolia</i>	0.86	0.25	-	-	-
12	<i>Albizia lebbek</i>	0.69	0.20	-	-	-
13	<i>Betula alnoides</i>	0.60	0.17	-	-	-
14	<i>Taxus wallichiana</i>	0.12	0.03	-	-	-
15	<i>Sauraria nepalensis</i>	0.32	0.09	-	-	-
15	<i>Azadirachta indica</i>	0.17	0.05	-	-	-
17	<i>Brassaiopsis hainla</i>	0.05	0.02	-	-	-
18	<i>Cinnamomum tamala</i>	0.06	0.02	-	-	-
19	<i>Abies pindrow</i>	0.01	0.00	-	-	-
	<b>Total AGC (tonnes)</b>	<b>344.55±9.18</b>	<b>100</b>	<b>Total AGC (tonnes)</b>	<b>455.12±49.18</b>	<b>100</b>
	<b>Total AGC (tonnes/ha)</b>	<b>20.01 ± 0.53</b>	<b>-</b>	<b>Total AGC (tonnes/ha)</b>	<b>74.23 ± 8.02</b>	<b>-</b>

the forest's total biomass, highlighting its role as the main biomass contributor. *Alnus nepalensis* and *Quercus leucotrichophora*, with AGB values exceeding 50 Mg, also played notable roles in the ecosystem, though their biomass decreases sharply relative to their IVI. Despite a decline in AGB, these species maintain ecological importance, suggesting they play crucial roles beyond biomass contribution. Other species, such as *Rhododendron* spp., *Myrica esculenta*, and *Schima wallichii*, contributed minimally to both biomass and ecological significance, with much lower AGB compared to the dominant species. These species showed a declining trend in both IVI and AGB, reinforcing their secondary ecological roles in MPF. The total IVI for MPF was 300, indicating a relatively balanced distribution among species. The total AGB was 733.09 Mg, supporting the idea of biomass being more evenly distributed, with *P. patula* remaining dominant in both biomass and ecological importance (Figure 6). In TPF, *S. borneensis* had the highest IVI (134.07) and biomass (666.15 Mg). *T. grandis*, with an IVI of 101.35 and AGB of 190.40 Mg, also holds a significant ecological role, despite a lower biomass contribution. This suggests that while *T. grandis*'s biomass is lower than *S. borneensis*'s, its ecological importance remains substantial. *S. mahagoni* and *Melia*

*azedarach* showed further declines in IVI and AGB, reflecting reduced ecological significance and biomass contribution. *Dalbergia sissoo* and *B. ceiba*, with very low IVI and AGB, are among the least ecologically significant species in TPF. Both forests had a total IVI of 300, but TPF's total AGB of 968.34 Mg is notably higher, indicating biomass concentration in a few dominant species (Figure 8). This pattern suggests TPF is characterized by fewer species with larger biomass per individual, unlike MPF, where more species contribute more evenly to biomass. The correlation between IVI and AGB was strongly positive in MPF ( $\rho = 0.78, p < 0.001$ ) but weaker in TPF ( $\rho = 0.42, p = 0.08$ ), implying that in the Mid-Hills, ecologically dominant species (high IVI) disproportionately contribute to biomass. Conversely, Terai forests showed a decoupling of ecological importance and biomass accumulation, likely due to the dominance of a few high-AGB species, such as *S. borneensis*.

The Shapiro-Wilk test for normality revealed that the IVI values for MPF significantly deviated from normal distribution ( $W = 0.570, p < 0.001$ ), while IVI values for TPF were approximately normally distributed ( $W = 0.826, p = 0.099$ ). Despite the non-normality detected in MPF, a Welch two-sample t-test was conducted to compare IVI values between

FIGURE 8 Importance Value Index (IVI) and Forest aboveground biomass (AGB) differentiation in both PFs



MPF and TPF. The results indicated no statistically significant difference in IVI between the two forest types ( $t = -1.486$ ,  $df = 5.786$ ,  $p = 0.1896$ ). The mean IVI was lower in MPF (mean = 15.79) compared to TPF (mean = 50.00), but the 95% confidence interval (-91.06 to 22.63) crossed zero, suggesting the observed difference was not statistically meaningful (Figure 9a).

Similarly, the Shapiro-Wilk test revealed that AGB values for both MPF ( $W = 0.493$ ,  $p < 0.001$ ) and TPF ( $W = 0.692$ ,  $p = 0.005$ ) significantly deviated from a normal distribution. Despite violating normality assumptions, a Welch two-sample t-test was conducted to compare AGB between MPF and TPF. The results indicated no statistically significant difference in AGB between the two forest types ( $t = -1.154$ ,  $df = 5.353$ ,  $p = 0.2975$ ). The mean AGB was lower in MPF (mean = 38.58 tonnes) compared to TPF (mean = 161.39 tonnes), but the 95% confidence interval (-391.07 to 145.46) included zero, showing that the difference was not statistically significant (Figure 9b).

### Floristic diversity

Table 2 presents the Shannon Diversity Index (H) statistics for two forest types, MPF and TPF. The Shannon Diversity Index, a measure of species diversity, shows higher average diversity in MPF (Mean H = 0.7) compared to TPF (Mean H = 0.35). MPF also exhibits greater variability (SD. H = 0.59) and a higher maximum value (Max. H = 2.04) than TPF (Max. H = 1.02). The median diversity in MPF (Median. H = 0.54) is nearly double that of TPF (Median. H = 0.29), suggesting consistently higher species diversity in MPF. Despite differences in mean and median values, the interquartile range (IQR. H) is similar for both forest types, indicating comparable variability within the central 50% of the data. The comparison of Shannon diversity indices between MPF and TPF using a Welch two-sample t-test showed no statistically significant difference between the two forest types ( $t = 1.89$ ,  $df = 21.41$ ,  $p = 0.072$ ). Although the mean Shannon Index

was higher in MPF (mean = 0.698) compared to TPF (mean = 0.348), the difference was not statistically significant at the 5% level. The 95% confidence interval for the mean difference ranged from -0.035 to 0.735, indicating substantial overlap between the groups (Figure 10a). Although MPF exhibited a higher average Shannon diversity than TPF, the difference was marginal and did not reach statistical significance. This suggests that while MPF may tend to have greater species diversity, the variability within and between forests types likely contributed to the observed non-significant result.

The dataset provides statistics on the Simpson Diversity Index (D) for MPF and TPF. The mean Simpson index for MPF (0.35) is higher than that for TPF (0.21), indicating that MPF has greater species evenness and less dominance by any single species. Additionally, the median Simpson index for MPF (0.23) is higher than TPF's (0.15), further supporting the idea that MPF has a more balanced distribution of species. While MPF has a slightly higher standard deviation (0.28) and maximum value (0.84) compared to TPF (0.22 and 0.61, respectively), this suggests greater variability in species evenness across MPF areas. Both forest types have similar interquartile ranges (IQR), with MPF at 0.38 and TPF at 0.41, indicating that the central 50% of diversity values are distributed similarly in both forests. The minimum Simpson index value of 0 for both forest types suggests that some areas have complete species dominance (Table 2). The Simpson diversity indices of MPF and TPF were compared using a Welch two-sample t-test. The analysis showed no statistically significant difference in Simpson diversity between the two forest types ( $t = 1.3901$ ,  $df = 24.806$ ,  $p = 0.1769$ ). The mean Simpson Index was higher in MPF (mean = 0.347) compared to TPF (mean = 0.213), but the difference was not significant at the 5% level. The 95% confidence interval for the mean difference ranged from -0.064 to 0.332, suggesting considerable overlap in Simpson diversity between the two groups (Figure 10b). Although MPF had a higher mean Simpson diversity than TPF, the difference was not statistically significant, implying that both forest types maintained relatively comparable levels of species evenness and dominance.

FIGURE 9 Comparison of Importance Value Index (IVI) and above-ground biomass (AGB) between MPF and TPF

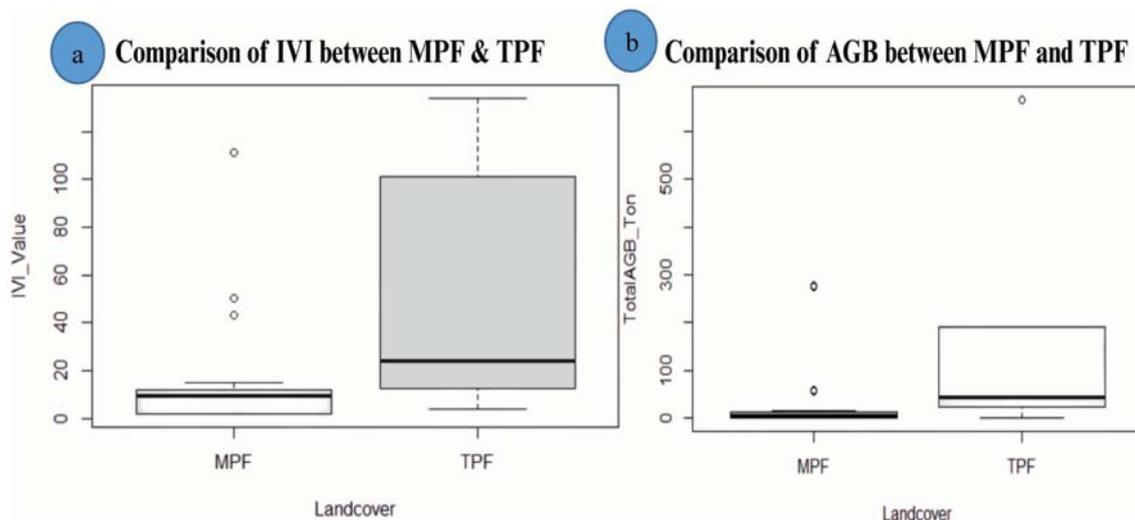
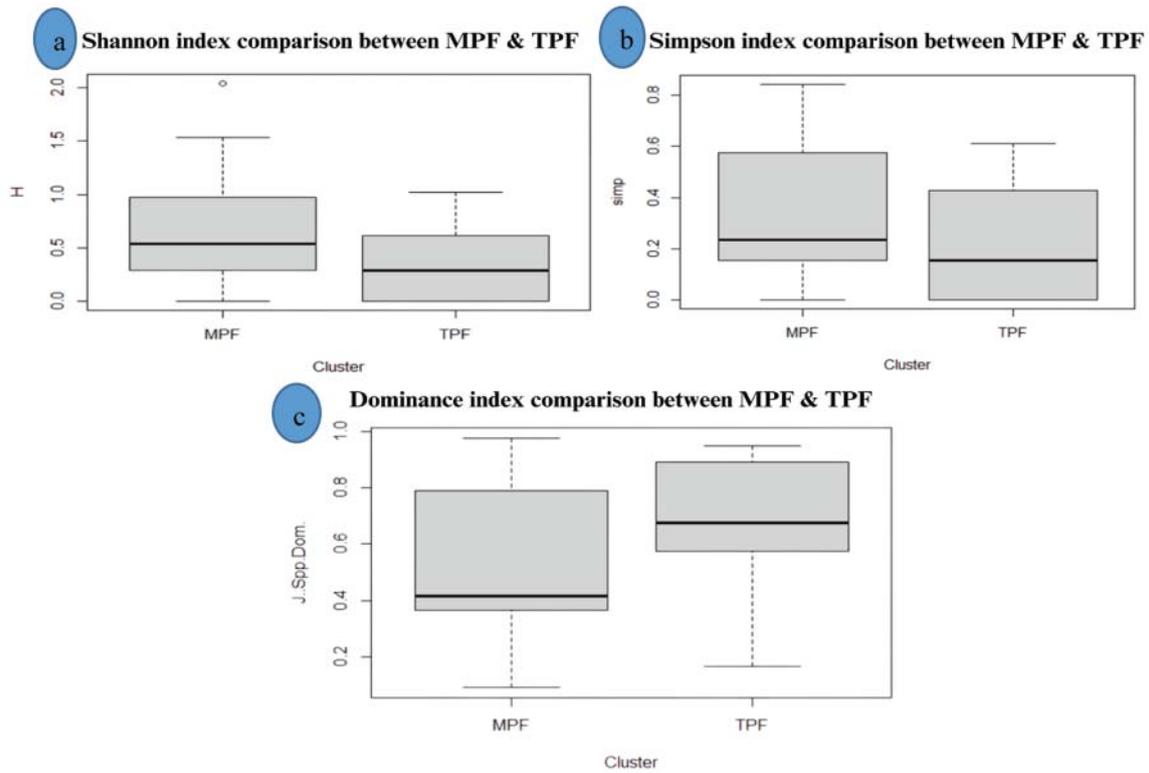


FIGURE 10 Comparison of Shannon, Simpson, and dominance diversity indices between MPF and TPF

TABLE 2 Descriptive statistics of Shannon ( $H'$ ) and Simpson ( $D$ ) diversity indices in MPF and TPF

PF	Shannon Diversity Index ( $H'$ )						Simpson Diversity Index ( $D$ )					
	Mean $H'$	Min. $H'$	Max. $H'$	SD. $H'$	IQR. $H'$	Median $H'$	Mean $D$	Min. $D$	Max. $D$	SD. $D$	IQR. $D$	Median $D$
MPF	0.7	0	2.04	0.59	0.61	0.54	0.35	0	0.84	0.28	0.38	0.23
TPF	0.35	0	1.02	0.36	0.6	0.29	0.21	0	0.61	0.22	0.41	0.15

The dominance indices between MPF and TPF were compared using a Welch two-sample t-test. The analysis showed no statistically significant difference in dominance between the two groups ( $t = -0.8737$ ,  $df = 17.079$ ,  $p = 0.3944$ ). The mean dominance index was slightly lower in MPF (mean = 0.524) than in TPF (mean = 0.634), but the 95% confidence interval ( $-0.375$  to  $0.155$ ) included zero, indicating no meaningful difference in species dominance patterns between the two forest types (Figure 10c). This findings suggested that species dominance, reflecting how much a few species numerically dominate the forest community, did not differ substantially between the types.

The Shapiro-Wilk test results revealed that the Shannon Index for MPF was normally distributed ( $W = 0.90804$ ,  $p = 0.1476$ ), whereas it was not normally distributed for TPF ( $W = 0.86901$ ,  $p = 0.04064$ ). Similarly, the Simpson Index showed normal distribution for MPF ( $W = 0.90887$ ,  $p = 0.1517$ ) but not for TPF ( $W = 0.85106$ ,  $p = 0.02296$ ). In contrast, the Dominance Index was found to be normally distributed for both MPF ( $W = 0.9303$ ,  $p = 0.3439$ ) and TPF ( $W = 0.88219$ ,  $p = 0.1655$ ).

### Farmer preference for species diversity

Interviews with farmers confirmed that species selection was a deliberate process driven by a combination of economic and subsistence needs. In the Mid-Hills, *P. patula* was consistently ranked as the most preferred and valuable species by a majority of landowners (12 out of 14). When explaining their preference, farmers primarily cited its fast growth for timber and its usefulness as firewood (mentioned by respondents). This stated preference is directly reflected in its ecological dominance, as it also had the highest IVI (111.01) in MPF. Similarly, *A. nepalensis* was highly valued for its soil improving properties and fodder, explaining its significant presence and IVI.

In the Terai, the ecological dominance of *S. borneensis* (IVI 134.07) was a direct result of farmer strategy. All TPF owners (14/14) identified it as their most preferred species, unequivocally due to its high market value as timber. *T. grandis* was the second most preferred species for the same reason. The strong correlation between farmer preference ranks and species' IVI in both regions (Spearman's  $\rho = -0.71$  to  $-0.91$ ,

TABLE 3 Spearman's rank correlation between farmer preference ranks (1 = most preferred) and species ecological metrics in MPF and TPF

Rank	Species	Region	IVI ( $\rho$ )	$p$ -value	Shannon ( $\rho$ )	$p$ -value
1.	<i>Pinus patula</i>	MPF	-0.82	0.003	-0.75	0.012
1.	<i>Shorea borneensis</i>	TPF	-0.91	<0.001	-0.68	0.021
2.	<i>Tectona grandis</i>	TPF	-0.76	0.008	-0.62	0.042
2.	<i>Alnus nepalensis</i>	MPF	-0.71	0.015	-0.59	0.053

$p < 0.05$ ; Table 3) statistically validates that the ecologically dominant species were indeed those most deliberately selected and valued by the farmers.

## DISCUSSION

### Forest structure and composition

Both MPF and TPF showed a reverse-J diameter distribution, indicating active regeneration. Similar structural patterns have been observed in community-managed forests of Nepal's Terai region (Gautam *et al.* 2004, Joshi *et al.* 2019), suggesting some silvicultural commonalities despite different ownership models. However, TPF forests had a higher proportion of medium to large-diameter trees compared to MPF, suggesting different forest development stages and management approaches. The prevalence of small-diameter trees in MPF may indicate younger forests, higher human disturbance, or differences in silvicultural practices compared to TPF (Silwal *et al.* 2017).

The observed reverse-J distribution indicates active natural regeneration and a sustainable population structure in both MPF and TPF forests (Figure 3). Such patterns are characteristic of forests undergoing continuous recruitment of younger trees (Acharya 2004, Gautam *et al.* 2004). However, the comparatively steeper decline in stem density in MPF suggests either younger forest stands, more frequent disturbances, or differential forest management practices compared to TPF. The greater retention of larger-diameter trees in TPF could reflect relatively mature forest conditions or more effective conservation practices.

### Carbon stock and biomass distribution

The comparison between these two forest types reveals distinct ecological patterns. MPF is characterized by higher species richness and a broader distribution of IVI and AGB among many species. This results in a more balanced contribution to biomass across the species present. In contrast, TPF shows a greater concentration of biomass in a few species, such as *S. borneensis* and *T. grandis*, leading to a higher overall AGB despite having fewer species. The dominance of a small number of species in TPF highlights the forest's structural differences, with fewer but larger contributors to the ecosystem's biomass. This structural dominance also resulted in significantly higher carbon density in TPF, with an average

aboveground carbon stock of  $74.23 \pm 8.02$  t/ha, compared to just  $20.01 \pm 0.53$  t/ha in MPF. Despite similar total carbon values, the per-hectare data show that TPF forests are much more carbon-dense, reflecting their mature structure and the biomass concentration in fewer large individuals. Both forests, however, are ecologically important and offer valuable insights into the role of private forests in Nepal, especially regarding farmers' preferences for species selection (Adhikari *et al.* 2004). The results emphasize the varied ecological roles of different species in these two forest types, with implications for forest management and conservation efforts. The clear differences between MPF and TPF highlight the diverse ecological contributions of species across Nepal's private forests, with MPF supporting greater species diversity and TPF exhibiting a higher concentration of biomass in a few dominant species. The strong IVI-AGB correlation in MPF suggests that ecologically dominant species (e.g., *P. patula*) are primary drivers of both ecosystem function and carbon storage, consistent with mixed-species forests where niche complementarity boosts biomass (Liang *et al.* 2016). In TPF, the weaker correlation indicates anthropogenic selection for high-value timber species (e.g., *S. borneensis*), where biomass is concentrated in a few species regardless of their broader ecological role (Bowman and Zilberman 2013). This pattern directly aligns with the farmer preference data (Section 3.6), where Terai landowners prioritized high-value timber species with concentrated biomass over ecologically diverse assemblages.

The lack of significant differences in carbon stock between the regions, despite different forest structures, matches findings from studies in Nepal's lowland and hill forests (Sharma *et al.* 2017, Subedi *et al.* 2010). However, the higher concentration of biomass among a few species in TPF (especially *S. borneensis*) indicates a vulnerability to selective logging and biodiversity loss, similar to patterns seen in tropical forests elsewhere (Chave *et al.* 2003). In contrast, the more evenly spread biomass in MPF, despite lower biomass per species, improves ecological resilience and supports multiple ecosystem services (Clark and Clark 2000).

### Floristic diversity

Although MPF showed higher species richness and diversity indices than TPF, the differences were not statistically significant. The diversity indices observed in MPF are comparable to those reported for community-managed forests in the Mid-Hills region (Joshi *et al.* 2023b), indicating that private

forests in this region can maintain similar levels of biodiversity as their community-managed counterparts. This finding aligns with studies indicating that hill forests often maintain higher species heterogeneity compared to lowland plantations dominated by commercially valuable species (Acharya *et al.* 2011, Bhattarai *et al.* 2020). Higher diversity and evenness in MPF may promote forest stability and resistance to environmental stress (Magurran 2004). The partial violation of normality assumptions, especially for the Shannon and Simpson diversity indices in TPF, indicates more variability and ecological diversity within TPF compared to MPF. Such deviations from normality are common in forests with uneven species distribution or dominance by a few species (Magurran 2004). The observed variability highlights the importance of using non-parametric statistical methods when analyzing ecological metrics in structurally diverse or fragmented landscapes, as recommended in studies of tropical forest diversity (Chave *et al.* 2003). Using appropriate statistical techniques ensures the robustness of diversity comparisons and improves the reliability of ecological interpretations across different forest management systems (Lindenmayer *et al.* 2000).

### Farmer preferences and forest management

Farmers' preferences for species also differ across various parts of the country based on geographic regions (Asrat *et al.* 2010). Our survey data directly confirms that farmers' preferences for species are shaped by geographic and economic context. This aligns with studies on agroforestry systems in Nepal, where species selection is a deliberate strategy for risk reduction, income diversification, and climate adaptation (Bhandari *et al.* 2021, Joshi *et al.* 2024a). The connection between the IVI and farmers' preference for species diversity involves balancing ecological benefits (such as long-term sustainability and ecosystem services) with economic incentives (like short-term profits and market demands). Farmers who recognize and value the ecological significance of species with a high IVI are more likely to incorporate them into their farming systems, especially if they practice sustainable or biodiverse farming methods (Melvani *et al.* 2022). On the other hand, market pressures can sometimes cause farmers to favor species with lower IVI but higher immediate returns (Lemma *et al.* 2025). Geographic and economic factors clearly influence farmers' species preferences (Bowman and Zilberman 2013). In the Mid-Hills, *P. patula* emerged as the most preferred species, with an IVI greater than 100, likely reflecting farmers' selection for its multiple benefits including timber production and adaptability to local conditions (Evans 1992). Following *P. patula*, *Alnus nepalensis*, and *Q. leucotrichophora* have IVIs above 40, indicating moderate farmer preference. The choice of *P. patula* and *A. nepalensis* in the Mid-Hills region reflects the need for fast-growing species that provide timber, fodder, fuelwood, and soil stabilization services (Pandey *et al.* 2024). Farmers in the Mid-Hills likely choose these species because of their ability to offer multiple benefits (Baul *et al.* 2013).

