



Trees outside forests (TOF): A nature-based solution and investment for climate resilience

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ABSTRACT: *Trees Outside Forests (TOF) represents a transformative Nature-based Solution (NbS) with the potential to address climate change while delivering diverse ecological and socio-economic benefits. These systems provide critical ecosystem services, including air and water purification, biodiversity conservation, carbon sequestration, and climate regulation. With 31.15 million hectares of TOF coverage, as highlighted in ISFR 2023, India exemplifies the vast potential of these systems to enhance climate resilience. TOF systems are projected to sequester 3.4 gigatons of CO₂ by 2040, making significant contributions to global climate targets, such as limiting warming to 1.5°C or 2°C, as outlined in the IPCC AR6 report. On a global scale, TOF could remove an additional 1–2 gigatons of CO₂ annually, supporting net-zero goals by mid-century. However, barriers such as insufficient planting material quality, inadequate policy frameworks, and limited financial incentives hinder the expansion and adoption of TOF systems. Addressing these challenges requires innovative solutions, including Payments for Ecosystem Services (PES), Minimum Support Prices (MSP) for tree-based products, and certification systems to enhance market access for sustainably produced timber. Strengthening TOF as a core NbS can simultaneously combat climate change, restore degraded ecosystems, improve rural livelihoods, and support national commitments under the Bonn Challenge, Nationally Determined Contributions (NDC), and Sustainable Development Goals (SDGs). This paper positions TOF as a pivotal investment for climate resilience, offering a scalable and impactful strategy for achieving a sustainable and equitable future while addressing the pressing challenges of our time.*

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1. INTRODUCTION

Globally, ecosystems, animals, and people are all at serious risk from accelerated climate change. The unprecedented accumulation of greenhouse gases has resulted in warming the Earth and its atmosphere at rates not seen in the geological record (UNEP, 2020). Since the industrial revolution, atmospheric CO₂ levels have risen by around 50 per cent and reached 422.5 ppm in 2024, driving a global temperature increase of approximately 1°C above pre-industrial levels (IPCC, 2023; IEA, 2025). This warming has triggered significant and often unanticipated impacts on biodiversity, including shifts in species' genetic

makeup, survival strategies, behaviours, and population dynamics. Alarmingly, at least 10,967 species on the IUCN Red List of Threatened Species are directly affected by climate change, increasing their risk of extinction. A stark example is the Bramble Cay melomys (*Melomys rubicola*), the first recorded mammal extinction caused by climate change, as rising sea levels eradicated its habitat on the Great Barrier Reef's Bramble Cay. Beyond its direct effects, climate change is amplifying the frequency and intensity of extreme weather events, including prolonged droughts, hurricanes, and sea-level rise, which disrupt ecosystems and human communities alike. Addressing these challenges necessitates an integrated strategy that prioritizes rapid reductions in greenhouse gas emissions and leverages Nature-based Solutions (NbS), such as reforestation and wetland restoration, to enhance resilience and mitigate future impacts (IUCN, 2019).

Nature-based Solutions (NbS) have gained significant recognition as a strategic approach to tackling urgent environmental and societal challenges (UNEP, 2020). First introduced by the International Union for Conservation of Nature (IUCN) in the 21st century, the concept has been supported by the development of a

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comprehensive framework to guide its design, implementation, and evaluation. As defined by IUCN (2020), NbS are actions aimed at enhancing human well-being and biodiversity while effectively addressing societal issues through the protection, sustainable management, and restoration of ecosystems. The Global Standard for NbS, which consists of eight criteria and 28 indicators (Fig. 1), provides a detailed framework to help practitioners develop, apply, and assess these solutions. Similarly, the European Commission (2020) also defined NbS as actions inspired and supported by nature that are cost-effective, deliver environmental, social, and economic benefits, and build resilience. These interventions, tailored to local contexts, promote the efficient use of resources and foster diverse natural processes in urban, rural, and marine environments.



