RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

FTA HIGHLIGHTS OF A DECADE
2011–2021

Biomass, Bioenergy and Biomaterials

Ten years of
forests, trees and agroforestry
research in partnership for
sustainable development

About the FTA Highlights series

This publication is part of a series that highlights the main findings, results and achievements of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA), from 2011 to 2021 (see full list of chapters on the last page).

FTA, the world's largest research for development partnership on forests, trees and agroforestry, started in 2011. FTA gathers partners that work across a range of projects and initiatives, organized around a set of operational priorities. Such research was funded by multiple sources: CGIAR funders through program-level funding, and funders of bilateral projects attached to the programme, undertaken by one or several of its partners. Overall this represented an effort of about 850 million USD over a decade.

The ambition of this series is, on each topic, to show the actual contributions of FTA to research and development challenges and solutions over a decade. It features the work undertaken as part of the FTA program, by the strategic partners of FTA (CIFOR-ICRAF, The Alliance of Bioversity and CIAT, CATIE, CIRAD, Tropenbos and INBAR) and/or with other international and national partners. Such work is presented indifferently in the text as work "from FTA" and/or from the particular partner/organization that led it. Most of the references cited are from the FTA program.

This series was elaborated under the leadership of the FTA Director, overall guidance of an Editorial Committee constituted by the Management Team of FTA, support from the FTA Senior Technical Advisor, and oversight of the FTA Independent Steering Committee whose independent members acted as peer-reviewers of all the volumes in the series.

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FTA HIGHLIGHTS OF A DECADE
2011–2021

Biomass, Bioenergy and Biomaterials

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List of acronyms

CGIAR	Consortium of International Agricultural Research Centers
CIRAD	Centre de coopération internationale en recherche
EFI	European Forest Institute
FAO	Food and Agriculture Organization
FSC	Forest Stewardship Council
FTA	Forests, Trees and Agroforestry
GHG	Greenhouse gas
GLF	Global Landscapes Forum
GPSNR	Global Platform for Sustainable Natural Rubber
ICRAF	World Agroforestry Centre
INBAR	International Bamboo and Rattan Organisation
IRSG	International Rubber Study Group
ITTO	International Tropical Timber Organization
NDC	Nationally determined contribution
REDD+	Reducing Emissions from Deforestation and forest Degradation, plus
SDG	Sustainable Development Goal
SMI CBA	Sustainable Markets Initiative Circular Bioeconomy Alliance
SNR-I	Sustainable Natural Rubber Initiative
TPP	Transformative Partnership Platform
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

The demand for woody biomass for energy and biomaterials is increasing rapidly in line with the global population rise and changing consumption patterns for sustainable resources. Central to meeting this demand is the question of how woody biomass production and use can be reconciled with biodiversity protection, climate change resilience and mitigation, and inclusive prosperity for local communities. Modern, efficient and sustainable forms of bioenergy and biomaterial production and use can play a key role in combating climate change while providing social, economic and environmental benefits to rural communities and critical industries, but these forms are not available to everyone. Thus, attention to social inclusion in the development agendas related to sustainable biomass production, use and trade is vital. Over the last decade, the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) has undertaken basic and applied research on multiple dimensions of woody biomass production and use for energy and materials, such as sustainable production, value chains and investments, enterprise development, and green growth through forest and tree-based circular economies. This highlight discusses the key outputs and findings from FTA work on biomass production and use for bioenergy and biomaterials, in particular woody biomass production in forests and plantations and on farms; the use of biomass; and related value chains. It also considers work on policies that promote sustainability in the sector and discusses the requirements for a shift to a forest- and tree-based bioeconomy.

1. Introduction

Wood is the most versatile renewable material on Earth, and its production and use as traditional woodfuel, pulp for paper and textile fibres, and sawlogs for wood products fuel industries and economies across the globe, from the local to the global scale. Similarly, bamboo, rattan and rubber are versatile non-timber materials whose historical use in Asia is being amplified throughout the world in both the materials and energy industries. Forests, trees outside forests, and production landscapes are the sources of these critical materials. Renewed interest in woody biomass (Box 1) is linked to a recognition of its role in decarbonizing economies and industries through reducing dependence on high-carbon processes and materials, especially in the energy and materials sectors, and in sustaining rural livelihoods and well-being. Global industrial roundwood production could increase by 45% by 2050 in response to increasing global resource use due to urbanization and subsequent construction, increasing demand for housing, and a shift towards low-carbon materials (Gresham House 2020).