In contrast, the preference for *S. borneensis* and *T. grandis* in the Terai reflects market-driven timber economies. Such

patterns reinforce the need for region-specific forest management strategies that balance ecological sustainability with farmers' livelihoods (Dhakal *et al.* 2015, Maraseni *et al.* 2020). None of the preferred species overlap between the Terai and the Mid-hills, demonstrating the role of environmental conditions in shaping farmer preferences (Thorn 2019). Farmers in the Terai, with its warmer climate and more fertile soils, are inclined toward species like *Shorea robusta*, *T. grandis*, and *Swietenia mahagoni*, which thrive in these conditions and offer high economic returns (Dhakal 2008). In contrast, Mid-hills farmers favor species such as *P. patula* and *Alnus nepalensis*, which are better adapted to the colder, more rugged terrain and provide practical benefits like soil enhancement and fodder (Gauli *et al.* 2022). Other species in the Terai, such as *Rhododendron* spp., *M. esculenta*, and *Choerospondias axillaris*, exhibited lower IVI scores (<20), suggesting that while they are less prioritized for timber, they still hold significant value for farmers through their fruits, medicinal properties, and ecological services, a trend similarly observed in multipurpose species within tropical agroforestry systems (Nair 1993).

### Policy implications, limitations, and future research directions

Private forests in Nepal are vital for carbon sequestration, biodiversity conservation, and supporting livelihoods. Our findings, consistent with the significant carbon sequestration potential identified in community forests (Joshi *et al.* 2020) and agroforestry systems (Joshi *et al.* 2024b), underscore that beyond state-managed protected areas (Joshi and Bhatta 2023), privately held landscapes are indispensable for Nepal's climate goals. To realize the potential of private forests, our findings suggest that Nepal's national carbon register should create simplified procedures for smallholder carbon accounting so that private forest owners can take part in REDD+ benefit-sharing programs in order to fully utilize the potential of private forests. Future programs like REDD+ must therefore incorporate participatory frameworks and local ecological knowledge to ensure legitimacy and effectiveness (Joshi *et al.* 2026). In particular, incentives should be created to support multi-species plantations that lower the risk of species homogeneity and improve long-term resilience, even though Terai's high-carbon monocultures may produce early mitigation gains. Premium payments for mixed-species stands, technical assistance for diversifying dominant plots, and streamlined verification procedures in line with Nepal's forest sector strategy are examples of potential policy tools. MPF enhances ecological resilience through greater species diversity and evenly spread biomass, while TPF offers high carbon density with a few dominant species but is susceptible to selective logging. Policies should encourage region-specific management, promote biodiversity-friendly species, integrate private forests into REDD+ programs, and improve market access for non-timber products to align ecological and economic goals.

This study is limited to two physiographic regions and may not capture variability across Nepal's full landscape.

Furthermore, by design, we focused on private forests within a specific size range (0.1–0.5 ha). While this was necessary to control for area effects and target the most common form of private woodlots, it means our findings may not be directly transferable to very small homestead plantations or larger private forest estates. Future research should investigate how carbon sequestration dynamics scale with private forest area. Additionally, our carbon assessment is limited to aboveground carbon and does not include other ecosystem pools such as belowground biomass, deadwood, litter, or soil carbon. While this provides a consistent measure for comparison, future studies should incorporate these pools for a complete carbon budget. Furthermore, whereas farmer preference data provide insightful information about management drivers, these self-reported replies should be regarded as indicative rather than definitive due to the possibility of recall bias or subjective interpretation. Additionally, the study did not gather supplementary quantitative socio-economic data (e.g., household income, comprehensive market access), even though interviews revealed important species preferences and management justifications. Such measurements should be incorporated into future studies to further analyze livelihood factors and consequences. Field-based metrics and farmer surveys offer a snapshot of forest structure, carbon stock, and preferences but cannot fully capture long-term dynamics, market fluctuations, or disturbance regimes such as forest fires, which are known to significantly impact biodiversity and carbon stocks in Nepalese landscapes (Bhatta *et al.* 2022). Expanding coverage to more regions and forest types, along with long-term monitoring of forest changes under climate and socio-economic shifts, will enhance understanding of sustainability and resilience. Future work should also investigate socio-ecological factors influencing species selection and incorporate remote sensing with participatory methods to develop evidence-based, region-specific forest management policies.

## CONCLUSION

This study demonstrates that private forests in Nepal's Mid-Hills (MPF) and Terai (TPF) represent two distinct ecological models with contrasting contributions to climate mitigation and biodiversity. MPF, characterized by higher species richness and an even distribution of biomass among multipurpose species, offers greater ecological resilience. In contrast, TPF, dominated by a few high-value timber species, functions as a high-density carbon storage system, sequestering over three times more carbon per hectare ( $74.23 \pm 8.02$  t/ha) than MPF ( $20.01 \pm 0.53$  t/ha). Critically, these ecological patterns are directly shaped by farmer management strategies, which are themselves adaptations to regional socio-economic and environmental contexts. The strong correlation between ecological dominance (IVI) and biomass in MPF, and its decoupling in TPF, underscores that carbon storage mechanisms differ fundamentally between these systems. These findings highlight the significant, yet underutilized, role of private forests

in Nepal's national climate and development strategies. To unlock this potential, policy interventions must be region-specific. Incentivizing biodiversity-friendly species and mixed plantations in the Mid-Hills will sustain multiple ecosystem services, while integrating Terai forests into REDD+ frameworks could leverage their high carbon yield, provided safeguards for diversification are included. Future research should expand this framework to other physiographic regions and employ long-term monitoring to further solidify the evidence base for empowering private forest owners as key actors in sustainable development.

## DECLARATIONS

### Ethics Approval

Not applicable. This study did not involve human participants in a capacity that requires ethical approval from an institutional review board. The interactions with farmers were based on informal discussions and surveys regarding forest management practices, which did not collect sensitive personal data.

### Consent for Participation and Publication

Verbal informed consent was obtained from all private forest owners and farmers prior to their participation in the surveys and informal discussions. They were informed about the nature and purpose of the study, and that anonymized data would be used for publication. All authors have read and agreed to publish the manuscript.

### Availability of Data and Materials

The datasets generated and analyzed during the current study are not publicly available due to ongoing research but the data underlying this article will be shared on reasonable request to the corresponding author.

### Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Funding

This work was financially supported by the Major Project of the National Social Science Foundation of China (Grant No. 24&ZD108) and by the Directorate of Research and Extension, Agriculture and Forestry University, under the Sixth (Special) Faculty Call Research Project.

### Authors' Contributions

Conceptualization, R.J., H.Z. and T.M.; methodology, R.J., H.Z. and T.M.; software, R.J., J.G. and H.A.; validation, R.J., N.D. and H.A.; formal analysis, R.J. and H.A.; investigation,

R.J. and H.Z. and T.M.; resources, R.J.; data curation, R.J., N.D., J.G. and H.A.; writing – original draft preparation, R.J. and N.D.; writing – review and editing, R.J., H.Z., T.M. and H.S.; supervision, H.Z. and T.M.

### Acknowledgements

We are deeply grateful to all the private forest owners and farmers for their valuable support and cooperation during the data collection process. We would also like to thank the Forest Nepal software team for processing data and providing a free license. We sincerely thank the Editor and the anonymous reviewers for their insightful comments and constructive suggestions, which significantly improved the quality and clarity of this manuscript.

### Clinical Trial Registration

Not applicable.

### Generative AI Statement

During the preparation of this manuscript, the authors utilized ChatGPT (OpenAI) solely to assist with language editing and improving readability. Following its use, the authors thoroughly reviewed and revised the content as necessary and assumed full responsibility for the final published article.

### REFERENCES

- ACHARYA, B.K., SANDERS, N.J., VIJAYAN, L., and CHETTRI, B. 2011. Elevational gradients in bird diversity in the Eastern Himalaya: An evaluation of distribution patterns and their underlying mechanisms. *PLoS ONE* **6**(12): e29097. <https://doi.org/10.1371/journal.pone.0029097>
- ACHARYA, K.P. 2004. Does community forest management support biodiversity conservation? Evidence from two community forests from the mid-hills of Nepal. *Journal of Forest and Livelihood* **4**(1): 44–54.
- ADHIKARI, B., DI FALCO, S., and LOVETT, J.C. 2004. Household characteristics and forest dependency: Evidence from common property forest management in Nepal. *Ecological Economics* **48**(2): 245–257. <https://doi.org/10.1016/j.ecolecon.2003.08.008>
- ARYAL, K., MARASENI, T., and APAN, A. 2023. Transforming agroforestry in contested landscapes: A win-win solution to trade-offs in ecosystem services in Nepal. *Science of the Total Environment* **857**: 159301.
- ARYAL, U., NEUPANE, P.R., RIJAL, B., LAMICHANNE, P., PARAJULI, A., and MARASENI, T.N. 2025. Assessing the Impact of Leasehold Forestry in Nepal: Enhancing Livelihoods and Preventing Degradation. *Forests* **16**(3): 531.
- ASRAT, S., YESUF, M., CARLSSON, F., and WALE, E. 2010. Farmers' preferences for crop variety traits: Lessons for on-farm conservation and technology adoption. *Ecological Economics* **69**(12): 2394–2401. <https://doi.org/10.1016/j.ecolecon.2010.07.006>
- BAUL, T.K., TIWARI, K.R., ATIQUE ULLAH, K.M., and MCDONALD, M.A. 2013. Exploring agrobiodiversity on farm: A case from the Middle Hills of Nepal. *Small-scale Forestry* **12**: 611–629. <https://doi.org/10.1007/s11842-012-9234-y>
- BHANDARI, R.P., JOSHI, R., and PAUDEL, D. 2021. Agroforestry Practices for Climate Change Adaptation and its Contribution in Farmer's Income. *Grassroots Journal of Natural Resources* **4**(3): 42–51. <https://doi.org/10.33002/nr2581.6853.040305>
- BHATTA, M., JOSHI, R., and SAPKOTA, R.P. 2022. Assessment of Forest Fire and Its Impact on Plant Biodiversity of Buffer Zone, Langtang National Park, Nepal. *Indonesian Journal of Social and Environmental Issues* **3**(3): 241–251. <https://doi.org/10.47540/ijsei.v3i3.679>
- BHATTARAI, N., KARKY, B.S., AVTAR, R., THAPA, R.B., and WATANABE, T. 2023. Are countries ready for REDD+ payments? REDD+ readiness in Bhutan, India, Myanmar, and Nepal. *Sustainability* **15**(7): 6078. <https://doi.org/10.3390/su15076078>
- BHATTARAI, N., VETAAS, O.R., and GRYTNES, J.A. 2020. Species composition, diversity, and carbon stock in trees outside forests in Nepal. *Forest Ecology and Management* **458**: 117771. <https://doi.org/10.1016/j.foreco.2019.117771>
- BOWMAN, M.S., and ZILBERMAN, D. 2013. Economic factors affecting diversified farming systems. *Ecology and Society* **18**(1).
- BROWN, S. 1997. *Estimating biomass and biomass change of tropical forests: a primer* (Vol. 134). Food & Agriculture Org.
- BROWN, S. 2002. Measuring, monitoring, and verification of carbon benefits for forest-based projects. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* **360**(1797): 1669–1683. <https://doi.org/10.1098/rsta.2002.1026>
- BROWN, S., and LUGO, A.E. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia. Caracas* **17**(1): 8–18.
- BROWN, S.L., SCHROEDER, P., and KERN, J.S. 1999. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management* **123**(1): 81–90. [https://doi.org/10.1016/S0378-1127\(99\)00017-1](https://doi.org/10.1016/S0378-1127(99)00017-1)
- CADMAN, T., and MARASENI, T. 2012. The governance of REDD+: An institutional analysis in the Asia Pacific region and beyond. *Journal of Environmental Planning and Management* **55**(5): 617–635.
- CFD. 2017. *Private Forests Status Report*. Community Forestry Division (CFD), Department of Forests, Government of Nepal.
- CHAVE, J., ANDALO, C., BROWN, S., CAIRNS, M.A., CHAMBERS, J.Q., EAMUS, D., and YAMAKURA, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**(1): 87–99. <https://doi.org/10.1007/s00442-005-0100-x>

- CHAVE, J., CONDIT, R., LAO, S., CASPERSEN, J.P., FOSTER, R.B., and HUBBELL, S.P. 2003. Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama. *Journal of Ecology* **91**(2): 240–252. <https://doi.org/10.1046/j.1365-2745.2003.00757.x>
- CHAVE, J., COOMES, D., JANSEN, S., LEWIS, S.L., SWENSON, N.G., and ZANNE, A.E. 2009. Towards a worldwide wood economics spectrum. *Ecology Letters* **12**(4): 351–366. <https://doi.org/10.1111/j.1461-0248.2009.01285.x>
- CHAVE, J., RIÉRA, B., and DUBOIS, M.A. 2001. Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability. *Journal of Tropical Ecology* **17**(1): 79–96. <https://doi.org/10.1017/S0266467401001055>
- CLARK, D.A., BROWN, S., KICKLIGHTER, D.W., CHAMBERS, J.Q., THOMLINSON, J.R., and NI, J. 2001. Measuring net primary production in forests: concepts and field methods. *Ecological Applications* **11**(2): 356–370. [https://doi.org/10.1890/1051-0761\(2001\)011\[0356:MNPPIF\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2001)011[0356:MNPPIF]2.0.CO;2)
- CLARK, D.B., and CLARK, D.A. 2000. Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecology and Management* **137**(1–3): 185–198. [https://doi.org/10.1016/S0378-1127\(99\)00327-8](https://doi.org/10.1016/S0378-1127(99)00327-8)
- DeWALT, S.J., and CHAVE, J. 2004. Structure and biomass of four lowland Neotropical forests. *Biotropica* **36**(1): 7–19. <https://doi.org/10.1111/j.1744-7429.2004.tb00291.x>
- DFRS. 2015. State of Nepal's Forests. Forest Resource Assessment Nepal Project, Department of Forest Research and Survey (DFRS), Kathmandu, Nepal.
- DHAKAL, A. 2008. Silviculture and productivity of five economically important timber species of central terai of Nepal.
- DHAKAL, B., CHAND, N., SHRESTHA, H.L., SHRESTHA, A., DHAKAL, N., ADHIKARI, B., ...and BHANDARI, P. 2022. Paradoxes of aggravated vulnerability, marginalization, and peril of forest-based communities after increasing conservative forest and protected areas in Nepal: A policy lesson on land-based climate change mitigation. *World* **3**(3): 544–574.
- DHAKAL, M., KANDEL, B.R., and THAPA, B. 2015. Enhancing livelihoods from private and leasehold forestry in Nepal: Current status, challenges, and way forward. *Banko Janakari* **25**(1): 3–12. <https://doi.org/10.3126/banko.v25i1.13425>
- EVANS, J. 1992. *Plantation Forestry in the Tropics: Tree Planting for Industrial, Social, Environmental, and Agroforestry Purposes* (2nd ed.). Oxford University Press.
- FAO. 2020. Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/ca9825en>
- FAO. 2022. State of the World's Forests 2022: Forest pathways for green recovery and building inclusive, resilient and sustainable economies. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cb9360en>
- GAULI, P., BHATTA, S., SINGH, S.K., SHRESTHA, K., NIDAL, B., and ATREYA, K. 2022. Farming in the mountains of Nepal: crops, soil fertility, livelihoods and farm-forest linkages. *Archives of Agriculture and Environmental Science* **7**(3): 463–472. <https://dx.doi.org/10.26832/24566632.2022.0703021>
- GAUTAM, K.H., WEBB, E.L., and SHIVAKOTI, G.P. 2004. Forest cover change, physiography, local economy, and institutions in a mountain watershed in Nepal. *Environmental Management* **33**(1): 48–61. <https://doi.org/10.1007/s00267-003-3031-5>
- GoN. 2015. Working Procedures for Management of Private Forests, 2015. Ministry of Forests and Soil Conservation, Government of Nepal (GoN), Kathmandu, Nepal.
- HENRY, M., TITTONELL, P., MANLAY, R. J., BERNOUX, M., ALBRECHT, A., and VANLAUWE, B. 2009. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. *Agriculture, Ecosystems & Environment* **129**(1–3): 238–252. <https://doi.org/10.1016/j.agee.2008.09.006>
- HIRSCH, F., and SCHMITHÜSEN, F.J. 2010. *Private forest ownership in Europe* (Vol. 26). ETH Zurich.
- IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 4 – Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Retrieved from <https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>
- JOSHI, P., JOSHI, R., MAHARJAN, A., PANTA, M., and CHAND, P. 2023b. Vegetation diversity, structure, composition and carbon stock of community managed forests of Mid-hills, Nepal. *Asian Journal of Forestry* **7**(1): 29–36. <https://doi.org/10.13057/asianjfor/r070104>
- JOSHI, R., and BHATTA, M. 2023. Examining the Fluctuation of Soil Organic Carbon Levels: An Analysis of the Shuklaphanta National Park in Nepal. *Applied and Environmental Soil Science*, vol. 2023, Article ID 1814253, 9 pages, 2023. <https://doi.org/10.1155/2023/1814253>
- JOSHI, R., and SINGH, H. 2020. Carbon Sequestration Potential of Disturbed and Non-disturbed Forest Ecosystem: A Tool for Mitigating Climate Change. *African Journal of Environmental Science and Technology* **14**(11): 385–393. <https://doi.org/10.5897/AJEST2020.2920>
- JOSHI, R., CHHETRI, R., and YADAV, K. 2019. Vegetation Analysis in Community Forests of Terai Region, Nepal. *International Journal of Environment* **8**(3): 68–82. <https://doi.org/10.3126/ije.v8i3.26667>
- JOSHI, R., DHAKAL, N., KHAMCHA, R., SHARMA, P., PRABHAKAR, A., MARASENI, T., and ZHANG, H. 2026. Community Engagement and Indigenous Knowledge in Forest Conservation: A Pathway for Achieving Carbon Neutrality in Nepal. In: Singh, H. (eds) *Forestry for a Carbon-Neutral and Sustainable Future*. Sustainability Solutions. Springer, Cham. [https://doi.org/10.1007/978-3-032-06427-1\\_10](https://doi.org/10.1007/978-3-032-06427-1_10)
- JOSHI, R., PANGENI, M., NEUPANE, S.S., and YADAV, N.P. 2021b. Regeneration Status and Carbon Accumulation Potential in Community Managed Sal (*Shorea*

- robusta*) Forests of Far-Western Terai Region, Nepal. *European Journal of Ecology* **7**(1): 26–39. <https://doi.org/10.17161/eurojecol.v7i1.15005>
- JOSHI, R., SHARMA, B., SINGH, H., DHAKAL, N., AYER, S., and MARASENI, T. 2024b. Poplar Plantation as an Agroforestry Approach: Economic Benefits and its Role in Carbon Sequestration in North India. *Journal of Resources and Ecology* **15**(4): 880–888. 10.5814/j.issn.1674-764x.2024.04.009
- JOSHI, R., SHRESTHA, T.K., MISHRA, B., GAUTAM, J., MAHARJAN, B., GOSAI, K.R., MARASENI, T., and NEUPANE, B. 2023a. Assessment of Carbon Sequestration in Private Forests Across Two Different Physiographic Regions of Nepal: Implications for Conservation and Climate Change Mitigation. *Scientifica*, vol. 2023, Article ID 6599067, 13 pages. <https://doi.org/10.1155/2023/6599067>
- JOSHI, R., SINGH, H., CHETTRI, R., POUDEL, S., and RIJAL, S. 2021a. Carbon Sequestration Potential of Community Forests: A Comparative Analysis of Soil Organic Carbon Stock in Community Managed Forests of Far-Western Nepal. *Eurasian Journal of Soil Science* **10**(2): 96–104. <https://doi.org/10.18393/ejss.825066>
- JOSHI, R., SINGH, H., CHHETRI, R., and YADAV, R. 2020. “Assessment of Carbon Sequestration Potential in Degraded and Non-Degraded Community Forests in Terai Region of Nepal”. *Journal of Forest and Environmental Science* **36**(2): 113–121. <https://doi.org/10.7747/JFES.2020.36.2.113>
- JOSHI, R., TAMANG, G.M., BHANDARI, P., SHARMA, B., JOSHI, D., and BHUSAL, S. 2024a. Assessing the Potential of Agroforestry for Climate Change Adaptation: A Case Study from Lamjung, Nepal. *Journal of Resources and Ecology* **15**(2): 280–292. <https://doi.org/10.5814/j.issn.1674-764x.2024.02.004>
- KETTERINGS, Q.M., COE, R., VAN NOORDWIJK, M., and PALM, C.A. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management* **146**(1–3): 199–209. [https://doi.org/10.1016/S0378-1127\(00\)00460-6](https://doi.org/10.1016/S0378-1127(00)00460-6)
- KHAN, M.L., TRIPATHI, R.S., and ARUNACHALAM, A. 2017. Plant community structure and dynamics: A review. *Journal of Ecology and Environment* **41**: 38. <https://doi.org/10.1186/s41610-017-0036-2>
- KHANAL, Y., SHARMA, R.P., and UPADHYAYA, C.P. 2010. Soil and vegetation carbon pools in two community forests of Palpa district, Nepal. *Banko Janakari* **20**(2): 34–40. <https://doi.org/10.3126/banko.v20i2.4945>
- KHARAKWAL, S. 2009. Phytosociological studies and economic importance of vegetation around Morna Lake, District Etah, Uttar Pradesh, India. *Ethnobotanical Leaflets* **2009**(7): 3.
- LEMMA, S., ASFAW, Z., TOLERA, M., and TESHOME, A. 2025. Effects of management practices and socio-physical factors on perennial plant diversity of agroforestry systems of Gedeo landscapes, Southern Ethiopia. *Agroforestry Systems* **99**(1): 10. <https://doi.org/10.1007/s10457-024-01104-5>
- LINDENMAYER, D.B., MARGULES, C.R., and BOTKIN, D.B. 2000. Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology* **14**(4): 941–950.
- MAGURRAN, A.E. 2004. Measuring Biological Diversity. Blackwell Publishing.
- MARASENI, T.N., POUDYAL, B.H., RANA, E., KHANAL, S.C., GHIMIRE, P.L., and SUBEDI, B.P. 2020. Mapping national REDD+ initiatives in the Asia-Pacific region. *Journal of Environmental Management* **269**: 110763. <https://doi.org/10.1016/j.jenvman.2020.110763>
- MELVANI, K., MYERS, B., STACEY, N., BRISTOW, M., CRASE, B., and MOLES, J. 2022. Farmers’ values for land, trees, and biodiversity underlie agricultural sustainability. *Land Use Policy* **117**: 105688. <https://doi.org/10.1016/j.landusepol.2021.105688>
- NAIDU, C.V., KUMAR, M.S., and JUNTUK, R.R. 2016. Forests and their role in biodiversity conservation. *International Journal of Current Research* **8**(11): 41856–41860.
- NAIR, P.K.R. 1993. *An Introduction to Agroforestry*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- PANDEY, H.P., ARYAL, K., ARYAL, S., and MARASENI, T.N. 2023. Understanding local ecosystem dynamics in three provinces of the lowlands of Nepal. *Science of the Total Environment* **867**: 161501.
- PANDEY, H.P., MARASENI, T.N., and POKHREL, S. 2024. Comparison of Planted Pine versus Natural Mix Forests in Nepal. *Forests* **15**(6): 1070. <https://doi.org/10.3390/f15061070>
- RAUNIYAR, S.K., JOSHI, R., GHARTI-CHHETRI, D.B., BHANDARI, J., and BHANDARI, D. 2023. Effects of Plant Diversity and Soil Properties on Aboveground Biomass along Altitudinal Gradient: A Case Study from Grassland of Mustang District, Nepal. *Journal of Rangeland Science* **13**(1): 1–13. <https://10.30495/rs.2023.687344>
- SHANNON, C.E. 1948. A mathematical theory of communication. *The Bell System Technical Journal* **27**(3): 379–423.
- SHARMA, E.R., and PUKKALA, T. 1990. Volume Equations and Biomass Prediction of Forest Trees in Nepal. Ministry of Forests and Soil Conservation, Forest Survey and Statistics Division, Kathmandu, Nepal.
- SHARMA, M., SHARMA, R.K., and SHARMA, S. 2017. Variation in carbon storage among tree species in the planted forest of Kathmandu, Central Nepal. *Journal of Forest and Livelihood* **15**(1): 1–10. Available at: <https://www.jstor.org/stable/26978192>
- SILWAL, R., BARAL, S.K., and CHHETRI, B.B.K. 2017. Modeling taper and volume of Sal trees growing in the Western Terai region of Nepal. In *Proceedings of the First National Silviculture Workshop*, Department of Forest Research and Survey (DFRS), Kathmandu, Nepal, pp. 231–239.
- SIMPSON, E.H. 1949. Measurement of Diversity. *Nature* **163**.
- SORECHA, E., and DERIBA, A. 2017. Floristic composition, plant community types, and vegetation structure of Goro Mountain Range Forest, Southeast Ethiopia.