Fig. 1. The eight interconnected criteria of IUCN global standards for NbS (IUCN, 2020)

While NbS has been proposed for a wide range of applications, its relevance is particularly acute in addressing the twin global crises of climate change and biodiversity loss (UNEP, 2020). Climate change poses an unprecedented threat to biodiversity, with the Paris Agreement striving to limit global temperature increases to below 2°C, and ideally to 1.5°C. Achieving these goals requires immediate and concerted action by all nations before 2030. Exceeding the 1.5°C threshold risks severe weather-related disruptions and ecosystem collapse. The Sixth Assessment Report of the IPCC also underscores NbS as one of the most effective pathways for reducing carbon emissions by 2030, emphasizing measures such as protecting and restoring forests and ecosystems and improving the management of agricultural landscapes (IPCC, 2023). Beyond climate mitigation, NbS are integral to achieving the United

Nations Sustainable Development Goals (SDGs), offering solutions to critical issues like disaster risk reduction, food and water security, and public health (UNEP, 2020).

Trees Outside Forests (TOF) refer to trees that grow beyond recorded forest areas, encompassing a range of locations such as alongside linear features like roads, canals, and bunds, as well as in small woodlots, block plantations, homesteads, community lands, farmlands, and urban settings (FSI, 2019). These systems are vital for supporting the livelihoods of millions, providing food, materials, employment, and income. TOF also deliver critical ecosystem services, including clean air and water, enhanced soil health, animal habitats, biodiversity conservation, carbon sequestration, and climate regulation (GoI, 2014; CIFOR-ICRAF, 2024). The global significance of TOF systems lies in their potential to sequester substantial amounts of carbon. In India, for instance, nearly 80 million hectares of TOF are estimated to sequester 3.4 gigatons of carbon dioxide equivalent by 2040, supporting the country’s commitments under the Nationally Determined Contributions (NDC), the Bonn Challenge, Land Degradation Neutrality goals, and the Sustainable Development Goals (SDGs) (Duraisami *et al.*, 2022).

Recognizing the multifaceted value of TOF systems, India has made significant strides in promoting its expansion. Various policies and initiatives have been launched to encourage agroforestry practices and support TOF systems. Key policies include the National Agroforestry Policy (2014), the Green India Mission (2010), the National Bamboo Mission (2006), and Nagar Van (City Forests) (2020). Notably, the Trees Outside Forests in India (TOFI) program—a five-year partnership between the United States Agency for International Development (USAID) and the Government of India was launched to expand TOF in seven states across the country: Andhra Pradesh, Assam, Haryana, Odisha, Rajasthan, Tamil Nadu, and Uttar Pradesh. This initiative aims to improve livelihoods and ecosystem services by using TOF as a Nature-based Solution (NbS) for climate resilience.

Despite these efforts, significant challenges hinder the widespread adoption and impact of TOF systems. Key barriers include a lack of quality planting material, insufficient technical capacity, knowledge gaps, limited market access, financing constraints, and inadequate attention to land tenure, gender equity, and social inclusion (ICFRE, 2020; Singh *et al.*, 2020). Addressing these obstacles is essential for maximizing the potential of TOF systems in mitigating climate change and supporting sustainable development.

The operationalization of NbS through TOF systems presents an unparalleled opportunity to tackle climate challenges while fostering economic and ecological resilience. However, achieving this vision requires a comprehensive understanding of the current status, dynamics, potential, and constraints within the sector. Efforts should also focus on developing integrated solutions, including improved extension services, public-private partnerships for market development, incentives for small-scale farmers, and the integration of TOF in urban planning to maximize the multifunctional benefits of these systems. By addressing these challenges, TOF systems can effectively contribute to India's sustainable development goals and climate resilience strategies (Girardin *et al.*, 2021; IPCC, 2023).

Nature-Based Solutions (NbS) for Climate Resilience

Nature-based Solutions (NbS) are increasingly recognized for their critical role in climate change adaptation and mitigation through the restoration, conservation, and sustainable management of ecosystems worldwide (IUCN, 2022). Over the past decades, there has been a growing focus on harnessing the potential of NbS to address the dual challenges of climate change and biodiversity loss. Natural ecosystems, integral to NbS, function both as sinks and sources of greenhouse gases (GHGs), which are the primary drivers of global warming. Evaluating the effectiveness of NbS requires an integrated analysis of societal, ecological, and economic factors.