Rattan mats

Photo by Lucy McHugh/CIFOR

Box 1. **Woody biomass**

This publication uses the term "**woody biomass**" to denote the organic material from trees, shrubs, bamboo and rattans. Although bamboo and rattan are not technically wood, their lignified tissue gives them properties of structural strength and specific heat capacity that are similar to those of wood. Woody biomass also includes wood and residues from mechanical and chemical processing. This publication excludes discussion of research related to bioenergy derived from non-woody sources, such as seeds and agricultural residues.

Woody biomass for bioenergy and biomaterials was one of the 25 operational research priorities of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) Research outputs on the production, use and trade of woody biomass are presented here using a cross-sector approach across FTA that considers energy poverty, climate change, and food and nutritional security through diverse production systems, including forest landscapes, trees on farms, and plantations. FTA has helped to integrate bioenergy and biomaterials in landscape mosaics by evaluating various production typologies (such as extractive systems, trees on farms, and industrial plantations) and identifying the conditions required for these production systems to meet increasing demand while supporting livelihoods and enhancing biodiversity conservation.

FTA and partner scientists, in collaboration with practitioners and policymakers, have pursued a diverse research and implementation agenda for the production, use and value chains of woody biomass for energy and materials. Spanning regions, scales and sectors, FTA projects have provided results that help to illuminate and optimize the synergies and trade-offs of producing and using biomass for bioenergy and biomaterials. The FTA program has produced leading knowledge products, contributed to key negotiation processes, and aided in the development of transformational policies on questions related to sustainability. The focus was on how to increase the production of woody biomass to meet increasing demands in the bioenergy and biomaterials sectors, and, how to do it in an environmentally sustainable, socially acceptable, and economically equitable manner.

Orphan services to support economic and human development. It is important for technological solutions intended to reduce energy poverty to take into account impacts on climate change and on the environment so that development can be maintained in the future. See Box 2 for definitions of some of the terms used in this highlight.

Box 2. Terms used in this publication

Bioenergy: is not a single concept but includes many different systems, each with different fuels and implications, such as solid biomass, first generation liquid biofuels, and second generation systems for liquid fuels or electricity.