- International Journal of Biodiversity and Conservation* **9**(11): 321–332. <https://doi.org/10.5897/IJBC2017.1126>
- SUBEDI, B.P., PANDEY, S.S., PANDEY, A., RANA, E.B., BHATTARAI, S., BANSKOTA, T.R., CHARMAKAR, S., and TAMRAKAR, R. 2010. Forest Carbon Stock Measurement: Guidelines for Measuring Carbon Stocks in Community-Managed Forests; ANSAB, FECOFUN, ICIMOD: Kathmandu, Nepal, 2010; ISBN 9789937226127.
- SUN, W., and LIU, X. 2020. Review on carbon storage estimation of forest ecosystem and applications in China. *Forest Ecosystems* **7**: 1–14. <https://doi.org/10.1186/s40663-019-0210-2>
- TARIN, M.I., AHMED, M., WAHAB, M., KHAN, N., and AHMED, A. 2017. Phytosociological attributes of trees and shrubs in relation to topographic and soil variables at Changa Manga Forest Plantation, Punjab, Pakistan. *Journal of Biodiversity and Environmental Sciences* **10**(4): 85–98.
- TEAM, R.C. 2024. R language and environment for statistical computing, R Foundation for Statistical. *Computing*.
- THORN, J.P. 2019. Adaptation “from below” to changes in species distribution, habitat and climate in agro-ecosystems in the Terai Plains of Nepal. *Ambio* **48**(12): 1482–1497. <https://doi.org/10.1007/s13280-019-01202-0>
- TOLE, L. 2010. Reforms from the ground up: a review of community-based forest management in tropical developing countries. *Environmental Management* **45**(6): 1312–1331. <https://doi.org/10.1007/s00267-010-9489-z>
- UGLAND, K.I., GRAY, J.S., and ELLINGSEN, K.E. 2003. The species–accumulation curve and estimation of species richness. *Journal of Animal Ecology* **72**(5): 888–897.
- ZANNE, A.E., LOPEZ-GONZALEZ, G., COOMES, D.A., ILIC, J., JANSEN, S., LEWIS, S.L., MILLER, R.B., SWENSON, N.G., WIEMANN, M.C., and CHAVE, J. 2009. *Global wood density database*. Dryad. <https://doi.org/10.5061/dryad.234>
- ZHANG, J., HUANG, J., and YANG, B. 2013. Species diversity and distribution patterns of forest vegetation in a nature reserve in the southern Taihang Mountains of China. *Forest Science and Practice* **15**(4): 293–301. <https://doi.org/10.1007/s11632-013-0416-1>
- ZOBEL, D.B., DHAKAL, L.P., JHA, P.K., and YADAV, U.K.R. 1987. *A Practical Manual for Ecology*. Ratna Book Distributors, Kathmandu, Nepal.

# Youth knowledge, engagement, and challenges in forest management and governance in Africa: a literature review

C. WEKESA<sup>a</sup>, A. ROOS<sup>b\*</sup>, D. GITONGA<sup>c</sup>, L. POPOOLA<sup>c</sup>, D. MUTTA<sup>c</sup>, M-L. AVANA-TIENTCHEU<sup>c</sup>, C. MARK-HERBERT<sup>b</sup>, F. BABALOLA<sup>c,d</sup>, J. CHEBOIWO<sup>e</sup> and P. MBILE<sup>f</sup>

<sup>a</sup>Kenya Forestry Research Institute (KEFRI), Taita Taveta Research Centre, P.O. Box 1206-80304, Wundanyi, Kenya

<sup>b</sup>Swedish University of Agricultural Sciences (SLU), Department of Forest Economics, Box 7060, 750 07, Uppsala, Sweden

<sup>c</sup>African Forest Forum (AFF), P.O. Box 30677-00100, Nairobi, Kenya

<sup>d</sup>Department of Forest Resources Management, University of Ilorin, Ilorin, 240003, Kwara State, Nigeria

<sup>e</sup>Independent consultant, Kenya

<sup>f</sup>Independent consultant, Cameroon

\*Corresponding author: anders.roos@slu.se

Email: chemukukefri@gmail.com, anders.roos@slu.se, D.Gitonga@cifor-icraf.org, L.Popoola@cifor-icraf.org, D.Mutta@cifor-icraf.org, m.l.avana@cifor-icraf.org, cecilia.mark-herbert@slu.se, F.Babalola@cifor-icraf.org, jkchemangare@yahoo.com, pmbile@gmail.com

## HIGHLIGHTS

- Traditional forest knowledge among African youth is steadily declining.
- Youth face significant barriers to participation in sustainable forest management, including insecure tenure, limited training opportunities, and inadequate inclusion in decision-making.
- Rural youth depend on forests but lack secure and sustainable livelihood opportunities in rural areas.
- Opportunities for urban youth to engage in sustainable forestry and tree-based value chains remain understudied, yet are critical for the future of forests.
- Youth empowerment in forestry requires targeted education, supportive policy reform, and meaningful engagement mechanisms.

## SUMMARY

Africa's forests are vital for biodiversity, livelihoods, and climate stability, yet they face increasing threats from anthropogenic activities and climate change. As the continent's youth population grows, their role in sustainable forest management becomes more critical. A literature review of empirical studies published between 2000 and 2024 found that urbanisation and modernisation are eroding traditional forest knowledge, though many rural youths remain dependent on the forests. Barriers such as insecure land tenure, limited training, exclusion from decision-making, and lack of support hinder youth engagement. Despite these challenges, young people show strong interest in sustainable forest use and conservation, though urban youth perspectives are underrepresented. To enhance youth involvement, the review recommends inclusive policies, better education on forest management, and integrating indigenous and scientific knowledge. Empowering African youth as conservationists and sustainable forest managers is crucial for addressing environmental challenges; future research should prioritize women and male youth from rural as well as urban areas, as both these groups remain underrepresented in the existing literature.

Keywords: African youth, forest governance, forest management, NTFPs, sustainability

## INTRODUCTION

The African continent contains approximately 16% of the world's forest area, which is vital for both ecosystem functioning and human wellbeing. These forests encompass a wide range of ecosystems, including tropical rainforests, savannahs, shrublands, and mangroves, as well as trees outside forests (FAO 2020). Home to at least 9 000 tree species (BGCI 2021), Africa's forests play a critical role in sustaining biodiversity, supporting livelihoods, enhancing resilience, and regulating the climate. As Africa's population is projected to increase from 1.55 billion in 2025 to 2.47 billion by 2050 (United Nations 2024), the importance of forests in delivering

essential ecosystem services is expected to grow further. Yet deforestation and forest degradation in Africa – primarily driven by agricultural expansion and unsustainable land-use practices, and potentially intensified by climate-related factors (Trisos *et al.* 2022 p. 1290, Wimberly *et al.* 2024) – risk exacerbating existing land-use pressures and heightening forest vulnerability. Because these environmental threats are largely anthropogenic, effective responses depend on collective action and sustained societal commitment (Trisos *et al.* 2022, Sections 9.3–9.4).

African youth are a driving force in forest conservation and sustainable development across the continent. As the world's youngest continent, Africa has over 400 million

young people aged 15–29, which is 3.5 times the youth population of Europe (United Nations 2025). While there is no single global definition of youth, the United Nations uses ages 15–24 for statistical purposes, the OECD often applies 15–29, and the African Union, through the African Youth Charter, defines youth as 15–34 (African Union 2006, United Nations 1981, OECD 2021). Regardless of the exact definition, Africa's youth population share is strikingly larger than in most other regions. By 2050, the continent is expected to account for 25% of the global population, up from 18% in 2024. This large youth cohort is increasingly educated, ambitious, and vocal in demanding change (Ickowitz Foundation 2022, 2024), positioning them as key actors in driving a transformative environmental agenda (von Hellermann 2010, Gitonga et al. 2023, Ickowitz Foundation 2024).

The role of forests in achieving sustainable development is reflected across multiple Sustainable Development Goals (SDGs), including protecting biodiversity and forest cover (SDG 15), enhancing climate resilience and carbon mitigation (SDG 13), supporting the water cycle (SDG 6), contributing to poverty alleviation and improved nutrition (SDGs 1 and 2), and creating decent, sustainable employment in the forestry sector (SDG 8).

Understanding the perspectives, activities, and aspirations of African youth regarding forests is therefore essential for effective forest governance. As they transition into adulthood, their experiences will shape future environmental actions (Lerner 2018), highlighting the importance of exploring contemporary youth–forest relationships (Brown et al. 2021, Gitonga et al. 2023). Meaningful youth engagement in forest-related discourse is vital – not only because they are tasked with confronting environmental challenges, but also due to their potential to drive innovative solutions. Increasingly, young people are recognised as agents of change in natural resource management (Zulu et al. 2023), with organisations such as the United Nations and African Union emphasising their pivotal role in sustainable development (African Union 2006, UN 2018). Nevertheless, youth–forest dynamics remain underexplored and poorly understood.

Africa's youth navigate a complex landscape of opportunities and challenges, where the aspiration to shape their future and contribute to the continent's development remains central. In some aspects, this group has made meaningful progress. In recent decades, improvements in health and education have expanded their prospects. Life expectancy rose from 53 years in 2000 to 64 years in 2023 (WHO 2024), while literacy rates increased from 61% to 75% during the same period. However, despite these gains, African youth still face greater difficulties than their peers elsewhere. Poverty remains widespread, with approximately 440 million people – around 40% of the continent's total population – living in extreme poverty in 2023 (Ingutia 2023, United Nations 2024). Many young people struggle to secure stable livelihoods, often relying on informal employment and experiencing chronic unemployment or prolonged socioeconomic stagnation – commonly referred to as “waithood” (Brown et al. 2021, Calvès et al. 2007, Carreras et al. 2020, Sumberg et al. 2021).

While education has increased awareness of global issues such as climate change (Ickowitz Foundation 2022, 2024, Simpson et al. 2021), it does not always guarantee employment, especially as rapid population growth and sluggish economic performance strain job markets (Boti Phiri 2022). Rural youth in particular face barriers to entering productive agriculture, including limited land and capital access (Brown et al. 2021, Magagula and Tsvakirai 2020). As a result, many perceive farming and forestry as labour-intensive and unattractive, prompting migration to urban areas (Sumberg et al. 2017). Others pursue diversified livelihoods, combining farming with off-farm income-generating activities (LaRue et al. 2021). Beyond economic hardship, African youth are affected by conflict and forced migration. Sub-Saharan Africa hosts over 20 million refugees (UNHCR 2025), and many young people are at risk of being recruited into armed groups due to education gaps, resource scarcity, and social exclusion (Ismail and Olonisakin 2021).

Systemic barriers also curtail youth political agency and marginalise their participation in decision-making processes. Despite Africa's demographic youthfulness, political leadership is still dominated by older generations, often fueling disillusionment and disengagement among young people (Ickowitz et al. 2022, 2024). Nonetheless, many youths are actively forging alternative pathways to influence, creating a sustainable future through climate action and eco-entrepreneurship, leveraging their skills to shape more resilient communities (Ickowitz Foundation 2024, Simmons 2022).

Although research has examined the economic and social struggles of African youth, their role in forest governance – and its implications for sustainable development – remains insufficiently explored. A deeper understanding of how young people engage with forest resources is essential for shaping policies that support youth livelihoods while promoting forest ecosystem sustainability (Brown 2021). This includes advancing forest landscape restoration, enabling youth entrepreneurship within a forest-based green economy, preserving traditional ecological knowledge, formulating equitable policies, applying agroforestry and implementing climate-smart forest practices at the local level.

This review investigates African youths' experiences, knowledge, and aspirations related to forests and broader environmental challenges. It examines their awareness of forest resources, participation in forest-based economies, and perspectives on forest governance at local, national, and continental levels. The objective is to enhance understanding of how African youth can be more effectively integrated into forest management, agroforestry and sustainable development efforts – both to improve their socio-economic prospects and to support environmental resilience.

The body of literature examining African youth–forest connections through a sustainability lens remains limited. While historical studies of forest-related practices (including youth involvement) exist, the aspirations and visions of young people – who will shape future forest governance – are seldom explored. A natural and constructive first step in addressing

this gap is to assess the current state of knowledge and identify research needs to inform future policy, strategy, and academic inquiry. This review therefore aims to synthesise existing peer-reviewed knowledge on the relationship between African youth and forests, including agroforestry. It does not include an analysis of the formal forest education organization, content and development (Onatunji *et al.* 2019, 2021). This analysis uses a dynamic and forward-looking lens, with a focus on forest knowledge, youth engagement, and future aspirations for sustainable forest use.

**METHODOLOGY**

**Framework**

This review adopts a temporal perspective on African youth–forest relations, recognising youth as a group whose forest-related knowledge, practices and aspirations are shaped by past experiences, present socio-economic conditions and future expectations. This perspective is particularly relevant in Africa, where a rapidly growing youth population is increasingly expected to play a central role in sustainable development and forest governance (African Union 2006, United Nations 2018, Ickowitz Foundation 2024).

The analytical orientation is informed by research emphasising that learning, agency and change emerge over time through the interaction of experience, knowledge and institutional context (Argyris and Schön 1978, Easterby-Smith and Lyles 2011, Emirbayer and Mische 1998). It also aligns with sustainability transition perspectives, which highlight how long-term change in resource governance depends on the gradual reconfiguration of practices, roles and power relations across generations (Geels 2002, Fischer *et al.* 2015).

This perspective provides the rationale for organising the review around four themes: (1) youth experiences and knowledge of forests, (2) current youth engagement in forest use and forest-based livelihoods, (3) youth perspectives and aspirations regarding future forest governance, and (4) recommendations proposed in the literature to strengthen youth inclusion. Together, these themes link existing empirical evidence to the broader situation of African youth and help assess how current patterns of engagement may shape future roles for young people in sustainable forest management.

**Selection and analysis**

The review process was informed by the PRISMA 2020 guidelines, which provide a structured framework for the transparent identification, screening, and reporting of studies in systematic reviews (Page *et al.* 2021). The review focused on empirical publications in English published between 2000 and 2024 and primarily accessed through scientific databases. Searches were conducted using Web of Knowledge, Scopus, and Google Scholar, employing the search terms outlined in Table 1.

Although few studies explicitly examined the nexus between African youth and forests, the review included empirical research addressing youth knowledge, practices, views and aspirations towards forests, whether as a primary or secondary focus. Definitions of ‘youth’ varied across studies and were not always explicitly stated; such variation was accepted provided that the research addressed relevant aspects of the youth–forest relationship. The search strategy combined concepts related to forests, African countries, and youth using Boolean operators, with truncation applied where appropriate (e.g., “agroforest\*”) to capture variations in terminology (Table 1). The initial identification phase yielded

TABLE 1 Search terms and selection criteria used for the literature review (2000–2024). Overview of key search terms across fields and concepts (forest, youth, Africa) and their rationale for inclusion during the identification and screening phases

Phase	Field	Concept / Scope	Search Words & Criteria	Records (n)
Step 1: Identification	Title	Forest (Ecological Scope)	“Forest” or “tree” or “wood” or “timber” or “bioenergy” or “Non-timber forest products” or “NTFP” or “agroforest*”	383,856
Step 2: Identification	Abstract	Africa (Geographic Scope)	“Africa” or names of all African countries (linked with “or”)	4,988
Step 3: Identification	All Fields	Youth (Demographic Scope)	“Youth” or “young people” or “youngsters” or “young adults” or “generation” or “age-groups” or “student*”	279
Step 4: Identification	All Fields	Linkages (Socioeconomic Scope)	“View*” or “attitude*” or “perception*” or “vision” or “aspiration*” or “engagement” or “occupation” or “livelihoods” or “career” or “knowledge”	95
Step 5: Screening	Title	Refinement	Removal based on title relevance	35
Step 6: Screening	Abstract	Refinement	Removal based on abstract relevance	31
Step 7: Complementation	N/A	Addition	Added publication not from peer-reviewed publication	32

95 references, which were first screened by title to exclude studies clearly outside the scope, reducing the dataset to 35 studies. Abstract screening further narrowed the selection to 31 peer-reviewed studies. One additional non-peer-reviewed study on youth – science linkages (Gitonga *et al.* 2023) was included, resulting in a final corpus of 32 references. For each study, information on publication year, country, source, research approach, and key findings was extracted using a standardised framework. The selected studies generally incorporated a youth perspective, often in comparison with older adults. The studies were then synthesised thematically according to the four analytical categories outlined in the above framework, enabling the identification of patterns, gaps, and variations in youth knowledge, engagement, and barriers related to forest-based activities across different contexts.

## LITERATURE REVIEW RESULTS

### General overview

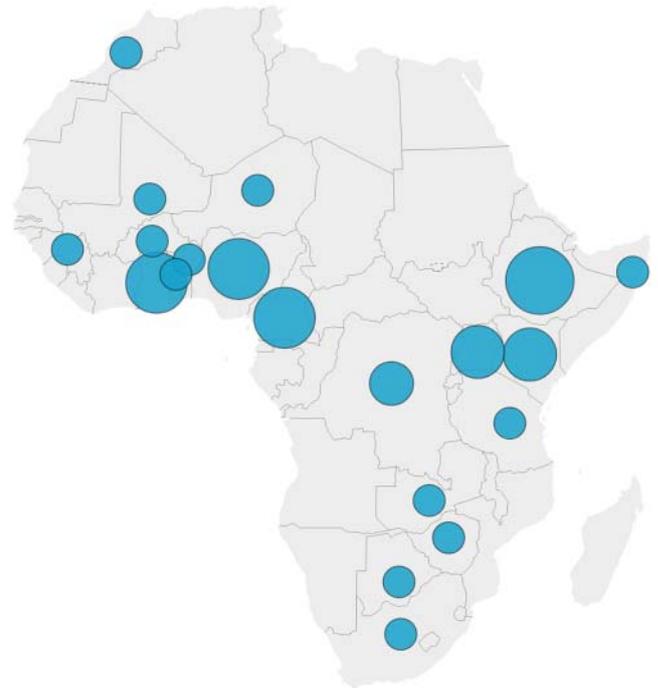
The reviewed literature spans the period from 2000 to 2024, reflecting growing, albeit still modest, scholarly attention to youth engagement with forest use and perceptions of forests (Appendix 1). Only two studies were published before 2010, followed by ten between 2010 and 2019. Since 2020, 20 studies have been recorded, suggesting increased interest in youth-related forest use and governance. However, it remains unclear whether this rise reflects a broader expansion in forest-related research across Africa or a specific increase in youth-focused studies. The publications appear in diverse interdisciplinary journals, underscoring the multifaceted nature of the topic. Key journals represented include *Forest Policy and Economics* (4), *Heliyon* (2), *Journal of Ethnobiology and Ethnomedicine* (2), and *Southern Forests: A Journal of Forest Science* (2), alongside 22 studies published in other outlets.

The studies span 20 countries, with Ethiopia, Cameroon, and Ghana most frequently represented (Figure 1). A few cover multiple countries (Lemke and Claeys 2020, Luiselli *et al.* 2019). North Africa is represented by only one study.

While the topics vary, most focus on forest management and governance, primarily in rural contexts (Appendix 1).