Griscom *et al.* (2017) identified 20 NbS approaches for climate mitigation, spanning forestry (six approaches), agriculture (ten approaches), and wetlands (four approaches). Together, these approaches offer a cumulative mitigation potential exceeding 23,000 teragrams (Tg) of carbon dioxide equivalent annually. Properly implemented NbS can significantly contribute to global temperature reduction in the long term. For example, preserving intact ecosystems, improving the management of working lands, and restoring degraded ecosystems collectively hold the potential to mitigate approximately 10 Gt CO₂e annually—a figure that exceeds the emissions from the global transportation sector (Girardin *et al.*, 2021). Moreover, the United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN) (2021) projected that NbS could achieve annual emission reductions and removals of at least 5 Gt CO₂e by 2030, increasing to at least 10 Gt CO₂e by 2050, even after accounting for deployment uncertainties and safeguard requirements.

In essence, NbS contribute to climate action in three critical ways: (1) reducing GHG emissions by curbing deforestation and unsustainable land use; (2) sequestering carbon dioxide from the atmosphere through ecosystem restoration; and (3) enhancing ecosystem resilience to support communities in adapting to climate hazards such as floods, droughts, heatwaves, and forest fires. Within this framework, Trees Outside Forests (TOF) hold substantial promise. TOF systems, by serving as carbon sinks, reducing emissions, and bolstering ecosystem services, can be viewed as an effective NbS. Their role in emission reduction and climate resilience positions TOF as a valuable investment for achieving both national and global climate goals.

TOF: Indian scenario

Trees Outside Forests (TOF) are defined as "all trees growing outside recorded forest areas, irrespective of the patch size" (FSI, 2023). This classification encompasses diverse forms of tree systems, with India exhibiting at least 47 distinct TOF types identified by Duraisami *et al.* (2022). These include monoculture and mixed-species tree plantations, homegardens, urban forests, fruit orchards, linear plantations along rivers and roads, and block plantations. TOF systems provide invaluable ecological, economic, and social benefits, acting as renewable resources essential for forest produce such as timber, firewood, and small wood. The agroforestry sector, in particular, serves as India's primary source of wood production, reflecting the system's prominence in rural and urban landscapes. Moreover, TOF contributes significantly to climate change mitigation by serving as a carbon sink. Every patch of vegetation globally absorbs carbon, making TOF an effective tool for achieving India's climate and restoration goals. These include achieving 33% forest and tree cover under the National Forest Policy (1988), sequestering an additional 2.5 to 3 billion tonnes of carbon dioxide equivalent (CO₂e) under the Paris Agreement, and restoring 26 million hectares of degraded land under the Bonn Challenge (CIFOR-ICRAF, 2024).

The Forest Survey of India (FSI) Reports 2021 and 2023 provide critical insights into the evolving role of TOF in India, showcasing its increasing coverage and significance. The FSI Report 2021 highlighted the impact of community-driven afforestation and reforestation efforts over the past decade, enabled by advanced satellite imagery and geospatial technologies that improved precision in TOF mapping. Building on this, the FSI (2023) revealed that TOF covers 31.15 million hectares, making up about 9.22% of India's total land area. Maharashtra, Odisha, and Karnataka are the leading states in TOF coverage, with areas of 26,866 km², 24,474 km², and

23,676 km², respectively. Various initiatives like the National Agroforestry Policy (2014), Green India Mission (2010), and Nagar Van (City Forests) programs have contributed immensely to upscaling the TOF systems in India.

The potential for TOF expansion is further amplified by mosaic restoration - a strategy that integrates trees into diverse land uses such as rainfed farmlands. According to the World Resources Institute (WRI), in India, approximately 87 million hectares are available for TOF enhancement through mosaic restoration, primarily in agroforestry systems (Chaturvedi *et al.*, 2018). Increasing tree cover in these areas to just 20 per cent could sequester an estimated 3.4 gigatonnes (Gt) of CO₂ in aboveground biomass by 2040. Such efforts, supported by targeted tree plantation programs and community involvement, hold the promise of strengthening India's TOF sector as a cornerstone of sustainable development and climate resilience.