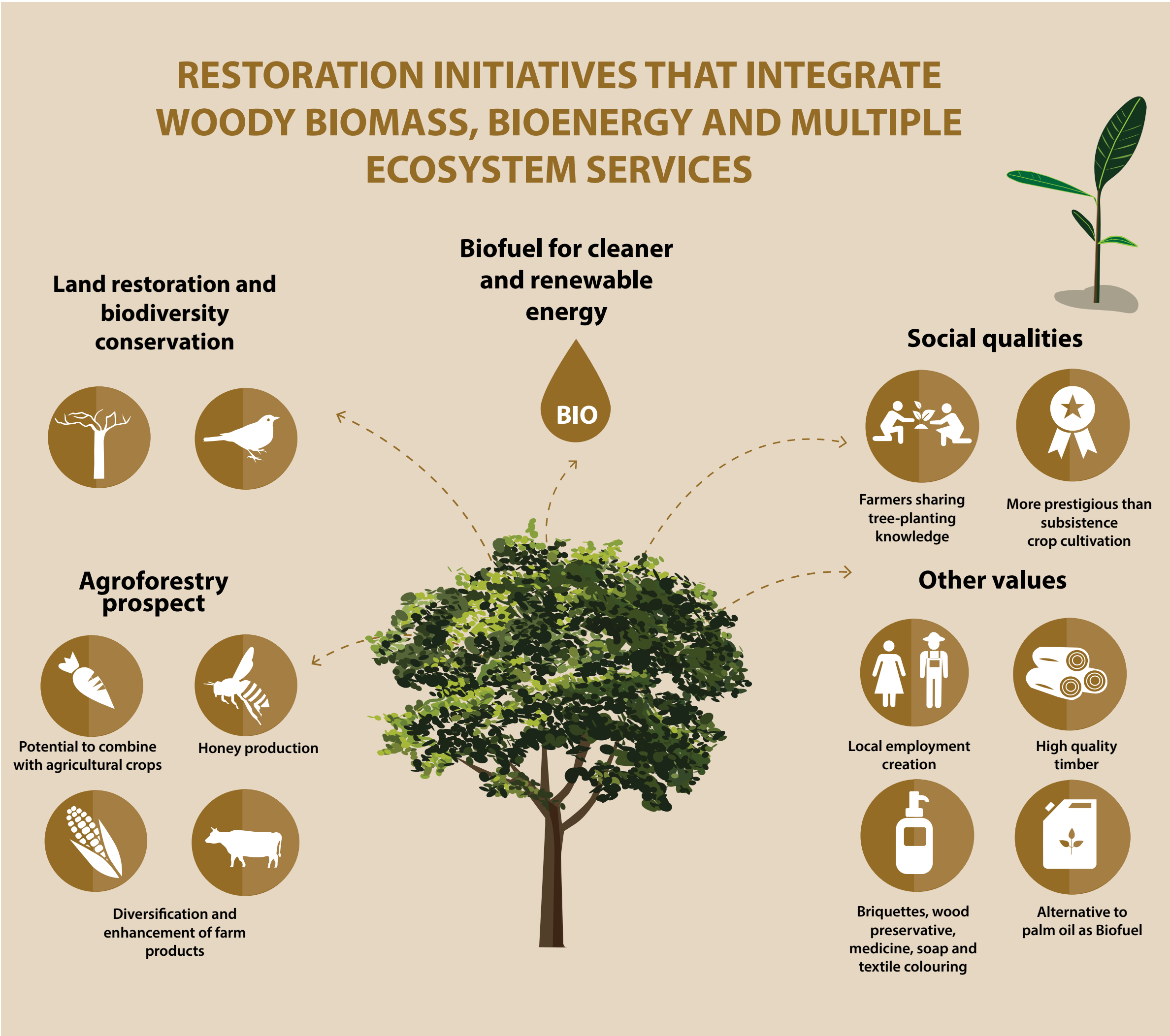
Circular bioeconomy: is an economy powered by nature. It is a new economic model that emphasizes the use of renewable natural capital and focuses on minimizing waste and replacing the wide range of non-renewable, fossil-based products currently in use.

Energy poverty: is the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development. It is important that technological solutions intended to reduce energy poverty take into account impacts on climate change and on the environment so that development can be maintained in the future.

Net zero: refers to a state in which the greenhouse gases going into the atmosphere are balanced by their removal from the atmosphere. The term is important because — for CO_2 at least — this is the state at which global warming stops. The Paris Agreement underlines the need for net zero, requiring states to achieve this balance by the second half of the 21st century.

Pyrolysis oil: sometimes also known as bio-crude or bio-oil, is a synthetic fuel being considered as substitute for petroleum. It is obtained by heating dried biomass without oxygen in a reactor at a temperature of about 500 °C with subsequent cooling. Pyrolysis oil is a kind of tar and normally contains levels of oxygen too high to be considered a pure hydrocarbon. As such, it is distinctly different from petroleum products.

Regenerative economics: is an economic system that works to regenerate capital assets. In standard economic theory, one can either "regenerate" one's capital assets or consume them until the point where the asset cannot produce a viable stream of goods and/or services. What sets regenerative economics apart from standard economic theory is that it takes into account and gives specific economic value to the principal or original capital assets: the earth and the sun.



2. Sustainability

Studies indicate that the sustainable use of many renewable resources is being exceeded on a global scale and that future use must be approached with great care (Baral and Holmgren 2015). While increasing food, feed and fibre production per unit area can theoretically reduce pressure on land, the underlying effects of such yield increases on landscapes and on climate change are uncertain. Achieving sustainability in wood production, use and value chains is especially critical in the rural energy subsector, given that approximately 55% of global wood consumption is for woodfuel and charcoal, on the order of 1.7 million m^3, and accounting for 9% of the global primary energy supply (Bailis et al. 2017).

With the increasing global demand for woody biomass in the energy and materials sectors, the sustainability of wood production, use and trade is under pressure. Four common perceptions are associated with the increasing production of biomass for energy and materials, especially through planted forests: there is not enough land on which to grow biofuel crops (see Box 3), increasing biofuel production may supplant much-needed food crops and environmental conservation areas, the production could destroy native vegetation, and it leads to biodiversity loss if not managed appropriately at the landscape scale.