The dominant theme across literature is community forestry and livelihoods, which is addressed in sixteen studies (Gichuki *et al.* 2000, Yami *et al.* 2013, Yusuf *et al.* 2013, Ebifa-Othieno *et al.* 2017, Giuliani *et al.* 2017, Osei *et al.* 2019, Abebe *et al.* 2020, Ahononga *et al.* 2020, Chukwuone *et al.* 2020, Nigussie *et al.* 2021, Kudzinawo *et al.* 2022, Lucungu *et al.* 2022, Piabuo *et al.* 2022, Zikargae *et al.* 2022, Bayala *et al.* 2024, Opelele Omeno *et al.* 2024). Eleven studies specifically focus on youth or consider both youth and women as marginalised groups (Yusuf *et al.* 2013, Giuliani *et al.* 2017, Macneil *et al.* 2017, Luiselli *et al.* 2019, Lemke and Claeys 2020, Uduji and Okolo-Obasi 2020, Galabuzi *et al.* 2021, Nketia *et al.* 2022, Gitonga *et al.* 2023, Jama *et al.*

FIGURE 1 Countries covered by the review (number of studies within brackets): Benin (1), Botswana (1), Burkina Faso (1), Cameroon (4), Democratic Republic of Congo (2), Ethiopia (5), Ghana (4), Guinea (1), Kenya (3), Mali (1), Morocco (1), Niger (1), Nigeria (4), Tanzania (1), Somalia (1), South Africa (1), Togo (1), Uganda (3), Zambia (1), Zimbabwe (1). (Luiselli *et al.* 2019 and Lemke and Claeys 2020 studied multiple countries)



2023, Bamwesigye *et al.* 2024). Nine studies explore indigenous knowledge (Tanyanyiwa and Chikwanha, 2011, Ebifa-Othieno *et al.* 2017, Chukwuone *et al.* 2020, Ameneshewa *et al.* 2023) or other traditional knowledge related to tree species, medicinal plants, and practices (Dovie *et al.* 2008, Bobo *et al.* 2015, Luiselli *et al.* 2019, Galabuzi *et al.* 2021, Yanou *et al.* 2024). While sixteen articles examine forests in relation to rural livelihoods and community forest management, youth are often a secondary rather than the primary focus. Six studies discuss agency and power dynamics within communities (Yami *et al.* 2013, Bobo *et al.* 2015, Garekae *et al.* 2017, Lucungu *et al.* 2022, Zikargae *et al.* 2022, Kimengsi *et al.* 2024). Several studies, such as Ebifa-Othieno *et al.* (2017) and Zikargae *et al.* (2022), address multiple themes. The role of urban youth in African forest contexts is rarely examined. Although a few studies consider urban perspectives – for example, Ebifa-Othieno *et al.* (2017) on perceptions of non-timber forest products (NTFPs), Gitonga *et al.* (2023) on youth activism, and Luiselli *et al.* (2019) on bushmeat consumption, most research focuses on and was conducted in rural settings.

A variety of qualitative and quantitative approaches were employed. For instance, Ameneshewa *et al.* (2023) use ethnographic tools such as interviews and focus groups to study indigenous knowledge in southern Ethiopia. Osei *et al.* (2019) applied surveys and statistical analysis to examine

smallholder motivations for reforestation. Several studies, including Bayala *et al.* (2024), adopt mixed methods. Gitonga *et al.* (2023) provide a detailed case study based on a youth workshop in Kenya. Overall, fourteen studies employ qualitative methods, twelve use quantitative approaches, and six combine both.

### Youth forest knowledge and learning

Key findings on youth forest knowledge are summarised in Table 2. The reviewed literature highlights a decline in the transmission of traditional forest knowledge to youth, raising concerns for sustainable forest management. Ebifa-Othieno *et al.* (2017) find that rural youth in Uganda participate in forestry activities but know less about tamarind (*Tamarindus indica*) uses than elders. Similarly, Abebe *et al.* (2020) report a weakening of knowledge transmission in Ethiopia, with elders noting that “the youth do not listen to elders anymore.” Tanyanyiwa and Chikwanha (2011) observe that youth place less value on sacred forests, while Bobo *et al.* (2015) note diminished awareness of species-specific taboos, both among Cameroonian youth. This erosion of traditional knowledge is linked in some studies to modernisation and limited intergenerational mentoring (Abebe *et al.* 2020, Ebifa-Othieno *et al.* 2017). Ameneshewa *et al.* (2023) emphasise that because indigenous knowledge is embedded in local history and social traditions, declining ecological knowledge could undermine sustainable forest use and management.

Generational shifts in forest values may also result from differing time horizons. Abebe *et al.* (2020) report that younger households in Ethiopia often prioritise short-term needs over long-term knowledge retention, a concern more prevalent among older generations. Likewise, Tanyanyiwa and Chikwanha (2011), Chukwuone *et al.* (2020), and Ameneshewa *et al.* (2023) find that older generations perceive themselves as the primary custodians of indigenous knowledge. As Ameneshewa *et al.* (2023, p. 2) state in their Ethiopian study: “Forest resources in the Shato core area have been safeguarded, managed, and utilised sustainably for many generations because of this indigenous knowledge system. The study shows that today’s youth do not recognize these strategies.”

However, the decline in traditional forest knowledge is not uniform across all contexts or locations. Rural youth continue to retain certain practices and insights. For instance, Galabuzi *et al.* (2021) report that agricultural youth in Uganda possess knowledge of strip cropping and on-farm tree cultivation. Similarly, Uduji and Okolo-Obasi (2020) find that Nigerian youth maintain both knowledge of and interest in traditional non-timber forest product (NTFP) practices. Chukwuone *et al.* (2020) document youth familiarity with techniques such as controlled harvesting, although their understanding of other forms of indigenous knowledge is more limited. Likewise, Dovie *et al.* (2008) observe that rural youth in South Africa are knowledgeable about species used for fuelwood and construction but have less awareness of medicinal plants.

However, the overall trend points to a gradual reduction in traditional and indigenous knowledge among youth, partly influenced by the expansion of formal education, which

Chukwuone *et al.* (2020) note often diminishes interest in traditional practices. Limited schooling can also have adverse ecological consequences. For example, in Ethiopia, lack of education, landlessness and unemployment drive land clearing for cultivation, contributing to ongoing deforestation (Abebe *et al.* 2020).

Various capacity-building initiatives have been introduced to address rural knowledge gaps in conservation and sustainable forest management. Zikargae *et al.* (2022) describe forest and land management programmes in Ethiopia, while Gichuki (2000) reports on youth groups in Kenya engaged in wetland conservation. However, participation in conservation and restoration efforts remains uneven. Both Lucungu *et al.* (2022) and Abebe *et al.* (2020) find limited interest among youth in acquiring conservation skills. Economic challenges and urbanisation further constrain youth involvement in forest-based enterprises and the preservation of traditional and indigenous knowledge, particularly among those who divide their time between urban and rural settings (Lucungu *et al.* 2022). Despite these challenges, innovative conservation education targeting youth is emerging. Gitonga *et al.* (2023) document a Kenyan workshop on youth-led NTFP commercialisation, reforestation, and ecotourism.

### Patterns of youth participation

Although research highlights a growing disconnect between youth and forests, many young people continue to depend heavily on forest resources. Table 2 highlights patterns of youth participation in forest use and management. Studies in Benin (Ahononga *et al.* 2020) and Uganda (Ebifa-Othieno *et al.* 2017) specifically show that rural youth prioritise provisioning services, such as timber and non-timber forest products (NTFPs). In Botswana, forest dependency is highest among young households with limited educational attainment (Garekae *et al.* 2017). Youth with few livelihood alternatives often turn to farming and forest-based income sources, drawing on their physical capabilities and practical skills (Abebe *et al.* 2020, Chukwuone *et al.* 2020, Garekae *et al.* 2017, Opelele Omeno *et al.* 2024).

Macneil *et al.* (2017, p. 444) observe in Cameroon that young people engaged in a variety of forest activities throughout the year, such as collection of NTFPs and firewood, hunting and fishing. Galabuzi *et al.* (2021) found that limited land access remains a major barrier to intensive forest management and agroforestry for young rural men and women in Uganda:

*“Agroforestry by women and youths presents a chance to reverse deforestation effects including landslides, water stress, and food insecurity around Mount Elgon. However, the women and youth involved were generally poor, land insecure, and illiterate, limiting their potential and interest in agroforestry tree technologies”* (Galabuzi *et al.* 2021, p. 3306).

Land scarcity also reduces youth interest in forest restoration, particularly when farming options are restricted. In

TABLE 2 Youth forest knowledge, patterns of participation, aspirations &amp; concerns, and key recommendations for enhancing youth engagement (2000–2024)

Reference	Youth forest knowledge and learning	Patterns of youth participation	Aspirations on forests expressed by youth	Key recommendations for enhancing youth engagement in forest governance
Abebe <i>et al.</i> 2020	Youth have limited access to formal education because of remoteness and cost	Youth landlessness drives deforestation; youth excluded from decision-making	Youth desire for land access, jobs, and rural livelihoods	Apply adaptive co-management; recognize community diversity and youth roles
Ahononga <i>et al.</i> 2020	Youth know less about cultural and regulating ecosystem services than elders	Not explicitly assessed	Not explicitly assessed	Improve information on cultural, regulating, and supporting ecosystem services
Ameneshewa <i>et al.</i> 2023	Weak transmission of indigenous forest knowledge; declining intergenerational learning	Youth are marginal in customary and state forest governance	Forests increasingly viewed by youth as economic assets	Document indigenous knowledge; integrate indigenous and scientific systems; revitalize customary institutions
Bamwesigye <i>et al.</i> 2024	Strong awareness of climate–forest links; learning mainly perception-based	High willingness to engage in agroforestry; low influence in formal governance	Forests valued by youth for climate adaptation, livelihoods, and resilience	Integrate indigenous knowledge; strengthen agroforestry education; support youth-led initiatives
Bayala <i>et al.</i> 2024	Youth possess local ecological knowledge but have limited understanding of community resource management area rules	Youth numerically represented but with low influence and accountability	Youth support conservation if benefits and transparency are ensured	Build youth capacity; ensure transparent representation; strengthen bottom-up governance
Bobo <i>et al.</i> 2015	Declining knowledge of wildlife taboos among youth	Youth disengaging from traditional conservation norms	Not explicitly assessed	Reconcile conservation goals with changing youth values
Chukwuone <i>et al.</i> 2020	Youth actively practice indigenous forest management techniques	Youth participate mainly through labour, not through decision-making	Youth view forests as livelihood and income resources	Support youth access to credit; clarify rights; target young household heads
Dovie <i>et al.</i> 2008	Youth possess high practical knowledge of fuelwood and construction species	Youth participate through daily forest use	Not explicitly assessed	Include youth knowledge in management; design age-sensitive co-management
Ebifa-Othieno <i>et al.</i> 2017	Youth know fewer medicinal and cultural uses of <i>Tamarindus indica</i>	Youth are active in harvesting but are excluded from ownership and decision-making	Rural youth seek income; urban youth disengaged	Improve value addition; provide nutrition and conservation education
Galabuzi <i>et al.</i> 2021	Practical knowledge focused on fast-growing income trees	Youth participate mainly as labourers and have limited land-use rights	Trees valued by youth as economic assets	Strengthen forestry extension; improve land access and inputs for youth
Garekae <i>et al.</i> 2017	Experiential knowledge centred on extraction and trade	Youth show high involvement driven by poverty and unemployment	Forests seen by youth as livelihood safety nets	Provide skills training; promote alternative livelihoods; include youth in planning

TABLE 2 *Continued*

Reference	Youth forest knowledge and learning	Patterns of youth participation	Aspirations on forests expressed by youth	Key recommendations for enhancing youth engagement in forest governance
Gichuki 2000	Conservation knowledge gained through hands-on projects	Youth participate via youth-led conservation groups	Young people wish to combine income generation with conservation	Support youth groups with training and finance
Gitonga <i>et al.</i> 2023	Strong awareness of ecosystem services and green enterprises	Youth are active in youth-led groups but have limited statutory power	Youth try to combine conservation with business opportunities	Include youth in participatory forest management; improve market access
Giuliani <i>et al.</i> 2017	Limited formal education; forest knowledge implicit through wild resource use	Youth excluded from associations and land access	Young people desire financial independence and stable rural livelihoods	Improve vocational training; enhance access to land and rural services
Jama <i>et al.</i> 2023	Moderate climate change knowledge; awareness drives forestation intent	Youth participate mainly through advocacy rather than formal governance	Forests valued for climate regulation and future benefits	Strengthen climate education; align forest policy with youth values
Kimengsi <i>et al.</i> 2024	Youth disengaging from traditional forest knowledge	Youth largely absent from forest institutions	Preference for non-forest urban livelihoods	Create youth-friendly forest institutions; provide engagement incentives
Kudzinawo <i>et al.</i> 2022	Skills in NTFP cultivation implied but not assessed	Youth participation not analysed separately	NTFP production as viable livelihood	Promote NTFP value chains for youth livelihoods
Lemke and Claeys 2020	Local knowledge implied through youth engagement	Youth excluded from communal land governance	Interest in land access and secure tenure	Build youth capacity for inclusive land governance
Lucungu <i>et al.</i> 2022	Youth have limited knowledge of traditional management	Outmigration reduces youth engagement	Mixed or negative views on co-management	Involve youth in developing forest management models
Luiselli <i>et al.</i> 2019	Limited bushmeat knowledge among youth	Youth mostly excluded from bushmeat trade	Preference for modern diets	Develop culturally relevant youth conservation messaging
Macneil <i>et al.</i> 2017	Youth knowledgeable about NTFPs and agroforestry	High engagement in forest-based livelihoods	Seek income diversification and food security	Support diversified, youth-centred forest livelihoods
Nigussie <i>et al.</i> 2021	Limited knowledge of biomass and bioenergy markets	Low participation among smallholders	Interest in income from biomass supply	Incentivize youth participation; support training and finance
Nketia <i>et al.</i> 2022	Basic knowledge from afforestation programs	Youth participation is constrained by political and logistical challenges	Desire stable jobs in restoration programs	Improve monitoring, depoliticize recruitment
Opelele Omeno <i>et al.</i> 2024	Knowledge gained through daily forest product use	Youth show high labour participation but have a limited governance role	Dependence on forests for income	Increase youth capacity in sustainable management
Osei <i>et al.</i> 2019	Familiarity with tree planting and agroforestry	Youth farmers show interest in tree planting	Interest in income-oriented tree planting	Incentivize youth reforestation programs
Piabuo <i>et al.</i> 2022	General appreciation of forest values; limited governance knowledge	Youth feel excluded from decision-making. Low revenues.	Desire education, jobs, and conservation	Adapt governance structures; co-create opportunities

TABLE 2 Continued

Reference	Youth forest knowledge and learning	Patterns of youth participation	Aspirations on forests expressed by youth	Key recommendations for enhancing youth engagement in forest governance
Tanyanyiwa and Chikwanha 2011	Limited indigenous knowledge among youth	Excluded from traditional forest governance	Disengagement from customary practices	Integrate indigenous knowledge into education and mentoring
Uduji and Okolo-Obasi 2020	Growing knowledge of NTFPs among rural youth	High involvement in NTFP collection; minimal institutional support. The role of corporate social responsibility projects	Desire better income and market access	Target corporate social responsibility to youth NTFPs
Yami et al. 2013	Practical knowledge from exclosure management	Youth participation is limited by social norms and restricted land access	Expect tangible benefits from conservation	Strengthen benefit-sharing and youth involvement
Yanou et al. 2024	Hybrid local and external knowledge systems	Participation in farming and landscape management	Desire resilient, productive landscapes	Integrate indigenous knowledge with youth training
Yusuf et al. 2014	Technical beekeeping knowledge through training	Participation enabled by low land requirements	Income generation and livelihood improvement	Improve training, species choice, and market linkages
Zikargae et al. 2022	Skills gained through non-formal environmental education	Youth participation is selective but improves when inclusion mechanisms are strengthened	Combine environmental restoration and livelihoods	Expand inclusive, experiential youth training

Ethiopia, fuelwood shortages and increasing youth landlessness have hindered forest conservation expansion through exclosures (Yami et al. 2013).

In parallel, other studies document that forest based ventures, including sustainable timber and NTFPs, are increasingly seen as viable income sources for rural youth (Uduji and Okolo-Obasi 2020). Ebifa-Othieno et al. (2017) and Gitonga et al. (2023) highlight NTFP income streams such as medicinal plants and food products that could boost youth participation in sustainable management. Two studies emphasise the income potential of NTFPs: Yusuf et al. (2013) on beekeeping and Kudzinawo et al. (2022) on moringa (*Moringa oleifera*). Beekeeping, in particular, is accessible to youth due to low capital and land requirements, though challenges such as fire hazards, bee abandonment and honey theft persist (Yusuf et al. 2013).

Research indicates that rural youth engage in forest-related activities by weighing the potential benefits and required effort against alternative livelihood options, influenced by broader socio-economic trends and patterns of urban migration. Lucungu et al. (2022) attribute the low participation of young people in community forestry activities in the Democratic Republic of the Congo to rural-to-urban migration – a trend similarly observed by Piabuo et al. (2022), Garekae et al. (2017), Giuliani et al. (2017) and Kimengsi et al. (2024). In Cameroon, many young people also migrate in an effort

to escape traditional roles, further weakening their ties to forest-based practices (Kimengsi et al. 2024). As urban income opportunities increase and the future of farming becomes increasingly uncertain and constrained, reliance on forest livelihoods continues to diminish. However, migration does not always lead to a complete severance of rural ties, the process can be gradual, with many young people balancing urban employment or education with time spent in their home villages. Nevertheless, economic priorities often take precedence over cultural attachments to local forests, as evidenced in Uganda (Ebifa-Othieno et al. 2017) and Cameroon (Bobo et al. 2015). This evolving relationship reflects a complex interplay of migration, economic pressures and cultural change.

At the same time, evidence suggests that young people possess significant potential to revitalise forest conservation and management efforts (Gichuki 2000, Gitonga et al. 2023). However, sustained engagement weakens when programmes are characterised by poor governance or mismanagement (Nketia et al. 2022). While youth-led, community-based forestry initiatives can enhance participation and local ownership (Gitonga et al. 2023), this momentum may be undermined by increasing migration to urban centres (Abebe et al. 2020, Piabuo et al. 2022).

Under adverse and unstable conditions, structural and economic barriers can push rural youth towards unsustainable or illicit livelihood strategies (Uduji and Okolo-Obasi 2020).

These shifts are often driven by poverty, exclusion from the benefits of resource extraction, and the failure of corporate social responsibility initiatives to meaningfully reach or empower young people. The authors claim that private sector involvement through corporate social responsibility could play a role in youth empowerment, particularly by supporting those engaged in the collection and trade of non-timber forest products (NTFPs). Although research on the relationship between urban African youth and forests remains limited, existing evidence suggests that youth in urban areas have little interest in NTFPs (Ebifa-Othieno *et al.* 2017); however, the workshop findings reported by Gitonga *et al.* (2023) indicate that some segments of urban youth may be interested in forest bioeconomy careers when these align sustainability with job creation and income generation.

### Aspirations on forests expressed by youth

Youth perspectives on the future use of forests vary across the studies reviewed. Table 2 identifies key youth aspirations covering viewpoints on access to land, inclusion in decision-making and interest in conservation practices. In rural areas, many young people express interest in improved forest management but report feeling excluded from decision-making processes and marginalised. They call for a more equitable share of forest-derived benefits (Abebe *et al.* 2020, Nigussie *et al.* 2021). In Ethiopia, Abebe *et al.* (2020) find that this sense of exclusion can even lead to intergenerational conflict. Community-based forest management initiatives struggle to engage young people, hindered by governance challenges or a lack of alignment with youth priorities (Lucungu *et al.* 2022). However, youth perspectives are not uniform. For example, Giuliani *et al.* (2017) report that young Moroccans are open to living in rural areas, provided sustainable livelihoods are available alongside essential services such as education and healthcare. There is also growing interest among youth in afforestation and agroforestry although the opportunities can be limited. In Ethiopia, for example, younger and female-headed households face significant constraints in developing forest-related activities (Nigussie *et al.* 2018). Meanwhile, in Nigeria and Kenya, youth are becoming increasingly receptive to modern forestry practices (Chukwuone *et al.* 2020, Gitonga *et al.* 2023).

Education emerges as a central mechanism for addressing forest decline. By expanding livelihood options beyond direct forest extraction, education can reduce youth dependence on forest resources that might otherwise contribute to deforestation (Garekae *et al.* 2017, Opelele Omeno *et al.* 2024). At the same time, the transmission of traditional ecological knowledge fosters innovation by combining traditional practices with modern approaches, as demonstrated in Uganda, Ethiopia, and Kenya (Ameneshewa *et al.* 2023, Gitonga *et al.* 2023). Practical, project-based learning – including training in green entrepreneurship and environmental initiatives – equips youth with the skills needed to establish viable forestry enterprises that deliver long-term environmental and economic benefits (Gitonga *et al.* 2023, Zikargae *et al.* 2022). Integrating indigenous knowledge into formal education systems can further

strengthen natural resource management while deepening young people's connection to sustainable forest use (Ameneshewa *et al.* 2023).

At the youth workshop, Kenyan youth expressed strong interest in training on governance, project management, resource mobilisation and green business. As one participant stated:

*“Recognizing that our forests are the key to our future, I am inspired to provide environmental education in schools. I am passionate about ensuring that young people are aware of the importance of nature conservation and actively participate in it”* (Gitonga *et al.* 2023, p. 17).

The youth also sought collaboration with community forest associations to strengthen their role in forest stewardship. However, despite this enthusiasm, participants felt that greater inclusion in decision-making at all levels is essential for full participation in sustainable forest initiatives (Gitonga *et al.* 2023).

### Recommendations formulated in the studies

The reviewed studies suggest various interventions to promote sustainable forest use among the youth. Table 2 presents suggestions related to forest education, land rights, policy inclusion and non-timber forest product development. A central theme in this list relates to the inclusivity of young people in forest management decisions. Abebe *et al.* (2020) stress that clear objectives and inclusive approaches are vital, ensuring marginalised groups – including youth – are actively involved in project planning. This echoes Garekae *et al.* (2017), who highlight youth as key stakeholders and agents of change in sustainable forest management. Galabuzi *et al.* (2021) argue that empowering youth and strengthening extension networks are essential for enhancing youth participation and leadership in forest management. However, for such initiatives to be effective, equitable participation in communal resource governance must be ensured. Similarly, Lemke and Claeys (2020) highlight that addressing governance challenges is critical to enabling all stakeholders – particularly young people – to play meaningful roles in the management of communal resources.

Youth engagement in the development of non-timber forest products (NTFPs) holds considerable environmental and economic potential. However, socio-economic and structural barriers continue to constrain meaningful participation (Abebe *et al.* 2020, Galabuzi *et al.* 2021), compounded by limited institutional and technical support for NTFP processing and value addition (Uduji and Okolo-Obasi 2019). Several studies therefore emphasise the need for policy frameworks that more effectively integrate youth into the forest sector (Gichuki *et al.* 2000), particularly through strengthened community forest associations (Gitonga *et al.* 2023).

Education emerges as a central mechanism for addressing these constraints. By expanding livelihood options beyond direct forest extraction, education can reduce youth dependence on forest resources that might otherwise contribute

to deforestation (Garekae *et al.* 2017, Opelele Omeno *et al.* 2024). At the same time, the transmission of traditional ecological knowledge fosters innovation by combining indigenous practices with modern approaches, as demonstrated in Uganda, Ethiopia, and Kenya (Ameneshewa *et al.* 2023, Gitonga *et al.* 2023). Strengthening knowledge-sharing platforms, improving market access, and providing training in agroforestry and sustainable forest management further promote green entrepreneurship, helping young people overcome land and financial constraints while increasing engagement in sustainable forestry (Galabuzi *et al.* 2021, Gitonga *et al.* 2023). Practical, project-based learning – including training in green entrepreneurship and environmental initiatives – equips youth with the skills needed to establish viable forestry enterprises that deliver long-term environmental and economic benefits (Gitonga *et al.* 2023, Zikargae *et al.* 2022). Integrating indigenous knowledge into formal education systems can further strengthen natural resource management while deepening young people's connection to sustainable forest use (Ameneshewa *et al.* 2023). Nonetheless, Macneil *et al.* (2017) emphasise the need for further research on youth-centred forest governance to better understand their role in decision-making. Forest management strategies must also incorporate climate change perspectives that reflect youth voices, ensuring the next generation is actively engaged in shaping resilient policies (Jama *et al.* 2023).