By recognizing the growing importance of TOF systems and building on actionable insights from recent FSI reports, India can unlock the full potential of TOF in addressing ecological restoration, economic empowerment, and climate adaptation challenges. This integrated approach can position TOF as a transformative solution for the country's sustainable future.

Role of TOF in achieving climate resilience

Trees Outside Forests (TOF) encompass diverse systems, including agroforestry, roadside plantations, urban green spaces, wastelands, and mangrove landscapes. These systems are vital as Nature-based Solutions (NbS) for addressing climate resilience by enhancing carbon sequestration, conserving biodiversity, and promoting sustainable land use. India, with its varied geographical and climatic conditions, has adopted a range of agroforestry systems that integrate trees with crops and livestock, making it a multifunctional land-use approach capable of addressing environmental and socioeconomic challenges. Agroforestry, covering an estimated 28.427 million hectares in India and maximum area is prevalent in Uttar Pradesh, Maharashtra, Rajasthan, and Andhra Pradesh (Arunachalam *et al.*, 2022 and 2024).

According to the India State of Forest Report (ISFR, 2023), agroforestry systems play a critical role in restoring degraded lands and achieving India's Nationally Determined Contributions (NDCs) under the Paris Agreement. These systems also enhance carbon sequestration potential through both aboveground biomass and belowground soil carbon storage (Table 1). For example, home gardens in the Idukki district of Kerala have demonstrated a carbon

density of 31.86 t ha⁻¹, reflecting their effectiveness as sustainable production units at the household level (Padmakumar *et al.*, 2021). Silvopastoral systems, which combine trees with pasture, are similarly impactful. Gupta *et al.* (2019) revealed that silvopastoral systems with higher tree densities store significantly more carbon in the soil, with values reaching up to 23.25 ± 0.78 Mg C ha⁻¹. Tea garden agroforestry systems in Northeast India, characterized by the presence of shade trees, also sequester approximately 4037.4 kg CO₂/ha/year, further underscoring the potential of agroforestry in diverse agroclimatic zones (Pramanik and Phukan, 2019; Rizvi *et al.*, 2021).

India's extensive road network of 5.5 million kilometres also holds considerable potential for carbon sequestration through roadside plantations. These trees not only store carbon but also mitigate the effects of climate change and urban heat islands. A study in the Bilaspur district of Chhattisgarh reported that roadside plantations have the potential to sequester approximately 176.64 tonnes of CO₂e, emphasizing their role in combating global warming (Raghula and Chandra, 2020). Similarly, urban green spaces such as parks and institutional gardens also contribute to carbon sequestration by capturing substantial amounts of carbon in both biomass and soil, as validated by studies conducted by Lahoti *et al.* (2020) and Pradhan *et al.* (2022). These urban ecosystems also provide co-benefits such as improved air quality and reduced heat stress, making them crucial for sustainable urban development.

Mangrove landscapes are another critical component of TOF, with their exceptional ability to sequester carbon. Globally, mangroves capture 14.2 Tg C annually, and in India, the Sundarbans alone sequester approximately 2.79 Tg C across 4264 km². Research by Kandasamy *et al.* (2021) revealed that carbon storage in mangrove plantations is significantly higher than in barren lands, with soil and tree biomass storing 22-fold and 56-fold more carbon, respectively. This highlights the importance of conserving and managing mangrove ecosystems to enhance their carbon storage capacity and support coastal resilience.

The collective contributions of agroforestry, roadside plantations, urban green spaces, and mangroves underscore the potential of TOF as a robust strategy for climate mitigation and adaptation. Studies such as Chaturvedi *et al.* (2018) have demonstrated that increasing tree cover in mosaic restoration areas to 20 per cent could sequester an additional 3.4 gigatonnes (Gt) of CO₂ by 2040. Such efforts, combined with targeted policies and community engagement, can significantly strengthen India's TOF sector, enabling it

Table 1. The potential of carbon storage in different agroforestry systems across India (Panwar *et al.*, 2022)