Box 3. Biofuels

Biofuels are non-fossil fuels usually derived from organic materials (biomass), including plant materials and animal waste. Wood-based solid biofuels include wood, wood waste, bio-briquettes, wood pellets and charcoal. This publication uses the terms "biofuel" and "bioenergy" interchangeably. Liquid and gaseous forms of biofuel, such as biodiesel, bioethanol, pyrolysis oil and biomass are not treated in this highlight. Biofuels are considered renewable energies, emit less than fossil fuels, and have received increasing attention in the transition to a low-carbon economy.

FTA has provided scientific evidence to generate knowledge and influence in the policy and implementation spheres in order to bring about a suite of development and conservation outcomes at multiple levels (Figure 1).

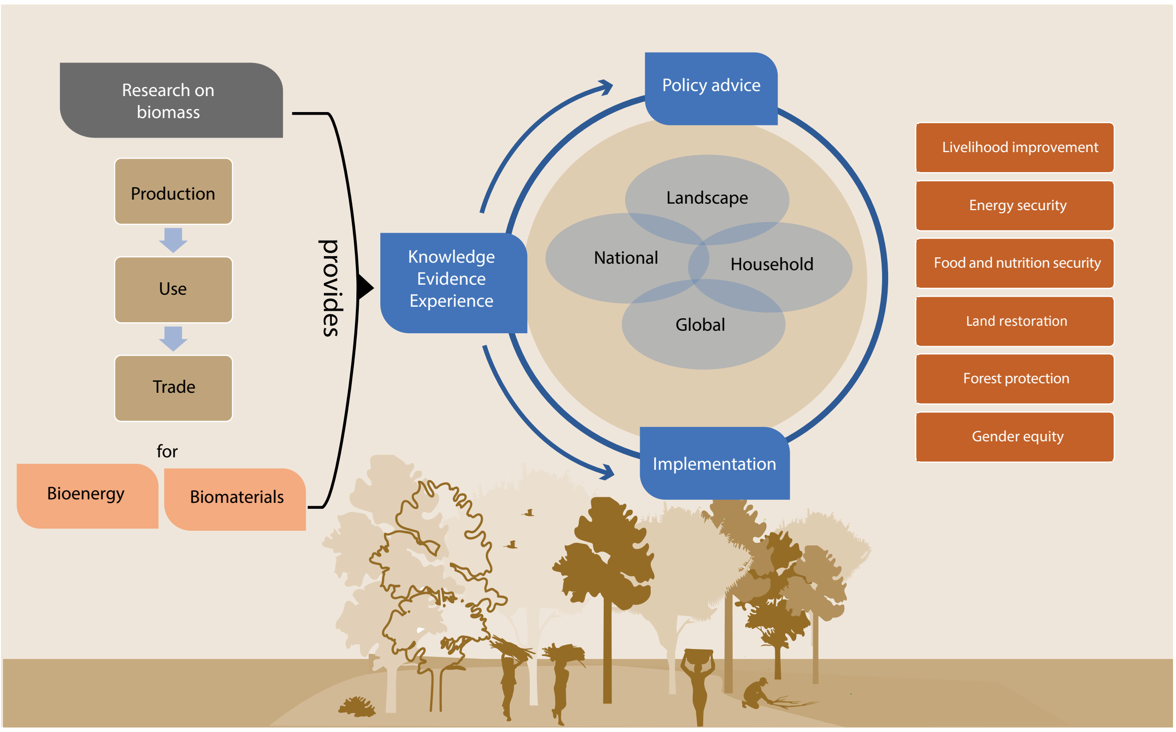


Figure 1. FTA areas of research centred on the production, use and trade of woody biomass for energy and materials

FTA researchers in Indonesia and elsewhere have demonstrated that large areas of degraded and underutilized land are available to accommodate this expansion, nationally and globally. Degraded land can be restored with climate-smart agroforestry systems that support food, energy and environmental conservation goals (Jaung et al. 2018; Rahman et al. 2019). Similarly, with careful planning and management at the landscape scale, bioenergy plantations on degraded land are a promising approach for restoring land and enhancing native biodiversity (Leksono et al. 2022; Shin et al. 2022).

Bolaina-cacao agroforestry system in the Peruvian lowlands.