Ultimately, investment in education, skills development and secure land tenure, supported by intentional engagement and mentoring, can empower youth as active leaders in rural sustainable development. Such efforts not only benefit young people but also contribute to both local and global environmental progress (Chukwuone *et al.* 2020, Giuliani *et al.* 2017, Uduji and Okolo-Obasi 2020, Zikargae *et al.* 2022).

## DISCUSSION

This review identified differing, and partly opposing, developments in the relationship between African youth and forests. There is a steady decline in interest in traditional rural livelihoods and a reduced curiosity to learn from older generations' forest knowledge among African youth due to modernisation and urbanisation. Despite this main trend, the rural youth population remains significant, exhibiting interest and curiosity for forest-based sustainable livelihoods that also provide means of income, although their engagement is constrained by structural challenges such as insecure land tenure, limited financial capital and exclusion from decision-making processes. Furthermore, the review revealed growing concern within youth groups for forest conservation, recognising forests as an integral contributor to a sustainable trajectory for the continent's development.

These trends can be explained by a combination of socio-economic transformations and institutional structures. The erosion of traditional and indigenous knowledge is linked to rural–urban migration caused by population increase, low agricultural productivity, reduced time in nature, the search

for better opportunities in cities, and the rise of formal education systems that do not integrate traditional ecological learning. Youth engagement is hampered by systemic barriers, including inadequate access to land and finance, inadequate representation in both traditional and formal governance structures, and a lack of targeted forest extension services. In urban contexts, disconnection from forest landscapes, combined with limited opportunities for forest-related career paths, may explain the weak engagement of urban youth in forest occupations. However, youth also demonstrate a growing interest in environmental issues, climate change, sustainable forests and the forest-based green economy, particularly where youth-led initiatives exist alongside access to supportive networks, training and resources.

The findings of this review resonate with earlier work by Brown (2021), which highlighted the marginal role youth play in forest governance across the Global South. Similarly, Sumberg *et al.* (2021) and Carreras *et al.* (2020) observed that African youth's aspirations for environmental or entrepreneurial engagement are often hampered by structural constraints. This review synthesises these insights by integrating more recent perspectives on youth agency from Gitonga *et al.* (2023), who documented youth interest in forest-based innovation, and aligns with the broader socio-ecological transition framework proposed by Geels (2002) and theory of agency by Emirbayer and Mische (1998), viewing youth as future agents of sustainability change.

Based on these findings, the following five key implications emerge for policy, industry, and youth groups:

1. Forest-related policies and decisions at all levels should explicitly recognize youth as stakeholders and actively integrate their voices into forest governance. This can be achieved by formalizing youth representation in local forest management planning and benefit-sharing agreements, as well as establishing meaningful youth participation in national and international fora.
2. Educational reforms should bridge formal training with indigenous knowledge, fostering both ecological literacy and vocational pathways into the forest bioeconomy. In practice, this entails developing site-specific curricula that combine scientific forestry training with intergenerational mentoring programs, where local elders and youth co-document traditional management practices.
3. Secure and equitable land rights for both women and youth are critical to foster long-term engagement and entrepreneurship in agroforestry and sustainable timber production. Rather than seeking top-down continental reform, local authorities can operationalize this by clarifying youth land-use rights within village bylaws and recognizing youth-led restoration groups as legal entities eligible for land concessions.
4. Both rural and urban youth should be engaged through innovation hubs that link forest sustainability to modern technologies. Such hubs can serve as incubators for “green” startups, providing technical training in information technology for forest monitoring or urban marketing tools.

5. Enterprises in the forest-based bioeconomy can develop sustainable markets for NTFPs as avenues for youth employment. This can be supported by establishing local value-addition facilities and incubation programs that offer skill-building in processing and fair-trade certification, tailored to the specific forest products of the region.

This review is limited by the relatively small number of youth-focused empirical studies across Africa, where some studies treated youth as a secondary demographic within broader forest governance analyses. In addition, unclear methodological descriptions constrained the depth of comparative insights. Both temporal and geographic coverage were uneven, limiting the generalisability of the results. It is likely that more insights could be gained about forest knowledge, experiences and aspirations among both young African women and urban youth. This review primarily focused on peer-reviewed literature and did not systematically include grey literature such as reports from NGOs, international organisations or research centres. While such sources provide valuable and often practice-oriented insights, their exclusion may limit coverage of ongoing initiatives and policy-relevant experiences related to youth and forest governance in Africa. The findings are constrained by the available literature, which lacks empirical data from conflict-affected regions where security challenges likely impede research, meaning the findings may not reflect the specific realities of youth in those volatile contexts.

Given Africa's rapid growth in youth and the pressing sustainability challenges it faces, more youth-focused forest research is needed. Future studies should investigate urban youth attitudes, consumption patterns, and activism related to forests and green value chains, as well as the gendered dynamics of youth–forest interactions. Research should also explore youth aspirations and innovation in forest landscapes, including youth-led restoration, NTFP commercialisation, and community forestry entrepreneurship. Employing longitudinal, action-research, and participatory approaches can deepen understanding of how youth perspectives and engagement evolve over time while positioning young people as co-creators of sustainable forest futures. Although this review focuses on Africa to ensure geographical and socio-political specificity, future comparative studies across the Global South could illuminate broader lessons for youth-inclusive forest governance while remaining sensitive to local contexts.

## CONCLUSIONS

This review set out to assess African youth's forest-related knowledge, participation and aspirations. It has demonstrated that youth are both vulnerable and vital actors in the future of Africa's forests. The disconnect between youth and the natural environment, including forests, if unaddressed, may undermine progress toward sustainable development goals. However, the studies also show that youth represent an untapped force for conservation, innovation and resilience.

The current body of literature is insufficient, and this review offers only an initial overview of the field. Continued and deeper research into the dynamic relationship between African youth and forests is essential for building sustainable and inclusive forest governance systems on the continent that benefit both the natural environment and the youth population.

## ACKNOWLEDGEMENT

We gratefully acknowledge the constructive advice provided by two anonymous reviewers.

## DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## FUNDING SOURCES

This work was supported by Formas, the Swedish government research council for sustainable development [grant number 2023-02582].

## GENERATIVE AI STATEMENT

During the preparation of this manuscript, the authors utilized ChatGPT (OpenAI) and Google Gemini (Google) for the purpose of language revision, grammar correction and editing. Following their use, the authors thoroughly reviewed and revised the content as necessary and assume full responsibility for the final published article.

## REFERENCES

- ABEBE, B.A., JONES, K.W., SOLOMON, J., GALVIN, K. and EVANGELISTA, P. 2020. Examining social equity in community-based conservation programs: A case study of controlled hunting programs in Bale Mountains, Ethiopia. *World Development* **135**: 105066. <https://doi.org/10.1016/j.worlddev.2020.105066>
- AFRICAN UNION. 2006. *African Youth Charter*. African Youth Charter. African Union Commission. [www.au.int/sites/default/files/treaties/7789-treaty-0033\\_-\\_african\\_youth\\_charter\\_e.pdf](http://www.au.int/sites/default/files/treaties/7789-treaty-0033_-_african_youth_charter_e.pdf) Accessed 27 February 2025.
- AHONONGA, F.C., GOUWAKINNOU, G.N., BIAOU, S.S.H., BIAOU, S., and SONOUNAMETO, R.C. 2020. Socioeconomic factors determining ecosystem services local perceptions in two ecological zones in Benin (West Africa). *International Journal of Biological and Chemical Sciences* **14**(5): 1716–1733. <https://doi.org/10.4314/ijbcs.v14i5.18>

- AMENESHEWA, W., KEBEDE, Y., UNBUSHE, D. and LEGESSE, A. 2023. Indigenous knowledge and forest management practices among Shekachoo people in the Sheka Biosphere Reserve: A case of Shato core area, South-west Ethiopia. *Cogent Social Sciences* **9**(2): 2275937. <https://doi.org/10.1080/23311886.2023.2275937>
- ARGYRIS, C., and SCHÖN, D.A. 1978. *Organizational learning: A theory of action perspective*. Addison-Wesley Publishing Company.
- BAMWESIGYE, D., YEBOAH, E., OZBALCI, S., FIALOVA, J., KUPEC, P., VERTER, N., and ASAMOAH, O. 2024. Climate change and potential of agroforestry in Uganda: Youth perceptions and willingness to participate in adaptation and transition efforts. *Forests* **15**(12): 2108. <https://doi.org/10.3390/f15122108>
- BAYALA, E.R.C., ROS-TONEN, M., YANOU, M.P., DJOUDI, H., REED, J., and SUNDERLAND, T. 2024. Towards more inclusive community landscape governance: Drivers and assessment indicators in northern Ghana. *Forest Policy and Economics* **159**: 103138. <https://doi.org/10.1016/j.forpol.2024.103138>
- BGCI. 2021. *State of the world's trees*. Botanical Gardens Conservation International.
- BOBO, K.S., AGHOMO, F.F.M., and NTUMWEL, B.C. 2015. Wildlife use and the role of taboos in the conservation of wildlife around the Nkwende Hills Forest Reserve, South-west Cameroon. *Journal of Ethnobiology and Ethnomedicine* **11**: 1–24. <https://doi.org/10.1186/s13002-015-0007-x>
- BOTI PHIRI, M.J. 2022. Addressing youth unemployment in Africa. In: TANYANYIWA, V.I. and CHIKWANHA, M. (eds.) *The Palgrave handbook of sustainable peace and security in Africa*. Cham: Springer International Publishing, pp. 433–443. [https://doi.org/10.1007/978-3-030-77489-9\\_27](https://doi.org/10.1007/978-3-030-77489-9_27)
- BROWN, H.C.P. 2021. Youth, migration and community forestry in the Global South. *Forests, Trees and Livelihoods* **30**(3): 213–225. <https://doi.org/10.1080/14728028.2021.1917923>
- CALVÈS, A.E., KOBIANÉ, J.F., and MARTEL, E. 2007. Changing transition to adulthood in urban Burkina Faso. *Journal of Comparative Family Studies* **38**(2): 265–283. <https://doi.org/10.3138/jcfs.38.2.265>
- CARRERAS, M., SUMBERG, J., and SAHA, A. 2021. Work and rural livelihoods: The micro dynamics of Africa's 'youth employment crisis'. *The European Journal of Development Research* **33**: 1666–1694. <https://doi.org/10.1057/s41287-021-00460-5>
- CHUKWUONE, N.A., ADEOSUN, K.P., and CHUKWUONE, C.A. 2020. Socioeconomic factors affecting households' use of indigenous forest management practices in managing non-wood forest products: Evidence from forest communities in Nigeria derived savannah. *Heliyon* **6**(10): e05047. <https://doi.org/10.1016/j.heliyon.2020.e05047>
- DOVIE, D.B., WITKOWSKI, E.T.F., and SHACKLETON, C.M. 2008. Knowledge of plant resource use based on location, gender and generation. *Applied Geography* **28**(4): 311–322. <https://doi.org/10.1016/j.apgeog.2008.07.002>
- EASTERBY-SMITH, M., and LYLES, M.A. (eds.). 2011. *Handbook of organizational learning and knowledge management*. 2nd ed. Chichester, UK: Wiley.
- EBIFA-OTHIENO, E., MUGISHA, A., NYEKO, P., and KABASA, J.D. 2017. Knowledge, attitudes and practices in tamarind (*Tamarindus indica* L.) use and conservation in Eastern Uganda. *Journal of Ethnobiology and Ethnomedicine* **13**: 1–13. <https://doi.org/10.1186/s13002-016-0133-8>
- EMIRBAYER, M., and MISCHÉ, A. 1998. What is agency? *American Journal of Sociology* **103**(4): 962–1023.
- FAO. 2020. *Global forest resources assessment 2020: Main report*. Food and Agriculture Organization of the United Nations, Rome.
- FISCHER, J., GARDNER, T.A., BENNETT, E.M., BALVANERA, P., BIGGS, R., CARPENTER, S., and TENHUNEN, J. 2015. Advancing sustainability through mainstreaming a social-ecological systems perspective. *Current Opinion in Environmental Sustainability* **14**: 144–149. <https://doi.org/10.1016/j.cosust.2015.06.002>
- GALABUZI, C., AGABA, H., OKIA, C.A., ODOUL, J., and MUTHURI, C. 2021. Women and youths participation in agroforestry: What counts and what doesn't around Mount Elgon, Uganda. *Journal of Mountain Science* **18**(12): 3306–3320. <https://doi.org/10.1007/s11629-021-6812-5>
- GAREKAE, H., THAKADU, O.T., and LEPETU, J. 2017. Socio-economic factors influencing household forest dependency in Chobe enclave, Botswana. *Ecological Processes* **6**: 1–10. <https://doi.org/10.1186/s13717-017-0107-3>
- GEELS, F.W. 2002. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy* **31**(8–9): 1257–1274.
- GICHUKI, C.M. 2000. Community participation in the protection of Kenya's wetlands. *Ostrich* **71**(1–2): 122–125. <https://doi.org/10.1080/00306525.2000.9639886>
- GITONGA, D., WEKESA, C., KISEU, E., KOWERO, G., MUTTA, D., OMONDI, R., and ROOS, A. 2023. *Kenyan youth perspectives on forests: Report from a youth-scientist dialogue on sustainable forestry*. Uppsala: Swedish University of Agricultural Sciences. <https://doi.org/10.54612/a.3n821idolh>
- GIULIANI, A., MENGEL, S., PAISLEY, C., PERKINS, N., FLINK, I., OLIVEROS, O., and WONGTSCHOWSKI, M. 2017. Realities, perceptions, challenges and aspirations of rural youth in dryland agriculture in the Midelt Province, Morocco. *Sustainability* **9**(6): 871. <https://doi.org/10.3390/su9060871>
- ICKKOWITZ FOUNDATION. 2022. *African Youth Survey 2022*. Ichikowitz Family Foundation. Retrieved from <https://ichikowitzfoundation.com/storage/ays/ays2022.pdf>
- ICKKOWITZ FOUNDATION. 2024. *African Youth Survey 2024*. Ichikowitz Family Foundation. <https://ichikowitzfoundation.com/storage/reports/September2024/GSLc mLTnruHzhTrIuDOV.pdf>
- INGUTIA, R. 2023. Has the sustainable development goal of reducing the proportion of youths not in education, employment or training by 2020 been met in Africa?

- Vulnerable Children and Youth Studies* **18**(2): 298–308. <https://doi.org/10.1080/17450128.2023.2174567>
- ISMAIL, O., and OLONISAKIN, F. 2021. Why do youth participate in violence in Africa? A review of evidence. *Conflict, Security & Development* **21**(3): 371–399. <https://doi.org/10.1080/14678802.2021.1922741>
- JAMA, O.M., DIRIYE, A.W., and ABDI, A.M. 2023. Understanding young people's perception toward forestation as a strategy to mitigate climate change in a post-conflict developing country. *Environment, Development and Sustainability* **25**(6): 4787–4811. <https://doi.org/10.1007/s10668-022-02145-6>
- KIMENGSU, J.N., MUKONG, A.K., FORJE, G.W., and GIESSEN, L. 2024. Institutional change pathways and implications for forest resource use in the Bakossi landscape of Cameroon. *Journal for Nature Conservation* **78**: 126567. <https://doi.org/10.1016/j.jnc.2023.126567>
- KUDZINAWO, C., AWUNYO-VITOR, D., and WONGNAA, C.A. 2022. Empirical examination of financial and economic viability of *Moringa oleifera* production in the Bono East Region, Ghana. *Forests, Trees and Livelihoods* **31**(4): 216–229. <https://doi.org/10.1080/14728028.2022.2077894>
- LARUE, K., DAUM, T., MAUSCH, K., and HARRIS, D. 2021. Who wants to farm? Answers depend on how you ask: A case study on youth aspirations in Kenya. *The European Journal of Development Research* **33**: 885–909. <https://doi.org/10.1057/s41287-020-00345-8>
- LEMKE, S., and CLAEYS, P. 2020. Absent voices: Women and youth in communal land governance. Reflections on methods and process from exploratory research in West and East Africa. *Land* **9**(8): 266. <https://doi.org/10.3390/land9080266>
- LERNER, R.M. 2018. *Concepts and theories of human development*. Routledge. <https://doi.org/10.4324/9781351307840>
- LUCUNGU, P.B., DHITAL, N., ASSELIN, H., KIBAMBE, J.P., NGABINZEKE, J.S., and KHASA, D.P. 2022. Local perception and attitude toward community forest concessions in the Democratic Republic of Congo. *Forest Policy and Economics* **139**: 102734. <https://doi.org/10.1016/j.forpol.2022.102734>
- LUISELLI, L., HEMA, E.M., SEGNIAGBETO, G.H., OUATTARA, V., ENIANG, E.A., DI VITTORIO, M., and FA, J.E. 2019. Understanding the influence of non-wealth factors in determining bushmeat consumption: Results from four West African countries. *Acta Oecologica* **94**: 47–56. <https://doi.org/10.1016/j.actao.2018.11.003>
- MACNEIL, C., BROWN, H.C.P., and SONWA, D.J. 2017. Investigations of the livelihood strategies of young men and women in forested landscapes of eastern Cameroon. *International Forestry Review* **19**(4): 437–448. <https://doi.org/10.1505/146554817822330560>
- MAGAGULA, B., and TSVAKIRAI, C.Z. 2020. Youth perceptions of agriculture: Influence of cognitive processes on participation in agripreneurship. *Development in Practice* **30**(2): 234–243. <https://doi.org/10.1080/09614524.2019.1670138>
- NIGUSSIE, Z., TSUNEKAWA, A., HAREGEWEYN, N., TSUBO, M., ADGO, E., AYALEW, Z., and ABELE, S. 2021. Small-scale woodlot growers' interest in participating in bioenergy market in rural Ethiopia. *Environmental Management* **68**(4): 553–565. <https://doi.org/10.1007/s00267-021-01418-6>
- NKETIA, S.K.K., TAKYI, S.A., AMPONSAH, O., YEBOAH, A.S., MENSAH, H., and AHADZIE, D.K. 2022. “Going green” rhetoric or reality: An assessment of the prospects and challenges of Ghana's youth in afforestation programme. *Society & Natural Resources* **35**(1): 20–37. <https://doi.org/10.1080/08941920.2021.1929678>
- OECD. 2021. Updated OECD Youth Action Plan. [https://one.oecd.org/document/C/MIN\(2021\)3/en/pdf](https://one.oecd.org/document/C/MIN(2021)3/en/pdf)
- ONATUNJI, A.B., OWUOR, J.A., RODRIGUEZ-PIÑEROS, S., BABALOLA, F.D., AKELLO, S., and ADEYEMI, O. 2021. *Building a successful forestry career in Africa: Inspirational stories and opportunities*. Vienna: International Union of Forest Research Organizations, 120 pp. <https://www.iufro.org/uploads/media/building-a-successful-forestry-career-in-africa.pdf>
- OPELELE OMENO, M., YING, Y., FAN, W., TOLERANT, L., CHEN, C., and KACHAKA, S.K. 2024. Household dependence on forest resources in the Luki Biosphere Reserve, Democratic Republic of Congo. *Environmental Management*: **74**(2): 282–298.
- OSEI, R., ZERBE, S., BECKMANN, V., and BOAITEY, A. 2019. Socio-economic determinants of smallholder plantation sizes in Ghana and options to encourage reforestation. *Southern Forests: A Journal of Forest Science* **81**(1): 49–56. <https://doi.org/10.2989/20702620.2018.1540906>
- PAGE, M.J., MCKENZIE, J.E., BOSSUYT, P.M., BOUTRON, I., HOFFMANN, T.C., MULROW, C.D., and MOHER, D. 2021. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **372**: n71. <https://doi.org/10.1136/bmj.n71>
- PIABUO, S.M., HOOGSTRA-KLEIN, M., INGRAM, V., and FOUNDJEM-TITA, D. 2022. Community forest enterprises (CFEs) as social enterprises: Empirical evidence from Cameroon. *Forest Policy and Economics* **135**: 102664. <https://doi.org/10.1016/j.forpol.2021.102664>
- SIMMONS, A. 2022. Enhancing the capacity of youth to adapt to the impact of climate change and other development calamities in Africa. *Climate Change Adaptation Framework and Youth Entrepreneurship in West Africa*: 1–11.
- SIMPSON, N.P., ANDREWS, T.M., KRÖNKE, M., LENNARD, C., ODOULAMI, R.C., OUWENEEL, B., and TRISOS, C.H. 2021. Climate change literacy in Africa. *Nature Climate Change* **11**(11): 937–944. <https://doi.org/10.1038/s41558-021-01077-6>
- SUMBERG, J., YEBOAH, T., FLYNN, J., and ANYIDOHO, N.A. 2017. Young people's perspectives on farming in Ghana: A Q study. *Food Security* **9**(1): 151–161. <https://doi.org/10.1007/s12571-016-0623-7>
- SUMBERG, J., FOX, L., FLYNN, J., MADER, P., and OOSTEROM, M. 2021. Africa's “youth employment”