Agroclimatic Region/States	Agroforestry System	Average Biomass Carbon (Mg/ha)	Average Soil Organic Carbon (Mg/ha)
Northern Himalayas	Agrisilviculture	32.61	58.07
	Agrihorticulture	29.61	64.34
	Silvipasture	44.59	47.63
Indo-Gangetic region	Agrisilviculture	7.95	15.25
Eastern and northeastern India	Homegardens	55.18	52.15
	Plantation crop-based AF	26.42	96.53
	Boundary plantations	9.74	51.95
	Block plantations	98.99	-
Western and Central India	Agrisilviculture	10.24	12.26
	Agrihorticulture	1.84	-
	Block plantations	38.12	14.55
Southern India	Agrisilviculture	11.93	17.08
	Plantation crop-based AF	107.95	65.82
	Block plantations	73.56	-
	Coffee plantation	131.27	125.29

to address climate challenges while promoting biodiversity conservation and socioeconomic development. This integrated approach positions TOF as a transformative solution for achieving sustainable development and climate resilience in India.

TOF: Issues, Challenges and Recommendations

Trees Outside Forests (TOF) provide significant ecological, economic, and social benefits, but their adoption and expansion face numerous barriers. India has implemented various policies and programs to encourage TOF, offering both monetary and non-monetary incentives. Financial support includes input subsidies, grants, credit facilities, minimum support prices (MSP), benefit-sharing mechanisms, and insurance schemes. Non-financial incentives focus on providing technical assistance, regulatory support, and developing supply chain infrastructure (Duraismi *et al.*, 2022). However, these measures are often insufficient to address the broader challenges associated with TOF implementation.

A key obstacle is the limited awareness among marginalized groups and women, who are traditionally the primary caretakers of TOF systems using native species. These communities are often unaware of available incentives and models due to gaps in research, outreach, and extension services (Peros *et al.*, 2022). The lack of high-quality planting materials, coupled with regulatory hurdles such as obtaining permits for harvesting and transporting farm-grown timber, further discourages farmers. Additionally, fragmented value chains and weak integration of supply chain systems create economic

disincentives for smallholder participation in TOF initiatives (Thomas *et al.*, 2021).

TOF systems remain undervalued in both national inventories and global frameworks, particularly in the Global South, where they are vital for livelihoods and ecosystem services (Peros *et al.*, 2022, Ramanan *et al.*, 2025). A lack of standardized definitions and consistent monitoring frameworks across regions limits their recognition and integration into conservation and climate action policies. Urban TOF systems, despite their potential to address urban heat islands, air pollution, and water management issues, have received minimal attention. Studies suggest that urban tree cover can reduce peak summer temperatures by up to 3°C and filter particulate matter from the air, offering substantial benefits for public health and city resilience (Seddon *et al.*, 2021).

Current TOF policies are heavily focused on timber production, often neglecting the potential of non-timber forest products such as fruits, fodder, and medicinal plants. This narrow approach restricts the economic scalability of TOF systems, particularly in rural areas where diversified tree products contribute to livelihoods. Furthermore, systemic inequities in accessing incentives and technical support disproportionately favor wealthier stakeholders. Women and smallholder farmers, who are integral to TOF management in rural areas, often lack access to decision-making processes and the benefits of these policies due to limited representation and weak extension systems (Peros *et al.*, 2022).

Fragmented value chains exacerbate these challenges. Farmers cultivating indigenous tree species face obstacles like complex transit regulations, unclear certification processes, and inadequate market access. While the demand for both timber and non-timber forest products is rising, the absence of robust supply chains reduces the economic viability of TOF systems. Improving certification standards and enhancing traceability mechanisms could help resolve these issues and promote greater farmer participation (Thomas *et al.*, 2021).

To overcome these barriers, a landscape-based restoration strategy is essential. This approach should prioritize the protection of existing TOF systems and the promotion of traditional models using native species (Duraisami *et al.*, 2022). Strengthening research and extension services is critical for bridging knowledge gaps and providing marginalized communities with the technical assistance needed to adopt TOF practices. Financial incentives should be expanded to include MSP schemes for indigenous species and diversify TOF outputs to include both timber and non-timber products. Standardized monitoring frameworks and clear definitions are also crucial for effectively integrating TOF into national and international reporting systems (Peros *et al.*, 2022).