Photo by Robin R. Sears

The sustainability challenge centres on the goal of increasing efficiency of use to reduce the volume of feedstock required to meet the increasing demand. The desired sustainability outcomes for production involve techniques that can best allocate land to the necessary woody biomass production in ways that do not compete with food production. With regard to woodfuel for cooking and heating, the goal of FTA research and implementation projects has been to provide evidence of improved public health outcomes through cleaner combustion stoves. In trade, the goal for both bioenergy and biomaterials is to support value chains that promote rural livelihoods and gender equity in access and income.

Aspirations for sustainability in the biomass and biomaterials sectors depend on how the ecosystem and its components are managed at the landscape scale. Gitz and Meybeck (2019) frame this perspective as a goal to use woody biomass as sustainable materials, harvested from sustainably managed forests, and traded on sustainable value chains. This publication focuses on research and outcomes related to improvements in the biological and technical dimensions of production and use, the socioeconomic dimensions of value chains, and challenges and gains in policy and implementation. Table 1 provides a summary of the key issues.

Table 1. Benefits and risks related to sustainable production and use of woody biomass for energy and materials, and related value chains

	Local	National	Global
Biomass production			
Benefits	• Industrial plantations offer rural employment • On-farm production provides self-sufficiency, reduces women's labour burden and increases income opportunities • Contributes to food and nutritional security	• Improves rural livelihoods and food security • Enhances local resilience and contributes to GHG emission reductions • Increases tree and forest cover to achieve landscape restoration targets	• Contributes to increasing forest cover • Restores degraded lands • Conserves terrestrial ecosystems • Supports climate resilience • Reduces GHG emissions • Co-produces bioenergy and biochar for soil amendment
Risks	• Food and nutrition insecurity from competition for land • Loss of trees, hence loss of livelihood opportunities • Risk of invasive species becoming dominant over endemic, ecologically and socially beneficial species	• Introduces incentives for land grabbing by wealthy investors • Degraded landscapes present environmental hazards, which lead to widespread socioeconomic problems and require expensive fixes • Introduces mono-cropping, with its associated environmental/ climate change risks	• Competes for land with food production and conservation at the global scale • Degrades forests and land
Biomass use			
Benefits	• Local production supports self-sufficiency • Simple technology makes it accessible • Reduced fuel consumption reduces women's energy burden in fuelwood collection	• Contributes to meeting national targets (nationally determined contributions, SDGs) • Reduces dependency on fossil fuels • Decreases demand pressure	• Contributes to the circular bioeconomy • Reduces dependence on high-carbon materials • Reduces GHG emissions • Improved technologies reduce negative health impacts associated with indoor air pollution • Micro gasification co-produces thermal heat for cooking and biochar for amending soil

Risks	• Negative health impacts from indoor air pollution • Excessive unpaid labour for women and children	• Unsustainable levels of GHG emissions • Increased demand for bioenergy leads to increased harvesting of tree biomass	• High GHG emissions • Negative health impacts from indoor air pollution • Forest and land degradation due to increased demand of biomass • Biodiversity loss
Biomass value chains			
Benefits	• Rational harvest and use of natural resources • Decrease in poverty • Women's empowerment • Innovation, entrepreneur engagement, investment		
Risks	• Perverse incentives for unsustainable harvests • Illegal and informal harvest • Human rights violations • Loss of tax revenue for the state • Marginalization of women to low-profit sections of the value chain		

Refugee women carrying wood for cooking on fields near by refugee camp Gado-Badzere, East Cameroon.

Photo by Emily Pinna/CIFOR

Sustainability in the wood-based bioenergy and biomaterials sectors contributes to improving human well-being, sustaining ecological and environmental services, and providing a pathway to support the global climate agenda (Bernal et al. 2018). In fact, woody biomass production, use and trade contributes to nearly all of the SDGs; see Figure 2 (Katila et al. 2017 and Timko et al. 2018).