- crisis is actually a “missing jobs” crisis. *Development Policy Review* **39**(4): 621–643. <https://doi.org/10.1111/dpr.12481>
- TANYANYIWA, V.I., and CHIKWANHA, M. 2011. The role of indigenous knowledge systems in the management of forest resources in Mugabe area, Masvingo, Zimbabwe. *Journal of Sustainable Development in Africa* **13**(3): 132–149.
- TRISOS, C.H., ADELEKAN, I.O., TOTIN, E., AYANLADE, A., EFITRE, J., GEMEDA, A., KALABA, K., LENNARD, C., MASAO, C., MGAYA, Y., NGARUIYA, G., OLAGO, D., SIMPSON, N.P. and ZAKIELDEEN, S. 2022. Africa. In: PÖRTNER, H.-O., ROBERTS, D.C., TIGNOR, M., POLOCZANSKA, E.S., MINTENBECK, K., ALEGRÍA, A., CRAIG, M., LANGSDORF, S., LÖSCHKE, S., MÖLLER, V., OKEM, A., and RAMA, B. (eds.) *Climate change 2022: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455. <https://doi.org/10.1017/9781009325844.011>
- UDUJI, J.I., and OKOLO-OBASI, E.N. 2020. Youth empowerment in non-timber forest products (NTFPs) of sub-Saharan Africa: The role of corporate social responsibility in Niger Delta, Nigeria. *Journal of Enterprising Communities: People and Places in the Global Economy* **14**(5): 729–752. <https://doi.org/10.1108/JEC-10-2018-0094>
- UNHCR. 2025. Refugee data finder. [www.unhcr.org/refugee-statistics?utm\\_source=chatgpt.com](http://www.unhcr.org/refugee-statistics?utm_source=chatgpt.com) Accessed 8 February 2025.
- UNITED NATIONS. 2018. *United Nation’s youth strategy*.
- UNITED NATIONS. 2024. *The sustainable development goals report 2024*.
- UNITED NATIONS. 2025. *World populations prospects 2024*. <https://population.un.org/wpp/> Accessed 19 February 2025.
- UNITED NATIONS. 1981. *Youth*. <https://www.un.org/en/global-issues/youth>
- WIMBERLY, M.C., WANYAMA, D., DOUGHTY, R., PEIRO, H., and CROWELL, S. 2024. Increasing fire activity in African tropical forests is associated with deforestation and climate change. *Geophysical Research Letters* **51**(9): e2023GL106240.
- VON HELLERMANN, P. 2010. The chief, the youth and the plantation: Communal politics in southern Nigeria. *The Journal of Modern African Studies* **48**(2): 259–283. <https://doi.org/10.1017/S0022278X1000003X>
- WHO. 2025. *World health data*. World Health Organization. [www.who.int/data](http://www.who.int/data) Accessed 17 February 2025.
- YAMI, M., MEKURIA, W., and HAUSER, M. 2013. The effectiveness of village bylaws in sustainable management of community-managed exclosures in Northern Ethiopia. *Sustainability Science* **8**: 73–86. <https://doi.org/10.1007/s11625-013-0214-2>
- YANOU, M.P., ROS-TONEN, M.A., REED, J., NAKWENDA, S., and SUNDERLAND, T. 2024. The hybridisation, resilience, and loss of local knowledge and natural resource management in Zambia. *Human Ecology* **52**(5): 1087–1105. <https://doi.org/10.1007/s10745-024-00645-w>
- YUSUF, S.F.G., LATEGAN, F.S., and AYINDE, I.A. 2014. Creating youth employment through modern beekeeping: Case study of selected youth trained in Moro Local Government Kwara State, Nigeria. *South African Journal of Agricultural Extension* **42**(2): 1–9.
- ZIKARGAE, M.H., WOLDEAREGAY, A.G., and SKJERDAL, T. 2022. Empowering rural society through non-formal environmental education: An empirical study of environment and forest development community projects in Ethiopia. *Heliyon* **8**(3): e09213. <https://doi.org/10.1016/j.heliyon.2022.e09213>
- ZULU, L.C., DJENONTIN, I.N., KAMOTO, J.F., KAMPANJE-PHIRI, J.M., and FISCHER, G. 2023. Do youth conceptualizations influence the inclusion of young people in sustainable agriculture intensification? Insights from Ghana and Malawi. *Environment, Development and Sustainability* **25**(12): 13909–13935. <https://doi.org/10.1007/s10668-022-02708-6>

APPENDIX 1 *Reviewed studies (2000–2024): year, country, focus*

Reference	Country	Title	Source	Study approach, methods, and respondents
Abebe <i>et al.</i> 2020	Ethiopia	Examining social equity in community-based conservation programs: A case study of controlled hunting programs in Bale Mountains, Ethiopia	World Development	Grounded qualitative study of local equity perceptions in community-based hunting, involving respondents stratified by age, gender, and role.
Ahononga <i>et al.</i> 2020	Benin	Socioeconomic factors determining ecosystem services local perceptions in two ecological zones in Benin (West Africa)	International Journal of Biological and Chemical Sciences	Quantitative survey of 689 respondents across two regions, analysing perceptions of ecosystem services stratified by age and socio-economic factors.
Amenesheva <i>et al.</i> 2023	Ethiopia	Indigenous knowledge and forest management practices among Shekachoo people in the Sheka Biosphere Reserve A case of Shato core area, South-west Ethiopia	Cogent Social Sciences	Qualitative study using interviews and observations to document indigenous management practices among elders, women, youth, and experts.
Bamwesigye <i>et al.</i> 2024	Uganda	Climate Change and Potential of Agroforestry in Uganda: Youth Perceptions and Willingness to Participate in Adaptation and Transition Efforts	Forests	Survey of 1,138 Ugandan youth using descriptive statistics and OLS regression to explore climate perceptions and willingness to adopt agroforestry.
Bayala <i>et al.</i> 2024	Ghana	Towards more inclusive community landscape governance: Drivers and assessment indicators in northern Ghana	Forest Policy and Economics	Qualitative assessment using key informant interviews, focus groups, and observations to identify inclusivity drivers and indicators in community resource governance.
Bobo <i>et al.</i> 2015	Cameroon	Wildlife use and the role of taboos in the conservation of wildlife around the Nkwende Hills Forest Reserve; South-west Cameroon	Journal of Ethnobiology and Ethnomedicine	Questionnaire survey of 126 households across seven villages documenting local uses, taboos, and cultural relationships with wildlife.
Chukwuone <i>et al.</i> 2020	Nigeria	Socioeconomic factors affecting households' use of indigenous forest management practices in managing non-wood forest products: evidence from forest communities in Nigeria derived savannah	Heliyon	Survey of 200 households in 10 forest communities identifying socioeconomic factors influencing indigenous management of non-wood forest products.
Dovie <i>et al.</i> 2008	South Africa	Knowledge of plant resource use based on location, gender and generation	Applied Geography	Survey of local knowledge regarding 267 woody plant species, examining differences in use based on gender and age.
Ebifa-Othieno <i>et al.</i> 2017	Uganda	Knowledge, attitudes and practices in tamarind ( <i>Tamarindus indica L</i> ) use and conservation in Eastern Uganda	Journal of Ethnobiology and Ethnomedicine	Cross-sectional survey of local indigenous knowledge, attitudes, and practices regarding the use and conservation of <i>Tamarindus indica</i> .
Galabuzi <i>et al.</i> 2021	Uganda	Women and youths participation in agroforestry: What counts and what doesn't around Mount Elgon, Uganda?	Journal of Mountain Science	Mixed-methods assessment using surveys, focus groups, and interviews to analyse socio-economic characteristics and agroforestry adoption among women and youth.
Garekae <i>et al.</i> 2017	Botswana	Socio-economic factors influencing household forest dependency in Chobe enclave, Botswana	Ecological Processes	Household surveys and logistic regression analysis identifying socio-economic determinants of forest dependency.

Reference	Country	Title	Source	Study approach, methods, and respondents
Gichuki 2000	Kenya	Community participation in the protection of Kenya's wetlands	Ostrich	Descriptive study of community-led wetland conservation initiatives, focusing on income generation, youth employment, and environmental protection.
Gitonga et al. 2023	Kenya	Kenyan Youth Perspectives on Forests Report from a youth-scientist dialogue on sustainable forestry	SLU Global	Workshop proceedings documenting youth perspectives (ages 18–25) on forest governance, sustainable management, and green economy engagement.
Giuliani et al. 2017	Morocco	Realities, Perceptions, Challenges and Aspirations of Rural Youth in Dryland Agriculture in the Midelt Province, Morocco	Sustainability	Participatory qualitative and quantitative study examining rural youth perspectives, aspirations, and gendered realities in dryland agriculture.
Jama et al. 2023	Somalia	Understanding young people's perception toward forestation as a strategy to mitigate climate change in a post-conflict developing country	Environment, Development and Sustainability	Survey of university students using structural equation modelling to examine perceptions and behavioural intentions toward forestation.
Kimengsi et al. 2024	Cameroon	Institutional change pathways and implications for forest resource use in the Bakossi landscape of Cameroon	Journal for Nature Conservation	Analysis of forest-dependent households using surveys, focus groups, interviews, and instrumental variable analysis to study non-timber forest product use.
Kudzinawo et al. 2022	Ghana	Empirical examination of financial and economic viability of Moringa oleifera production in the Bono East Region, Ghana	Forests, Trees and Livelihoods	Financial and economic viability assessment using farmer surveys, processing firm data, and project appraisal methods.
Lemke and Claeys 2020	Kenya, Tanzania, Mali, Guinea	Absent Voices: Women and Youth in Communal Land Governance. Reflections on Methods and Process from Exploratory Research in West and East Africa	Land	Exploratory research involving participatory workshops and field visits with social movements, academics, and legal actors regarding communal governance.
Lucungu et al. 2022	DRC	Local perception and attitude toward community forest concessions in the Democratic Republic of Congo	Forest Policy and Economics	Survey-based assessment of forest users using multinomial probit regression to analyse perceptions and attitudes toward community concessions.
Luiselli et al. 2019	Burkina Faso, Niger, Nigeria, Togo	Understanding the influence of non-wealth factors in determining bushmeat consumption: Results from four West African countries	Acta Oecologica	Survey of 2,453 urban and rural residents examining the influence of age, gender, and location on bushmeat consumption patterns.
Macneil et al. 2017	Cameroon	Investigations of the livelihood strategies of young men and women in forested landscapes of eastern Cameroon	International Forestry Review	Focus groups and surveys in six villages examining how youth (ages 19–30) utilize forest resources and agroforestry for subsistence.
Nigussie et al. 2021	Ethiopia	Small-Scale Woodlot Growers' Interest in Participating in Bioenergy Market in Rural Ethiopia	Environmental Management	Inductive qualitative research examining smallholder implementation of soil and water conservation, highlighting the inclusion of youth and women.

Reference	Country	Title	Source	Study approach, methods, and respondents
Nketia <i>et al.</i> 2022	Ghana	Going Green Rhetoric or Reality: An Assessment of the Prospects and Challenges of Ghana's Youth in Afforestation Programme	Society & Natural Resources	Assessment using surveys and institutional data to evaluate the potential and challenges of a national youth afforestation program.
Opelele Omeno <i>et al.</i> 2024	DRC	Household Dependence on Forest Resources in the Luki Biosphere Reserve, Democratic Republic of Congo	Environmental Management	Surveys and focus groups assessing household forest dependence and the influence of age, wealth, and education on resource reliance.
Osei <i>et al.</i> 2019	Ghana	Socio-economic determinants of smallholder plantation sizes in Ghana and options to encourage reforestation	Southern Forests	Survey and regression analysis of smallholder-led reforestation, examining how socio-economic factors influence plantation size and tree planting.
Piabuo <i>et al.</i> 2022	Cameroon	Community forest enterprises (CFEs) as Social Enterprises: Empirical evidence from Cameroon	Forest Policy and Economics	Document review, interviews, and focus groups assessing 38 community forest enterprises to determine their function as social enterprises.
Tanyanyiwa and Chikwanha 2011	Zimbabwe	The role of indigenous knowledge systems in the management of forest resources in Mugabe area, Masvingo, Zimbabwe	Journal of Sustainable Development in Africa	Qualitative study examining indigenous knowledge in forest conservation, documenting traditional practices and youth disengagement.
Uduji and Okolo-Obasi 2020	Nigeria	Youth empowerment in non-timber forest products (NTFPs) of sub-Saharan Africa: the role of corporate social responsibility in Niger Delta, Nigeria	Journal of Enterprising Communities	Participatory interviews and logit analysis evaluating the impact of corporate social responsibility on rural youth engaged in NTFP activities.
Yami <i>et al.</i> 2013	Ethiopia	The effectiveness of village bylaws in sustainable management of community-managed exclosures in Northern Ethiopia	Sustainability Science	Qualitative evaluation of community bylaws using local users, including youth, as the unit of analysis.
Yanou <i>et al.</i> 2024	Zambia	The Hybridisation, Resilience, and Loss of Local Knowledge and Natural Resource Management in Zambia	Human Ecology	Walking interviews and photovoice exploring Tonga local knowledge for landscape management, featuring youth and women as key knowledge holders.
Yusuf <i>et al.</i> 2014	Nigeria	Creating Youth Employment through Modern Beekeeping: Case Study of Selected Youth Trained in Moro Local Government Area Kwara State, Nigeria	South African Journal of Agricultural Extension	Structured interviews with 116 participants evaluating the adoption and productivity outcomes of youth beekeeping training.
Zikargae <i>et al.</i> 2022	Ethiopia	Empowering rural society through non-formal environmental education: An empirical study of environment and forest development community projects in Ethiopia	Heliyon	Qualitative study using thematic analysis to assess skills and knowledge acquisition among out-of-school youth in environmental projects.

# Empirical analysis of the links between China's forest product imports and tropical forest loss

X. SUN<sup>a</sup>, A.L. HAMMETT<sup>b</sup> and R. BUSH<sup>b</sup>

<sup>a</sup>*Forest Trends, 1203 19th Street NW, Washington DC, 20036, USA*

<sup>b</sup>*Department of Sustainable Biomaterials, Virginia Tech, Blacksburg, VA 24061, USA*

Email: xsun@forest-trends.org, himal@vt.edu, rbush@vt.edu

---

## HIGHLIGHTS

- Forest product exports to China are strongly linked to tropical forest loss in most regions.
- Agricultural expansion is the dominant driver of tropical forest loss, particularly in Latin America.
- Better governance is associated with reduced forest loss in Latin America but not in other tropical regions.
- Economic growth does not generally follow the Environmental Kuznets Curve pattern for tropical forest loss, except for tropical Africa.
- China is a globally important market for forest products and other commodities linked to forest loss (soybeans, beef, etc.). Hence, China's full impact on tropical forests is likely to be greater than appeared in this analysis.

## SUMMARY

China's forest product imports have surged over the past two decades, fueled by robust economic growth and an inadequate domestic timber supply. Many observers highlight the large and expanding trade volume as a significant driver of deforestation and forest degradation, especially in tropical regions. This research investigates the relationship between China's imports of wood-based forest product and tropical forest loss. A positive relationship between China's imports of wood-based forest products and the forest loss was found across all tropical countries, except those in Latin America. Additionally, land conversion to agricultural production and pasture for livestock are important drivers of the forest loss. The results provide insight into the complex policy, environmental and economic factors influencing tropical forest loss and the role of China's demand for tropical forest products. This research offers valuable guidance for the Chinese government in crafting balanced policies that protect domestic forests while addressing tropical forest loss.

Keywords: China, forest product imports, governance, land conversion, tropical forest loss

---

## INTRODUCTION

China's forest product imports had seen gradual growth but greatly increased after 1998, when the Natural Forest Protection Program (NFPP) was piloted. Currently more than half of China's timber supply is sourced from imports (World Economic Forum 2022), making it the world's largest timber importer. This substantial and expanding trade has been identified by many as a key driver of tropical deforestation and forest degradation. International efforts to mitigate these negative impacts have largely focused on reducing illegal logging in timber producing countries, with some progress being made (Lawson 2010, Cashore *et al.* 2016, Polo Villanueva *et al.* 2023).

China's demand affects the world timber market, and forest resources in each of the supplying countries. China's shift in domestic policy and growing demand for forest products may have significantly influenced forest conservation efforts in tropical supplier countries, where deforestation and forest degradation have long posed serious challenges. Understanding linkages between China's forest product imports and

tropical forest loss and its heterogeneous effects is critical for improving China's domestic forest policy and global cooperation against deforestation and forest degradation. The goal of this research was to determine whether and to what extent forest product exports to China explain deforestation and forest degradation in tropical supplying countries.

## CHINA'S FOREST PRODUCT IMPORTS FROM TROPICAL COUNTRIES

Since 1998, China's demand for forest products has surged, establishing it as the world's largest timber importer. Imports now account for over half of its timber supply (Sun *et al.* 2004, World Economic Forum 2022). Simultaneously, China's domestic wood processing industry, including wood-based panels and furniture, has become a significant producer of manufactured goods, establishing China as a major global hub for wood products manufacturing (Wang *et al.* 2023a).

For the purpose of this research, forest products refer to wood-based products, including wood products – items with

Harmonized System (HS) codes 4401–4421 and wooden furniture with HS codes 940161, 940169, 940330, 940340, 940350, and 940360 – as well as pulp and paper products, defined as items with HS codes 47 and 48. By analyzing China's forest product imports data 1998–2022, we found that China's forest product imports are characterized by domination of primary products, namely logs, sawnwood, wood chips and wood pulp. Among these, sawnwood imports have grown at a faster pace than logs, reflecting the trend of increasing restrictions by timber-producing countries on log exports to safeguard their forests and encourage domestic value-added processing. The rise in wood chip and wood pulp imports after 2017 was likely driven by China's ban on waste paper imports, which had supplied a large share of its wood pulp-based industry and reshaped demand for alternative raw materials in the paper sector (Wang *et al.* 2023a).

While the sources of logs, sawnwood, and wood pulp are diverse, with leading suppliers from both tropical and non-tropical regions, wood chips are primarily sourced from tropical and subtropical countries, including Vietnam and Australia. This indicates that China's imports impact tropical countries not only through timber (logs and sawnwood), but also across all categories of forest products.

China's forest products imported from tropical countries accounted for less than half of its total forest products imports from the world. The import mix from tropical countries follows the same patterns as the imports from the world. Logs and sawnwood are the top two product categories among wood products imported from tropical countries, and imports of pulp and paper are dominated by wood pulp. Papua New Guinea (PNG) and Solomon Islands are the top two suppliers of logs from tropical countries, and Thailand dominated supply of sawnwood from tropical countries to China, followed by growing importance of Gabon, Philippines and Brazil, based on import data in 2022 from China Customs.

Although tropical countries provided less than half of China's total forest product imports (e.g. 33% in 1998 and 43% in 2022), China's demand can be crucial for timber supplying countries. For example, PNG is the largest tropical timber supplier to China. In 2019, 86% of PNG's timber exports went to China (Global Witness 2020), the bulk of which consisted of logs harvested from natural forest areas, with minimal plantation production and a limited number of processing facilities (Forest Trends 2021). The PNG forestry sector faces significant governance and corruption challenges (Act Now 2023). Nongovernmental Organizations (NGOs) also reported sector-wide illegal activities (e.g. Global Witness 2018, Act Now 2023). Given the scale of the timber trade between PNG and China, the associated risks, and the vital role forests play in the livelihoods of PNG's people, it is essential to ensure that these resources are managed sustainably and harvested in accordance with the law. China can play a pivotal role in supporting this goal.

## LITERATURE REVIEW

Many researchers have studied the linkage between deforestation and forest products trade (e.g. Kastner *et al.* 2011,

Nonato *et al.* 2025, Robalino and Herrera 2010, Tian *et al.* 2017). Trade influences forest resources through multiple pathways (Robalino and Herrera 2010). Trade liberalization, defined as the reduction or elimination of tariffs, quotas, and other trade barriers, alters relative prices and thereby affects incentives for resource exploitation (Krueger 1998). Beyond this, trade can also affect broader economic factors like labor markets and incomes, which in turn may influence demand for forest products (Fischer 2010).

Additionally, trade volume can interact with and shape policies for the institutions that manage these resources (Fischer 2010). A review of literature examining the relationship between trade liberalization and deforestation reveals varied perspectives. For instance, Robalino and Herrera (2010) found contrasting views regarding the impact of timber extraction on deforestation. In some cases, increased timber extraction has led to higher deforestation rates, as it opens previously unexploited forests, facilitating activities such as agricultural expansion (Barbier *et al.* 1994).

However, others suggest that the impact of trade on deforestation depends on conditions such as governance quality, land tenure security, and the strength of environmental regulations, and that other deforestation drivers are also relevant (Robalino and Herrera 2010). Additionally, Feridun *et al.* (2006) argued that international trade in wood products could increase the use of plantation timber in wood processing, potentially reducing reliance on natural forests for timber. Nonato *et al.* (2025) showed how forest degradation and illegal timber harvesting in the Brazilian Amazon are connected to timber supply networks, highlighting trade-linked drivers of forest loss.

By linking forest stock change – the net change in forest biomass or carbon stock accounting for both forest growth and removal – with wood products trade for 1997–2007, Kastner *et al.* (2011) conducted a quantitative global assessment of the connections between forest change and international trade in wood products, finding that national-level forest change patterns are influenced by such trade. In countries with high demand for wood products due to large populations, trade can offer positive effects by providing wood imports, thereby alleviating pressure on domestic forests without compromising consumption levels. However, the gains in one region are often accompanied by costs and risks in others. Similarly, Tian *et al.* (2017) examined how the trade in forest products contributes to shifts in global forest landscapes. They suggested that trade liberalization could enable a more efficient global allocation of timber resources, improve resource utilization, and reduce worldwide wood consumption, ultimately supporting forest conservation.

The agricultural commodities most associated with global deforestation are beef, cocoa, coffee, natural rubber, oil palm, and soybeans, although there is a large variation among countries and regions along with the range of forestry products (Pendrell *et al.* 2019, 2022). Furthermore, a large and slightly increasing share of deforestation was attributed to international demand for timber and agriculture commodities, with China one of the largest consumers (Pendrell *et al.* 2019).

China's substantial and expanding trade in forest products is often highlighted as one of the significant drivers of deforestation and forest degradation abroad. While domestic forest protection has increased, maintaining high wood demand requires greater timber imports, which can adversely affect forest biodiversity in other nations (Mayer *et al.* 2005). Hoang and Kanemoto (2021), employing remote sensing data, examined shifts in global deforestation footprints between 2001 and 2015. They observed that China, like India and many developed countries, had achieved net forest gains domestically yet has also expanded the deforestation linked to its imports, with tropical forests being most at risk. Fuller *et al.* (2019) analyzed 15 years of data (2001–2015) for China's timber imports and for tree cover loss in four Congo Basin countries – Cameroon, Gabon, the Central African Republic, and the Republic of the Congo – finding a positive correlation between wood exports to China and tree cover loss in the region.

China also impacts deforestation in Brazil's Amazon in multiple ways, with the rapid growth in soybean and beef exports to China being major contributors to deforestation in this area (Fearnside *et al.* 2012, Fearnside and Figueiredo 2017). Additionally, Fearnside *et al.* (2012) argued that China's land acquisitions and timber imports have had negative environmental consequences in the Amazon. More information is needed on the role of China's imports of forest products in driving tropical forest loss, as well as on the influence of China's domestic forest protection policies in this context.

Inspired by the literature, this research aims to answer the following question: Is the growth of China's forest product imports one of the significant factors for the disappearance of tropical forests? To answer this question, a regression model was developed to examine associations between China's imports of forest products and tropical forest loss.