Ensuring equitable access to incentives and technical support is paramount. Women and smallholder farmers, who are essential stewards of TOF, must be actively included in decision-making processes and policy implementation. Simplifying regulations for timber transport and certification, along with strengthening market linkages, can make value chains more efficient and inclusive. Urban TOF systems should also be leveraged to mitigate heat islands, improve air quality, and enhance water regulation. Cities like Pune and Bengaluru, which have adopted green infrastructure strategies, illustrate the potential of urban TOF in sustainable city planning (Seddon *et al.*, 2021).

Non-governmental organizations (NGOs) and research institutions should play a more active role in supporting TOF through grants, capacity-building programs, and inclusive governance models. Introducing payment for ecosystem services (PES) schemes can further incentivize communities to maintain and expand TOF systems, ensuring their long-term sustainability (Duraisami *et al.*, 2022). By addressing these challenges and adopting a comprehensive approach, TOF systems can become a powerful Nature-based Solution (NbS) for climate resilience, biodiversity conservation, and sustainable rural development.

Conclusion

Trees Outside Forests (TOF) represent a pivotal Nature-based Solution (NbS) with the capacity to address critical climate challenges, support biodiversity conservation, and enhance socio-economic resilience. This comprehensive analysis underscores the significant contributions of TOF systems in advancing climate mitigation, adaptation, and sustainable development goals. From carbon sequestration to livelihood generation, TOF systems have emerged as a crucial component in India's environmental and socio-economic strategies, aligning with commitments under the Paris Agreement, the Bonn Challenge, and the Sustainable Development Goals (SDGs).

The findings highlight the extensive carbon sequestration potential of TOF systems, with projections indicating their capacity to store up to 3.4 gigatonnes of CO₂ by 2040. Moreover, the integration of TOF systems into agroforestry, urban landscapes, and mosaic restoration initiatives demonstrates their versatility and scalability in addressing diverse ecological and socio-economic needs. These systems not only act as carbon sinks but also provide critical ecosystem services, including soil health enhancement, biodiversity conservation, and climate regulation. Furthermore, their role in offering timber, fodder, fruits, and non-timber forest products underscores their importance in supporting rural livelihoods and economic development.

Despite these benefits, the expansion and adoption of TOF systems face several challenges. Key barriers include insufficient awareness among marginalized communities, inadequate access to quality planting materials, fragmented value chains, and inequitable distribution of financial and technical incentives. Women and smallholder farmers, who are central to TOF stewardship, often remain excluded from decision-making processes and policy benefits due to systemic inequities. Regulatory complexities, such as restrictions on harvesting and transport of farm-grown timber, further discourage broader participation.

To fully realize the potential of TOF systems, targeted and transformative actions are required. Policy interventions must focus on expanding financial mechanisms such as Payments for Ecosystem Services (PES) and Minimum Support Prices (MSP) for indigenous tree species, along with developing certification systems to enhance market access. Strengthened extension services and capacity-building initiatives are crucial for equipping marginalized communities with the knowledge and tools needed to adopt and manage TOF systems effectively. Additionally, integrating TOF into urban

green infrastructure planning can address pressing urban environmental challenges, such as heat island effects and air pollution, while contributing to overall ecological resilience.

The study also emphasizes the importance of standardized monitoring frameworks and consistent definitions to ensure that TOF systems are accurately represented in national and international reporting mechanisms. These measures will not only strengthen the visibility and valuation of TOF but also enable evidence-based policymaking and targeted investments.

In conclusion, TOF systems hold transformative potential for addressing climate change, restoring degraded ecosystems, and enhancing socio-economic development. India, with its vast biophysical potential and existing policy frameworks, is well-positioned to lead global efforts in leveraging TOF as a cornerstone of climate resilience strategies. While challenges remain substantial, the opportunities presented by TOF far outweigh the barriers, offering a viable pathway toward sustainable development and environmental stewardship. Immediate and collaborative action is imperative to unlock the full potential of TOF, ensuring a resilient and sustainable future for generations to come.

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