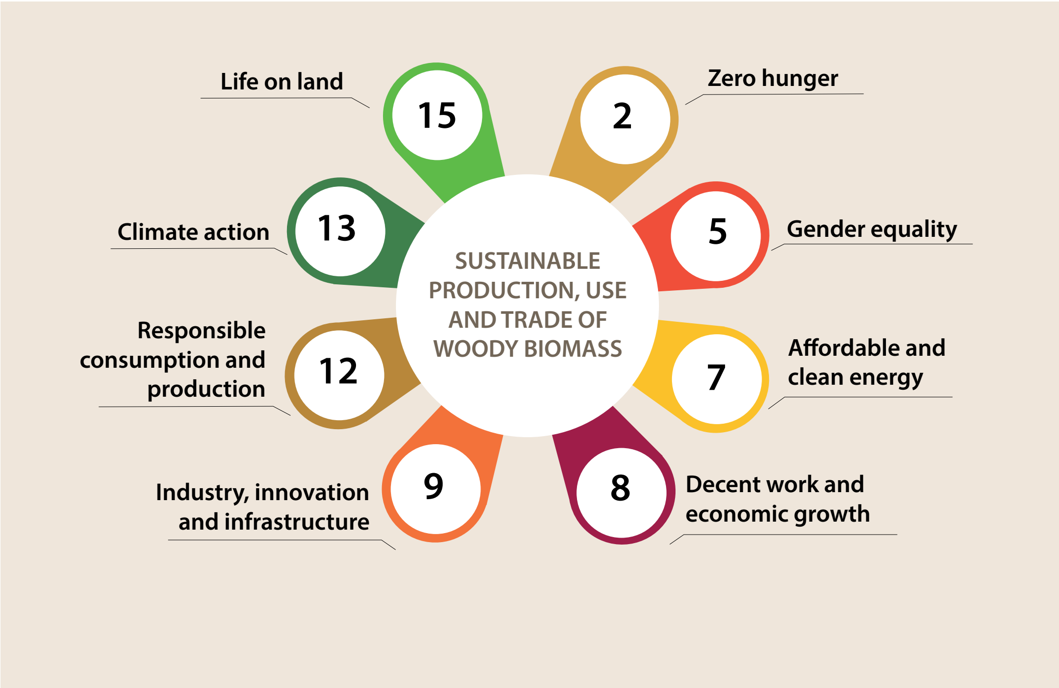


Figure 2. FTA work on biomass energy and biomaterials contributed to advances on at least eight SDGs

While they contribute most directly to SDG 7 on access to affordable and clean energy for all, they also support SDG 2 on hunger (Gitz et al. 2021; Jamnadass et al. 2015), SDG 13 on climate action, and SDG 15 on life on land. Achieving sustainable wood production, efficient use, and equitable value chains also contributes to SDG 5 on gender equality; SDG 8 on decent work; SDG 9 on industry, innovation and infrastructure; and SDG 12 on responsible consumption and production. Woody biomass production, use and trade also contribute to the objectives of the UN Framework Convention on Climate Change and the Paris Agreement (Moomaw et al. 2020).

Sustainable production and use of woody biomass figure in many components of the global development agenda. For example, some nations have agreed to the political mandates related to forests and greenhouse gas emissions reductions as defined in the Paris Agreement, the New York Declaration on Forests, and other international agreements (de Jong et al. 2017). As part of the green economy discourse, there is growing support for the preservation and expansion of forests, for their roles as a source of materials, a carbon sink, and habitat. For so many reasons, more forests, more trees and more wood are needed. At the core of the sustainability challenge for woody biomass production is the question of how to increase wood production while conserving forests and trees and maintaining the livelihoods of forest-dependent communities, particularly in Africa (Somorin 2010) and developing countries in other parts of the world.

3. Woody biomass production

Woody biomass for both energy and materials is sourced from three distinct types of landscapes: natural forest and woodland, where trees are extracted through either selective harvest or clear-cutting; tree plantations dedicated to the production of woody biomass, which undergo cyclical clear-cutting; and farm-based forests and agroforests, where landholders employ a variety of trees and forest management strategies to benefit from the diverse goods and services that trees provide. Currently, half of the timber in the world is sourced from planted forests, which represent only 7% of the global forest area (FAO 2021). Given the increasing global demand for wood and the calls to halt the degradation of natural forests, new efficiencies must be gained in wood production, especially from planted forests and agroforestry systems.