## METHOD AND DATA

### Empirical model

Deforestation refers to removal of trees and land conversion from forests into other uses such as agriculture (Hosonuma *et al.* 2012). FAO (2022) defined deforestation as “the conversion of forest to other land use independently of whether human-induced or not”, i.e. it is essentially referring to land use change. Forest degradation involves the thinning of the canopy and the loss of carbon in remaining forests, where the damage occurs without a change in land use (Hosonuma *et al.* 2012). To capture both deforestation and degradation, as potential impacts of China's imports, while reducing concerns over validity of deforestation data caused by different definitions of deforestation among countries, in this study forest cover loss (or forest loss in short) is used. This approximation has been used in remote-sensing-based methodologies (FAO 2022).

Many factors cause forest cover loss in tropical countries, including conversion of forest land to agricultural and

industrial use, poor enforcement of forest law and lack of governance, and demand for forest products. The panel data regression model was used to examine the impact of forest product exports to China on forest cover loss in supplying tropical countries, while controlling for other relevant factors. After taking the logarithm, the estimation model was as follows:

$$\text{Infloss}_{it} = \beta_0 + \beta_1 \text{Infpxp}_{it} + \beta_2 \text{gov}_{it} + \beta_3 \text{lnrpop}_{it} + \beta_4 \text{lnaprod}_{it} + \beta_5 \text{gdppc}_{it} + \beta_6 \text{lngdppc}_{it}^2 + \varepsilon \quad (1)$$

Where:

$\text{floss}_{it}$  denotes forest cover loss for country  $i$  in year  $t$ ;

$\text{fpexp}_{it}$  is forest product exports to China from country  $i$  in year  $t$

$\text{gov}_{it}$  refers to forest governance level of country  $i$  in year  $t$

$\text{rpop}_{it}$  is rural population of country  $i$  in year  $t$

$\text{aprod}_{it}$  is production of key agricultural commodities of country  $i$  in year  $t$

$\text{gdppc}_{it}$  is GDP per capita of country  $i$  in year  $t$

$\beta_0$  is an intercept term

$\beta_1 - \beta_6$  are parameters to be estimated, representing coefficient of impact of respective independent variables on a tropical country's forest loss

$\varepsilon$  is a random error term

The list of the tropical countries included in this research is based on the list used by the International Tropical Timber Organization (ITTO) (ITTO 2024), grouping into the following geographical regions: Africa, Asia-Pacific (Oceania, South Asia, and Southeast Asia), and Latin America (including countries in South America in addition to Mexico, Central America and the Caribbean). To identify any regional differences, regression model (1) was run four times – for all tropical countries; including those in Africa; Latin America; and the Asia-Pacific.

### Variable descriptions and data

Table 1 presents a summary description of all variables. Tree cover loss is commonly used as a proxy to forest loss (the variable *floss* in model (1), which is remote sensing data available starting from 2001 from Global Forest Watch (Global Forest Watch 2024). Tree cover is defined as woody vegetation with a height of at least 5 meters and a canopy density of at least 30 percent, measured at a 30-meter resolution (Hansen *et al.* 2013). Tree cover loss refers to the total removal of tree cover, whether due to human activities or natural events. Both FAOSTAT (FAO 2024) and the World Bank World Development Indicators (WDI) (World Bank 2024) report forest area data. Forest loss can be calculated as the area of forests reduced annually for each country. However, there has been inconsistent reporting of such data for some countries. Therefore, in this analysis, the tree cover loss data from Global Forest Watch was used because it is measured consistently at a global scale annually, and it utilizes remote sensing data which is considered more accurate.

Data on forest product exports (variable *fpexp*) from tropical countries to China are represented by China's reported

TABLE 1 Summary description of all variables

Variable	Definition	Expected relationship with the dependent variable	Source of data
floss	Tree cover loss of a tropical country	Dependent variable	Global Forest Watch
fpexp	Forest products exports from tropical country to China	Positive. Increases in exports may drive more harvest and forest loss if not sustainably managed	UN Comtrade
chshare	China's share in tropical country's forest product exports	Positive. Increases in exports may drive more harvest and forest loss if not sustainably managed	UN Comtrade
gov	Exporting country's governance level, using rule of Law as a proxy	Negative. Countries with a high level of rule of law have done a better job than countries with a low level of rule of law in restricting illegal logging and non-compliant harvest, so to lead less deforestation	Kaufmann and Kraay, 2023
rpop	Exporting country's rural population	Positive. Rural population growth may increase pressure on forests, particularly for forest-dependent populations.	World Bank's World Development Indicators Database
aproduct	Exporting country's production of key forest-risk commodities, including cattle and beef, Cocoa, Coffee, natural rubber, palm oil, and soybean.	Positive. Land conversion into agricultural production is considered one of the largest drivers of tropical deforestation.	FAOSTAT
area	Exporting country's total area of the crop harvest area and the area designated for cattle ranching	Positive. Land conversion into agricultural production is considered one of the largest drivers of tropical deforestation.	FAOSTAT
gdppc	Exporting country's GDP per capita	Positive for GDP per capita but negative for squared GDP per capita.	World Bank's World Development Indicators Database

imports from these countries when direct export data are unavailable. China's market share in a tropical country's forest product exports is also used as an alternative measure of exports to China. It is calculated by dividing the value of forest products exported to China by the total value of forest products exported globally from UN Comtrade database (United Nations Statistics Division, 2024). When a country's export value to China is not available from UN Comtrade, data on China's imports from that country is used.

The variable of forest governance level (the variable *gov*) was included in the model to capture the impacts of each exporting country's capacity in controlling illegal logging and associated trade on their forest products exports to China.

Illegal logging is typically defined as the harvesting, processing, transportation, and sale of forest products in violation of national or international laws (Tacconi *et al.* 2016). For each trade partner it is represented by rule of law ranking as a proxy. According to the definition of rule of law in the Worldwide Governance Indicators (WGI) database of the World Bank (Kaufmann and Kraay 2023), the Rule of Law reflects the level of trust and adherence to social rules by agents, particularly regarding the quality of contract enforcement, the protection of property rights, and the potential for crime and violence. The percentile rank represents the country's position among all countries covered by the composite indicator, with 0 indicating the lowest rank and 100 the highest. For example, in 2019 Myanmar's rule of law ranking was 12.98, while United Kingdom was 91.83.

Countries with higher levels of rule of law are better able to establish and enforce regulations that restrict illegal

logging and non-compliant harvesting, thereby reducing deforestation.

Rural population in tropics (the variable *rpop*) captures local demand and consumption for forest resources. Increases in rural population may intensify pressure on forests, especially where rural livelihoods rely heavily on forest products for subsistence, income, or energy, and where access to alternative resources remains limited. Jorgenson and Burns (2007) found that rural population changes tend to have more profound and more robust influences on deforestation rates. Rudel (2013) suggested that rural population growth is a dominant driver of deforestation in sub-Saharan Africa, as expanding populations increase demand for tropical food crops such as cassava and yams, leading to widespread forest clearing in tropical moist forests.

Forestland conversion to production of agricultural commodities and cattle ranching is considered one of the largest drivers of tropical deforestation (Ritchie 2021, WWF 2021). For this reason, agricultural production (the variable *aproduct*) is included in the model as a control variable. Production of key tropical agricultural commodities including cattle, cocoa, coffee, natural rubber, palm oil, and soybean are considered. However, data on agricultural production values are not available for these commodities from each tropical country. For aggregating purposes, the production area (the variable *area*) is used as an alternative variable of agricultural production. It is the total area of crop (cocoa, coffee, natural rubber, oil palm, and soybean) harvest and the area designated for cattle ranching, reported by FAOSTAT. The area for cattle ranching is based on the two FAOSTAT categories – "land

under permanent meadows and pasture” and “land under temporary meadows and pasture” (FAO 2024). A positive association of this variable with tropical forest loss is expected.

Both GDP per capita (the variable *gdppc*) and squared GDP per capita (the variable *gdppc2*) are included in the model to capture the effects of economic development on tropical forest loss and to test the environmental Kuznets curve (EKC) hypothesis. The EKC hypothesis suggests that environmental quality deteriorates during the early stages of economic development but improves in the later stages. In other words, the relationship between environmental degradation and per capita income follows a reverted-U shape (Dinda 2004, Sarkodie and Strezov 2019).

Deforestation and forest degradation bring about ecological damage, soil erosion and increased carbon emissions, and are a form of environmental degradation. The EKC hypothesis implies that deforestation and forest degradation may intensify during early industrialization and agricultural expansion, but slow or even reverse as economic growth enables investment in forest conservation, enforcement of logging regulations, and adoption of sustainable land-use practices. Thus, a positive coefficient for GDP per capita and a negative coefficient for squared GDP per capita are expected, according to the EKC hypothesis.

Data for socioeconomic and institutional variables, i.e. GDP per capita, governance level as represented by rule of law ranking, and rural population for each tropical country, is from the World Bank’s WDI database (World Bank 2024), which offers harmonized and comparable country-level data across time. Each tropical country’s production of agricultural commodities and production areas are from the FAOSTAT database (FAO 2024), which compiles officially reported national statistics through country reporting system.

Although these datasets differ in their underlying data-generation processes, they are complementary and consistent in spatial and temporal coverage. All variables are measured at the national level and harmonized to a common annual time frame prior to estimation. The combined use of FAOSTAT, UN Comtrade, Global Forest Watch, and WDI data is well established in empirical studies on deforestation, trade, and

economic development, supporting the comparability and robustness of the dataset used in this study.

The global economy and forest products trade were significantly affected by Covid-19 in 2020 and beyond. To avoid the impacts of the pandemic, the time period for this study is set from 2001 to 2019.

The summary statistics for the variables are presented in Tables 2 through 5.

## RESULTS

The model (1) was estimated by using fixed-effects panel data regression. Regressions for all tropical countries, African countries, Latin American countries, and Asia-Pacific countries, were conducted to identify regional differences. Panel data refers to datasets that contain observations on multiple entities (in this case, countries) over multiple time periods. This structure allows us to analyze changes over time and differences across countries. Fixed-effects regression is a method used to control unobserved variables that may influence the dependent variable and are constant over time within an entity but vary across entities. By controlling for unobserved, time-invariant factors, the model mitigates omitted variable bias that may otherwise distort the estimated effects of the independent variables. It allows for a more straightforward interpretation of how changes in independent variables impact the dependent variable over time (Angrist and Pischke 2009).

Estimation results from three different regressions are presented. In regression (1), the key variable is China’s share in a tropical country’s forest product exports (*chshare*), with a control variable representing the country’s total area of crop harvest and land designated for pasture (*area*), along with other control variables except for rural population (*rpop*). Regression (2) replaces *chshare* with the value of forest product exports from the tropical to China (*fpexp*). Regression (3) replaces the control variable *area* with the tropical country’s crop production (*aproduct*), while retaining all control variables. These variations in model specification allow us to

TABLE 2 Summary Statistics – all tropical countries

Variable description	Variable name used	Unit	Mean	SD	Min	Max
Tropical forest loss	floss	Thousand hectare	145	430	0	5 400
Forest product exports to China from tropical country	fpexp	Thousand US\$	146 310	447 168	0	5 359 562
China’s share in tropical country’s forest product exports	chshare		23%	27%	0	100%
Tropical country’s GDP per capita	gdppc	US\$	4 586	9 912	112	154 919
Tropical country’s rural population	rpop	Thousand	28 930	108 523	0	906 326
Tropical country’s agricultural harvest area	area	Thousand hectare	23 574	43 583	1	25 7397
Tropical country’s governance level	gov		35	21	0	98

TABLE 3 Summary Statistics – African countries

Variable description	Variable name used	Unit	Mean	SD	Min	Max
African country's tropical forest loss	floss	Thousand hectare	53	76	0	510
Forest product exports to China from African country	fpexp	Thousand US\$	38 751	76 585	0	40 9894
China's share in African country's forest product exports	chshare		27%	32%	0	100%
African country's GDP per capita	gdppc	US\$	2 008	3 184	112	22 943
African country's rural population	rpop	Thousand	13 379	21 165	230	99 300
African country's agricultural harvest area	area	Thousand hectare	17 949	18 686	63	88 874
African country's governance level	gov		27	20	0	84

TABLE 4 Summary Statistics – Asia-Pacific countries

Variable description	Variable name used	Unit	Mean	SD	Min	Max
Asia-Pacific country's tropical forest loss	floss	Thousand hectare	178	369	0	2 400
Forest product exports to China from Asia-Pacific country	fpexp	Thousand US\$	333 157	594 211	0	3 735 530
China's share in Asia-Pacific country's forest product exports	chshare		28%	26%	0	97%
Asia-Pacific country's GDP per capita	gdppc	US\$	7 675	18 617	301	154 919
Asia-Pacific country's rural population	rpop	Thousand	87 136	208 306	0	906 326
Asia-Pacific country's agricultural harvest area	area	Thousand hectare	23 477	51 238	1	220 135
Asia-Pacific country's governance level	gov		42	23	1	97

TABLE 5 Summary Statistics – Latin American countries

Variable description	Variable name used	Unit	Mean	SD	Min	Max
Latin American country's tropical forest loss	floss	Thousand hectare	244	665	1	5 400
Forest product exports to China from Latin American country	fpexp	Thousand US\$	151 379	553 658	0	5 359 562
China's share in Latin American country's forest product exports	chshare		13%	15%	0	71%
Latin American country's GDP per capita	gdppc	US\$	5 748	3 771	904	18 704
Latin American country's rural population	rpop	Thousand	6 269	8 059	136	32 875
Latin American country's agricultural harvest area	area	Thousand hectare	31 242	57 949	78	257 397
Latin American country's governance level	gov		40	19	9	88

assess the robustness of the findings. Across all three regressions, the key variable – the tropical country's forest product exports to China, measured as either *chshare* or *fpexp* – remains statistically significant, strengthening confidence in the results.

Table 6 shows the estimation results for all tropical countries. Forest products exports to China in both terms of absolute

value and China's share, agricultural production in terms of crop production and production area, and rural population are all statistically significant predictor variables. The positive and significant coefficients of these variables suggest that they have significant impacts on tropical tree cover loss. The significance of forest product exports value is relatively weak compared to China's share in tropical exports.

TABLE 6 Estimation results – all tropical countries

	(1) lnfloss	(2) lnfloss	(3) lnfloss
chshare	0.588*** (0.0973)		0.408*** (0.106)
lnaprod	0.181*** (0.0358)		
gov	0.00625 (0.00281)	0.00301 (0.00298)	0.00392 (0.00297)
gdppc	-0.0000149*** (0.00000303)	-0.00000788** (0.00000321)	-0.00000623* (0.00000330)
lngdppc <sup>2</sup>	0.207*** (0.0216)	0.115*** (0.0253)	0.0952*** (0.0240)
lnrpop		2.020*** (0.242)	2.028*** (0.245)
lnarea		1.372*** (0.251)	1.365*** (0.257)
lnfpexp		0.0163* (0.00980)	
_cons	-1.145*** (0.312)	-28.21*** (2.428)	-27.89*** (2.440)
N	1102	1094	1154
R <sup>2</sup>	0.237	0.247	0.256
adj. R <sup>2</sup>	0.192	0.199	0.210

Standard errors in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ 

GDP per capita and squared GDP per capita are also significant, but the sign of their respective coefficient is contradictory to the EKC hypothesis. Unexpectedly, the variable of governance level is not statistically significant.

Table 7, 8 and 9 present the regression results for Africa, Asia-Pacific, and Latin American regions. While forest products exports to China is statistically significantly correlated to the tree cover loss in Africa and Asia-Pacific, this is not the case in Latin America. Agricultural production and rural population have statistically significant positive impacts on tree cover loss in all three regions. In Latin America, the country's governance level is negatively and significantly correlated to the tree cover loss. The sign of coefficients of GDP per capita and squared GDP per capita for African countries seems consistent with EKC hypothesis, and significant when China's share in tropical country's forest products exports is used in the model.

## DISCUSSION AND CONCLUSIONS

This study examined the relationship between forest product exports to China and forest loss in tropical countries, using

TABLE 7 Estimation results – African countries

	(1) lnfloss	(2) lnfloss	(3) lnfloss
chshare	0.490** (0.144)		0.178** (0.165)
lnaprod	0.0944 (0.0630)		
gov	0.00956 (0.00521)	0.00507 (0.00560)	0.00884 (0.00567)
gdppc	0.0000911 (0.0000241)	0.0000712** (0.0000283)	0.0000838** (0.0000296)
lngdppc <sup>2</sup>	-0.295*** (0.0454)	-0.0642 (0.0743)	-0.190** (0.0750)
lnrpop		4.054*** (0.624)	4.377*** (0.644)
lnarea		0.965* (0.511)	0.999* (0.529)
lnfpexp		0.0411** (0.0169)	
_cons	-2.221*** (0.579)	-40.12*** (4.662)	-42.02*** (4.882)
N	475	468	508
R <sup>2</sup>	0.251	0.263	0.267
adj. R <sup>2</sup>	0.203	0.209	0.218

Standard errors in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.001$ 

fixed-effects panel data regression model. The results reveal a significant association between forest product exports to China and forest loss across all tropical regions, except for Latin America. These findings confirm that China as a globally important market has an indirect influence on efforts to mitigate tropical forest loss.

Forestland conversion from agricultural fields and/or pastures for cattle ranching is also significantly correlated to forest loss for all tropical countries. This supports findings of earlier studies that emphasize the significant role of land conversion in tropical forest loss (e.g. Pendrill *et al.* 2019, 2022). In Latin America, land conversion to agricultural production and pastures for cattle is a much more significant driver than forest products exports to China. Indeed, a growing number of studies have focused on and concluded the dominant role of agricultural commodities in driving deforestation (e.g. Pendrill *et al.* 2019, 2022, Ritchie 2021, WWF 2021), particularly in Latin America.

The EKC hypothesis suggests that as an economy grows, environmental degradation increases up to a certain income level (the turning point) after which continued economic growth leads to better environmental quality (Guo and Shahbaz 2024, Hussain *et al.* 2023, Wang *et al.* 2023b, 2024).

TABLE 8 Estimation results – Asia-Pacific countries

	(1) lnfloss	(2) lnfloss	(3) lnfloss
chshare	1.068*** (0.184)		0.959*** (0.192)
lnaprod	0.418*** (0.0757)		
gov	0.00907 (0.00510)	0.0115 (0.00470)	0.0112 (0.00520)
gdppc	-0.00000772** (0.00000296)	-0.00000262 (0.00000283)	-0.00000780** (0.00000298)
lngdppc <sup>2</sup>	0.122*** (0.0306)	0.0130 (0.0322)	0.121*** (0.0313)
lnrpop		1.051** (0.431)	1.365** (0.471)
lnarea		1.657*** (0.394)	1.170** (0.423)
lnfpexp		0.176*** (0.0203)	
_cons	-1.414** (0.470)	-22.87*** (3.764)	-21.85*** (4.157)
N	266	265	266
R <sup>2</sup>	0.423	0.510	0.418
adj. R <sup>2</sup>	0.381	0.472	0.373

Standard errors in parentheses  
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.001$

Empirical evidence from a global sample of 208 countries supports an inverted U-shaped relationship between GDP per capita and environmental degradation indicators such as carbon emissions, consistent with the EKC hypothesis (Wang *et al.* 2023b). Recent systematic reviews also affirm the ongoing relevance of the EKC framework, and studies incorporating governance factors show that institutional quality can affect the income level at which the turning point occurs (Hussain *et al.* 2023).

The regression results showed that GDP per capita and squared GDP per capita are mostly significant for tropical countries and across the three regions, but the sign of their coefficients is generally contrary to the EKC hypothesis, except for African countries. One possible explanation is that many tropical countries are still in early development stages, with income levels far below the EKC turning point, so economic growth continues to increase environmental pressure. In contrast, some African countries in the sample may be closer to the turning point, or they may face less intense agricultural expansion compared to Latin America or Asia-Pacific, meaning economic growth can coincide with slower forest loss. These patterns suggest that the relationship between economic growth and forest loss is context-dependent, with regional

TABLE 9 Estimation results – Latin American countries

	(1) lnfloss	(2) lnfloss	(3) lnfloss
chshare	0.0743 (0.231)		0.141 (0.229)
lnaprod	0.234*** (0.0474)		
gov	-0.00593** (0.00386)	-0.00783** (0.00376)	-0.00792** (0.00362)
gdppc	-0.0000630*** (0.0000186)	-0.0000283* (0.0000169)	-0.0000297* (0.0000170)
lngdppc <sup>2</sup>	0.232*** (0.0515)	0.184*** (0.0513)	0.208*** (0.0507)
lnrpop		1.445*** (0.304)	1.279*** (0.277)
lnarea		1.003** (0.340)	0.876** (0.332)
lnfp		0.0219 (0.0126)	
_cons	-0.922 (0.832)	-19.24*** (4.058)	-16.93*** (3.704)
N	361	361	380
R <sup>2</sup>	0.213	0.216	0.215
adj. R <sup>2</sup>	0.160	0.158	0.159

Standard errors in parentheses  
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.001$

differences driven by both development stage and structural characteristics.

Forest loss is significantly and negatively correlated with governance in Latin American countries, but not in tropical countries elsewhere. The low variation in forest governance levels among tropical countries may explain the lack of a significant impact of this variable on forest loss. In addition, while rule of law is a useful proxy for governance, it may not capture all relevant dimensions of forest governance. Other factors like enforcement effectiveness, local governance structures, and community involvement might be equally or more important in influencing forest loss. Furthermore, the relationship between governance and forest loss is complex. While poor governance can lead to illegal logging and deforestation, there might be other mitigating factors in certain regions that overshadow the effect of governance alone. This suggest that it is crucial to continue investigating other governance aspects, such as transparency, accountability, and community participation, that may more directly correlate with forest outcomes.

Tropical forest loss across all regions is positively correlated with rural population growth. This may reflect the continued importance of slash-and-burn or shifting cultivation agriculture

(Tinker and Struwe 1996) – practices widely used by rural, forest-dependent populations in developing countries to secure food and income. Recent research indicates that these practices remain a major driver of forest loss and environmental degradation in densely populated tropical areas (Bezerra et al. 2024, Mukul et al. 2022, Bieluczyk et al. 2025). In contrast, some researchers found that forest loss is positively correlated with urban population growth, rather than with rural population growth (DeFries et al. 2010). This finding may also be explained as urbanization is likely to be associated with greater demand for agricultural commodities, thus expanding industrial-scale agricultural production.

The analysis results confirmed the impacts of expansion of agricultural production on forest loss. While policies to reduce tropical forest loss among rural populations will address in part the causes of forest loss, efforts should also focus on reducing forest loss from industrial-scaled agriculture and timber production.

To conclude, forest product exports to China are significantly associated with tropical forest loss in most regions, highlighting China's indirect but important role in shaping deforestation outcomes in producer countries. Agricultural expansion, particularly land conversion for crops and cattle ranching, remains the dominant driver of forest loss, especially in Latin America, where its impact far exceeds that of timber exports. The relationship between economic growth, governance, and forest loss is highly context-dependent. Reducing tropical deforestation will require policies that are beyond timber-focused interventions and address the growing influence of forest-risk agricultural commodities and global demand.

## LIMITATIONS AND FUTURE RESEARCH

While the timber trade has historically been a significant driver of deforestation in tropical forest regions, the impacts of agriculture commodities on deforestation are now more significant in some regions. These commodities are often linked to illegal logging, road and infrastructure built to facilitate agriculture production. Apart from being a large forest products importer, China has also emerged as a major importer of soybeans, beef, and other commodities linked to deforestation (World Economic Forum 2022). Therefore, China's impacts on tropical forests are expected to be greater than what the analysis showed in this study. Research on quantifying China's tropical deforestation impacts as a major importer of forest-risk agricultural commodities would help for more informed policy development and implementation.

This study draws on secondary data from internationally recognized sources that are widely used in forestry and land-use research; however, several limitations should be noted. Agricultural and trade data from FAOSTAT and UN Comtrade rely on national reporting systems and may be affected by reporting gaps or inconsistencies across countries and years. Forest loss estimates from Global Forest Watch are derived from satellite-based observations and primarily capture tree

cover loss, which may not fully reflect forest degradation, selective logging, or changes in forest condition. Governance indicators from the World Bank's World Development Indicators provide broad, composite measures and may not capture all relevant aspects of forest governance, such as enforcement capacity or sub-national institutional variation. These limitations suggest that the results should be interpreted as indicative of broad regional patterns rather than precise estimates.

Overall, this study contributes to the growing body of research on China's role in tropical deforestation by applying a panel regression model to quantify the links between China's forest product imports and forest loss, highlighting the role of China's demand while providing insights relevant for policies aimed at mitigating trade-driven deforestation. To gain more detailed insights, future research could focus on country-specific case studies examining how exports to China impact deforestation in each country, as the key drivers of deforestation vary widely among countries and regions.

## ACKNOWLEDGMENTS

The valuable suggestions made by anonymous referees are gratefully acknowledged. Special thanks go to Y. Wang, for his assistance in data compiling and programing. We are also grateful to the support and guidance provided by G. Norton and B. Smith in conducting this research.

## GENERATIVE AI STATEMENT

During the preparation of this manuscript, the authors utilized ChatGPT (OpenAI) for refining responses to reviewers' comments and for language editing to improve clarity, coherence, and readability of the final manuscript text.

## LITERATURE CITED

- ACT NOW. 2023. *Timber legality risk assessment*. <https://actnowpng.org>. Accessed on May 14, 2024.
- ANGRIST, J.D., and PISCHKE, J. 2009. *Mostly harmless econometrics*. Princeton, NJ. Princeton University Press. 373 pp.
- BARBIER, E.B., BURGESS, J.C., BISHOP, J., and AYLWARD, B. 1994. *The economics of the tropical timber trade*: Routledge Revivals, London. 179 pp. <https://doi.org/10.4324/9780429352249>
- BEZERRA, J.S., ARROYO-RODRÍGUEZ, V., ARASAGISBERT, R., and MEAVE, J.A. 2024. Multiscale effects of slash-and-burn agriculture across the tropics: implications for the sustainability of an ancestral agroecosystem. *Sustainability* **16**(22): 9994.
- BIELUCZYK, W., DUARTE, M.P., MARTINS, G.L., MANDRO, J.A., DE CAMARGO, P.B., NORONHA, N.C., DE CÁSSIA PICCOLO, M., and TSAI, S.M. 2025. Slash-and-burn agriculture disrupts the carbon storage

- potential and ecosystem multifunctionality of Amazon's secondary forests. *Agriculture, Ecosystems & Environment* **381**: 109413.
- CASHORE, B., LEIPOLD, S., CERUTTI, P., BUENO, G., CARODENUTO, S., CHEN, X., DE JONG, W., DENVIR, A., HANSEN, C., HUMPHREYS, D., MCGINLEY, K., NATHAN, I., OVERDEVEST, C., RODRIGUES, R., SOTIROV, M., STONE, M., TEGENE, Y., VISSEREN-HAMAKERS, I., WINKEL, G., YEMELIN, V., and ZEITLIN, J. 2016. Global governance approaches to addressing illegal logging: Uptake and lessons learned. In: KLEINSCHMIT, D., MANSOURIAN, S., WILDBURGER, C., and PURRET, A. (ed.) *Illegal Logging and Related Timber Trade – Dimensions, Drivers, Impacts and Responses: A Global Scientific Rapid Response Assessment Report*. IUFRO World Series (35). Vienna: International Union of Forest Research Organisations, pp. 119–131. <https://www.iufro.org/science/gfep/illegal-timber-trade-rapid-response/report/>, accessed on February 6, 2026.
- DEFRIES, R.S., RUDEL, T., URIARTE, M., and HANSEN, M. 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience* **3**(3): 178–181.
- DINDA, S. 2004. Environmental Kuznets curve hypothesis: a survey. *Ecological Economics* **49**(4): 431–455.
- FAO. 2022. *The State of the World's Forests 2022. Forest pathways for green recovery and building inclusive, resilient and sustainable economies*. FAO. Rome. 166 pp. <https://doi.org/10.4060/cb9360en>
- FAO. 2024. *FAOSTAT*. FAO. <https://www.fao.org/faostat/en/#data/>, accessed on May 20, 2024.
- FEARNSIDE, P.M., FIGUEIREDO, A.M.R., and BONJOUR, S.C.M. 2012. Amazonian forest loss and the long reach of China's influence. *Environment, Development and Sustainability* **15** (2): 325–338. <https://doi.org/10.1007/s10668-012-9412-2>
- FEARNSIDE, P.M., and FIGUEIREDO, A.M.R. 2017. China's influence on deforestation in Brazilian Amazonia: A growing force in the state of Mato Grosso. In: RAY, R., GALLAGHER, K., LOPEZ, A., SANBORN, C., (ed.) *China and sustainable development in Latin America: The social and environmental dimension*, Anthem Press. pp. 229–266. <https://www.cambridge.org/core/books/china-and-sustainable-development-in-latin-america/chinas-influence-on-deforestation-in-brazilian-amazonia-a-growing-force-in-the-state-of-mato-grosso/3FC1ED099E0FF6318950EA4603478B1E>, accessed on June 15, 2024.
- FERIDUN, M., AYADI, F.S., and BALOUGA, J. 2006. Impact of trade liberalization on the environment in developing countries: the case of Nigeria. *Journal of Developing Societies* **22**(1): 39–56. <https://doi.org/10.1177/0169796X06062965>
- FISCHER, C. 2010. Does Trade Help or Hinder the Conservation of Natural Resources? *Review of Environmental Economics and Policy* **4**(1): 103–121. <https://doi.org/10.1093/reep/rep023>
- FOREST TRENDS. 2021. *Papua New Guinea timber legality risk dashboard*. Forest Trends. <https://www.forest-trends.org/publications/papua-new-guinea-timber-legality-risk-dashboard/>, accessed on November 18, 2024.
- FULLER, T.L., NARINS, T.P., NACKONEY, J., BONEBRAKE, T.C., SESINK CLEE, P., MORGAM, K., TROCHEZ, A., BOCUMA MENE, D., BONGWELEH, E., NIABO, K.Y., ANTHONY, N.M., GONDER, M.K., KAHN, M., ALLEN, W.R., and SMITH, T.B. 2019. Assessing the impact of China's timber industry on Congo Basin land use change. *Area* **51**(2): 340–349. <https://doi.org/10.1111/area.12469>
- GLOBAL FOREST WATCH. 2024. *Global Forest Watch dashboards*. World Resources Institute. <https://www.globalforestwatch.org/dashboards/global/?category=forest-change>, accessed on May 15, 2024.
- GLOBAL WITNESS. 2018. *A major liability: Illegal logging in Papua New Guinea threatens China's timber sector and global reputation*. Global Witness. <https://www.globalwitness.org/en/campaigns/forests/major-liability-illegal-logging-papua-new-guinea-threatens-chinas-timber-sector-and-global-reputation/>, accessed on August 20, 2024.
- GLOBAL WITNESS. 2020. *Bending the truth*. Global Witness. <https://globalwitness.org/en/campaigns/forests/bending-the-truth/>, accessed on February 6, 2026.
- GUO, X., and SHAHBAZ, M. 2024. The existence of environmental Kuznets curve: Critical look and future implications for environmental management. *Journal of Environmental Management* **351**: 119648.
- HANSEN, M.C., POTAPOV, P.V., MOORE, R., HANCHER, M., TURUBANOVA, S.A., TYUJAVINA, A., THAU, D., STEHMAN, S.V., GOETZ, S.J., LOVELAND, T.R., KOMMAREDDY, A., EGOROV, A., CHINI, L., JUSTICE, C.O., and TOWNSHEND, J.R. 2013. High-resolution global maps of 21st-century forest cover change. *Science* **342**(6160): 850–853. DOI: 10.1126/science.1244693.
- HOANG, N.T., and KANEMOTO, K. 2021. Mapping the deforestation footprint of nations reveals growing threat to tropical forests. *Nature Ecology & Evolution* **5**(6): 845–853.
- HOSONUMA, N., HEROLD, M., SY, V., FRIES, R., BROCKHAUSE, M., VERCHOT, L., ANGELSEN, A., and ROMIJIN, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters* **7**(4): 044009. DOI: 10.1088/1748-9326/7/4/044009
- HUSSAIN, I., AHMAD, E., and MAJEED, M.T. 2023. Curvature and turning point of the environmental Kuznets curve in a global economy: The role of governance. *Environmental Science and Pollution Research International* **30**(18): 5300753019. <https://doi.org/10.1007/s11356-023-25835-7>
- ITTO (International Tropical Timber Organization). 2024. *Group definitions – all tropical countries*. ITTO. [https://www.itto.int/biennial\\_review/group\\_definitions/](https://www.itto.int/biennial_review/group_definitions/), accessed on March 5, 2024.

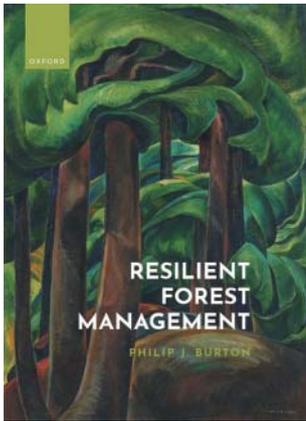
- JORGENSEN, A.K., and BURNS, T.J. 2007. Effects of rural and urban population dynamics and national development on deforestation in less-developed countries, 1990–2000. *Sociological Inquiry* **77**(3): 460–482.
- KASTNER, T., ERB, K.H., and NONHEBEL, S. 2011. International wood trade and forest change: A global analysis. *Global Environmental Change* **21**(3): 947–956. <https://doi.org/10.1016/j.gloenvcha.2011.05.003>
- KAUFMANN, D., and KRAAY, A. 2023. *Worldwide governance indicators: 2023 update*. World Bank. <https://www.govindicators.org>
- KRUEGER, A.O. 1998. Why trade liberalization is good for growth. *The Economic Journal* **108**(450): 1513–1522. <https://doi.org/10.1111/1468-0297.00354>
- LAWSON, S. 2010. Illegal logging and related trade: Indicators of the global response. Chatham House. London. Found at: [www.chathamhouse.org.uk](http://www.chathamhouse.org.uk)
- MAYER, A.L., KAUPPI, P.E., ANGELSTAM, P.K., ZHANG, Y., and TIKKA, P.M. 2005. Importing timber, exporting ecological impact. *Science* **308**(5720): 359–360. DOI: 10.1126/science.1109476
- MUKUL, S.A., HERBOHN, J., FERRAREN, A., and CONGDON, R. 2022. Limited role of shifting cultivation in soil carbon and nutrients recovery in regenerating tropical secondary forests. *Frontiers in Environmental Science* **10**: 1076506.
- PENDRILL, F., PERSSON, U.M., GODAR, J., and KASTNER, T. 2019. Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition. *Environmental Research Letters* **14**(5): 055003. <https://doi.org/10.1088/1748-9326/ab0d41>
- PENDRILL, F., GARDNER, T.A., MEYFROIDT, P., PERSSON, U.M., ADAMS, J., AZEVEDO, T., BASTOS LIMA, M.G., BAUMANN, M., CURTIS, P.G., DE SY, V., GARRETT, R., GODAR, J., GOLDMAN, E.D., HANSEN, M.C., HEILMAYR, R., HEROLD, M., KUEMMERLE, T., LATHUILLIERE, M.J., RIBEIRO, V., TYUKAVINA, A., WEISSE, M.J., and WEST, C. 2022. Disentangling the numbers behind agriculture-driven tropical deforestation. *Science* **377**(6611): abm9267. DOI: 10.1126/science.abm9267.
- POLO VILLANUEVA, F.D., TEGEGNE, Y.T., WINKEL, G., CERUTTI, P.O., RAMCILOVIC-SUOMINEN, S., MCDERMOTT, C.L., ZEITLIN, J., SOTIROV, M., CASHORE, B., WARDELL, D.A., HAYWOOD, A., and GIESSEN, L. 2023. Effects of EU illegal logging policy on timber-supplying countries: A systematic review. *Journal of Environmental Management* **327**: 116874.
- RITCHIE, H. 2021. *Cutting down forests: what are the drivers of deforestation?* Our World in Data. <https://ourworldindata.org/what-are-drivers-deforestation>, accessed on August 13, 2024.
- ROBALINO, J., and HERRERA, L.D. 2010. *Trade and deforestation: A literature review. Technical report. WTO Staff Working Paper, WTO*. DOI: 10.30875/a6679776-en
- RUDEL, T.K. 2013. *The national determinants of deforestation in sub-Saharan Africa*. *Philosophical Transactions of the Royal Society B: Biological Sciences* **368**(1625): 20120405. <https://doi.org/10.1098/rstb.2012.0405>.
- SARKODIE, S.A., and STREZOV, V. 2019. A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. *Science of the Total Environment* **649**: 128–145.
- SUN, X., WANG, L., and GU, Z. 2004. A brief overview of China's timber market system. *International Forestry Review* **6**(3–4): 221–226.
- TACCONI, L., CERUTTI, P.O., LEIPOLD, S., RODRIGUES, R.J., SAVARESI, A., TO, P.X., and WENG, X. 2016. *Defining illegal forest activities and illegal logging*. International Union of Forest Research Organizations (IUFRO).
- TIAN, M., LI, L., WAN, L., LIU, J., and de JONG, W. 2017. Forest product trade, wood consumption, and forest conservation – the case of 61 countries. *Journal of Sustainable Forestry* **36**(7): 717–728.
- TINKER, P.B., INGRAM, J.S., and STRUWE, S. 1996. Effects of slash-and-burn agriculture and deforestation on climate change. *Agriculture, Ecosystems & Environment* **58**(1): 13–22.
- UNITED NATIONS STATISTICS DIVISION. 2024. *UN Comtrade database*. <https://uncomtradeplus.un.org>, accessed on April 12, 2024.
- WANG, Y., SUN, X., and ZHU, C. 2023a. China's wood-based forest product imports and exports: trends and implications. *International Forestry Review* **25**(4): 503–516.
- WANG, Q., WANG, X., LI, R., and JIANG, X. 2024. Reinvestigating the environmental Kuznets curve of carbon emissions and ecological footprint in 147 countries: A matter of trade protectionism. *Humanities and Social Sciences Communications* **11**(1): 1–17. <https://doi.org/10.1057/s41599024026399>
- WANG, Q., ZHANG, F., and LI, R. 2023b. Revisiting the environmental Kuznets curve hypothesis in 208 countries: The roles of trade openness, human capital, renewable energy and natural resource rent. *Environmental Research* **216**: 114637. <https://doi.org/10.1016/j.envres.2022.114637>
- WORLD BANK. 2024. *World development indicators*. <https://databank.worldbank.org/source/world-development-indicators>, accessed on March 6, 2024.
- WORLD ECONOMIC FORUM. 2022. *China's role in promoting global forest governance and combating deforestation*. Insight Report. World Economic Forum. [https://www3.weforum.org/docs/WEF\\_China\\_Role\\_Promoting\\_Global\\_Forest\\_Governance\\_and\\_Combating\\_Deforestation\\_2022.pdf](https://www3.weforum.org/docs/WEF_China_Role_Promoting_Global_Forest_Governance_and_Combating_Deforestation_2022.pdf), accessed on March 6, 2024.
- WORLD WILDLIFE FUND (WWF). 2021. *Deforestation: A threat to people and nature*. WWF. <https://www.worldwildlife.org/stories/deforestation-fronts>, accessed on June 25, 2024.

# Book review

## Resilient Forest Management

Philip J. Burton

Oxford University Press, New York. 2025. Pp 1-376



Resilience is a valued quality of forests. Forestry has always been concerned with ensuring the ability of forests to adapt to changing needs and environments. Recent decades have seen rapid increases in the external shocks and stresses that forests experience and it is probable that the rate and intensity of external pressures will increase in the future. Managing for resilience will be an increasing challenge for

all forest stewards in the future. Burton has taken on the immensely ambitious challenge of presenting in a single volume an overview of how this resilience challenge is being tackled in the world's forests. The result is an encyclopedic work that draws upon a very wide range of scholarship and will be a valuable resource for scholars, students, policy makers and forestry practitioners. All those who are concerned with the future of forests should have this book close at hand at all times.

There has been a dramatic increase in studies of forest resilience in the past few years and Burton has provided us with a competent, well written and comprehensive review. The book synthesizes many hundreds of publications and draws heavily on the authors personal experiences of dealing with the problems of forests exposed to emerging threats. The author is based at the University of Northern British Columbia. British Columbia has been heavily dependent on forests throughout recent history but in recent decades these forests have been subject to unprecedented stresses. In recent decades alone there have been massive pest and disease attacks, fires on a massive scale, radical changes in civil society expectations for their forests and the forests have also been assailed by the imposition of tariffs on imports into their most important market. The author of this book has therefore conducted his global survey whilst studying in a location where the problems he is addressing have been as severe as anywhere in the world.

The book draws upon several recent ground-breaking syntheses by scholars throughout the world. Major reviews by the International Union of Forest Research Organizations, The United Nations Environment Program, The International Union for Conservation of Nature, the World Conservation Monitoring Center and others. Although written from a base in British Columbia the book draws upon lessons from almost all the forested biomes of the planet and all categories of

forests. The book gives a lot of attention to forests managed for industrial timber and especially those located in the boreal zone but the author did much of his research whilst on a sabbatical in New Zealand and draws upon Australasian experiences. Although industrial timber forests get a lot of attention the book includes examples from private forests, community forestry, conservation forests and trees outside forests. Given the scope of the work it is inevitable that some of the accounts of approaches and locations is a little superficial but as an entry point for anyone seeking to engage with the topic of resilience it would be hard to imagine a better synthesis. The book provides thoughtful discussions of what resilience is, what it looks like and how a broad range of actors have sought to achieve it. Examples range from Reduced Impact Logging on the Congo Basin, Community forestry in Brazil, natural forest protection in the Rocky Mountains and biodiversity management in industrial timber estates in Australia – and many others.

New challenges to resilience are emerging, in many countries the institutions charged with forest husbandry are losing their long-term influence and sometimes their political and financial support. The wisdom that resides within long-established “national forest services” may be declining as more studies are outsourced and more decisions are fought over by activists with little subject matter competence. The media, and the political elites that they inform, seek simple solutions to problems of forest resilience but the reality is that forests exist as highly complex social-ecological systems which are constantly changing. Many nations have failed to maintain forestry institutions that are fit for purpose. This book will fill at least some of the gaps in capacity.

It is ironic that the jurisdiction from which this book has emerged is itself facing challenges to the resilience of its forests. The impacts of pests and diseases and fires are unprecedented, the industry is facing emerging challenges in its key markets. The government is committed to restoring stewardship of the majority of its forests to their traditional owners whose rights were usurped by colonial settlers. This perfect storm of pressures on the forests and on the people who depend upon them provides a fundamental challenge. But, as Burton argues in this book, such challenges can also provide opportunities to make the fundamental changes that the future of forests and forestry will require.

The author has wisely refrained from the temptation to provide a check sheet of those management interventions that will provide for resilience – forest systems are too complex and their contexts too variable to make simple recipes for resilience useful.

However, a number of basic principles do emerge and do have wide application. The first is diversity, both of the components of forest systems, the species of trees that make up the forests, the markets that the forests supply and the people who enjoy the benefits of the forests. In general, maintaining the diversity of all components of the forest system will tend to enable greater resilience.

Adaptive management also increases the likelihood of achieving resilience. Adaptive management is provided by forestry institutions that are competent to observe, learn and adapt to changes. The ability to adapt is a function of the institutions that manage forests and the people who staff them. Well trained, highly skilled and experienced foresters are essential to enable management that can make forest management resilient.

The institutions that govern forests must themselves be resilient. The foresters who staff these institutions must be sensitive to the wide range of values that those forests will be required to provide. Forestry institutions must be able to negotiate amongst the beneficiaries of forests to broker deals and ensure that the interests of all concerned parties are sustained. Modern forestry has to manage for multiple values that vary from time to time and from place to place.

Forestry institutions must understand the values not only of those who live in and around the forests and depend upon them directly. Legitimate stakeholders may live in distant cities, may be impacted by impacts driven by forest changes in complex ways. An obvious example is achieving resilience to changes in carbon levels in the atmosphere and soils. Forest impact on climate in multiple ways and much forest management today is aimed at achieving better climatic outcomes.

Globalization is a further challenge. Global markets require resilience management but globalization is having ecological impacts. Pests and diseases are moving easily around the world and forests in many regions are now afflicted by pathogens from distant locations and to which they have little resistance. Managing for invasive species and pathogens will require new skills and technologies amongst forest professionals.

Burton's book covers the complete range of pressures to which forests will be exposed. It tells fascinating stories and will provide an excellent starting point for finding pathways to achieve "**resilient forest management**". People everywhere who make decisions on forest management will benefit from consulting this work. Those who have to make the decisions to ensure the resilience of the forests of the pacific northwest will be especially well served. Foresters everywhere will find much to help them confront the challenges of achieving resilience for the diverse forest systems that exist throughout the world.

**Professor Jeffrey Sayer**

*Department of Forest and conservation Sciences, Faculty of Forests and Environmental Stewardship, The University of British Columbia, Vancouver, Canada*