Thus, two key areas of focus in FTA research have been on which type of woody biomass suits which ecosystems, and on how to produce woody biomass in a manner that alleviates pressure on natural ecosystems, enables land rehabilitation and forest restoration, and generates multiple positive social outcomes, including improved resource access and increased income opportunities for rural people. Beyond the question of sustainable versus unsustainable practices per se, there is the more fundamental question of how to manage trade-offs and optimize the diversity of approaches to forest and tree conservation and sustainable wood production at the landscape level. Informing choices about optimal trade-offs requires understanding well, and quantifying, the level of risks and benefits in the diverse dimensions (economic, social and environmental) of different production (or conservation) options.

3.1 Natural forest management

Countries that have either policies or legislation that support sustainable forest management cover 99% of the global forest area (MacDicken et al. 2015). Despite this fact, the global demand for high-value timber drives unsustainable forest management through the extractive mode of production, resulting in forest degradation (Thompson et al. 2013; Cerutti et al. 2016) and forest land invasion and subsequent conversion (De Sy et al. 2015). The high demand for woodfuel, especially in arid and semi-arid regions, also results in deforestation and forest and woodland degradation (Cerutti et al. 2015). FTA scientists have quantified the resulting environmental degradation (Duguma et al. 2014; Sassen et al. 2015) and negative social impacts, such as food and nutritional insecurity. Improved management of tropical forests and woodlands is also an important element of the UNFCCC's REDD+ scheme, which contributes to the long-term supply of wood and biomaterials while supporting social welfare and biodiversity (Sasaki et al. 2016). For more information about work on REDD+ combating climate change with forest science conducted within FTA, see Highlight No. 11 in this series (Martius and Duchelle 2021).

While adopting principles and practices of sustainable forest management such as selective and reduced impact logging can help to improve the environmental outcomes of logging, barriers still exist for broadly achieving sustainability and resilience (Cerutti et al. 2016; Pirard et al. 2016; Sist et al. 2021). Furthermore, global warming is increasing the incidence of forest fires and other destructive agents, compounding the challenges for forest protection and sustainable management (Gutiérrez-Vélez et al. 2014).

Fallow forest management for timber, wildlife and soil fertility in the Peruvian lowlands.

Photo by Robin R. Sears

In addition to the unsustainable timber extraction practices inherent in many systems of natural forest management, weak and/or inadequate state forest institutions have resulted in the persistence of both illegal and informal logging from natural forests, exploitation of actors along value chains, and corruption by state and private actors (Mejia et al. 2015; Cerutti et al. 2016; Lescuyer et al. 2016; Sears et al. 2018). This leads to the loss of tax revenue for the state, insecurity for operators, and low competitiveness in international trade. Lescuyer et al. (2015) found that sustainable forest management initiatives to curtail illegal logging in forest concessions in Central Africa have little relevance to stakeholders, and occur in areas with unrectified land tenure and without sufficient financial support, and are thus not entirely successful. Others have identified barriers to natural forest management for timber in South America related to governance, resource rights, and stakeholder coordination (Duchelle et al. 2012; Putz et al. 2012; Herrero-Jáuregui et al. 2013; Cossío et al. 2014; Mejia et al. 2015).

Despite these difficulties, the technical and economic potential for sustainable forest management for some natural resources does exist. For example, FTA partners have conducted research on the management of natural populations of highly commercialized species such as rattans in the Democratic Republic of Congo, finding that integrating rattan and timber production in managed forests is a viable management strategy (Kahindo et al. 2015). In 2021, FTA began work with IKEA on rattan sustainability assessments in Sulawesi, Indonesia, to determine the sustained yield and natural regeneration of three species of rattan commonly harvested and used in IKEA products. This work has contributed to the development of sustainable management guidelines for rattan by FTA partners (Muralidharan et al. 2020).

3.2 Planted forests

Given the increased demand for wood and the difficulties in achieving sustainable supply, due to low productivity and ongoing restricted access in natural forests, alleviating harvest pressure on natural forest ecosystems requires increasing land allocations for more intensive tree plantation systems (IPCC 2020). In recent years, the FTA program has focused on synthesizing knowledge on the benefits, impacts and trade-offs of the expansion of large-scale timber and tree-crop plantations in the tropics and subtropics.

FTA scientists have shown that the conventional industrial-scale tree plantation model, while highly productive, presents environmental challenges (Brockerhoff et al. 2008; Bremer and Farley 2010; Baral et al. 2016) and

Happy farmer with pineapple in bioenergy research site in degraded peatland, Perigi, South Sumatra.

Photo by Himlal Baral/CIFOR

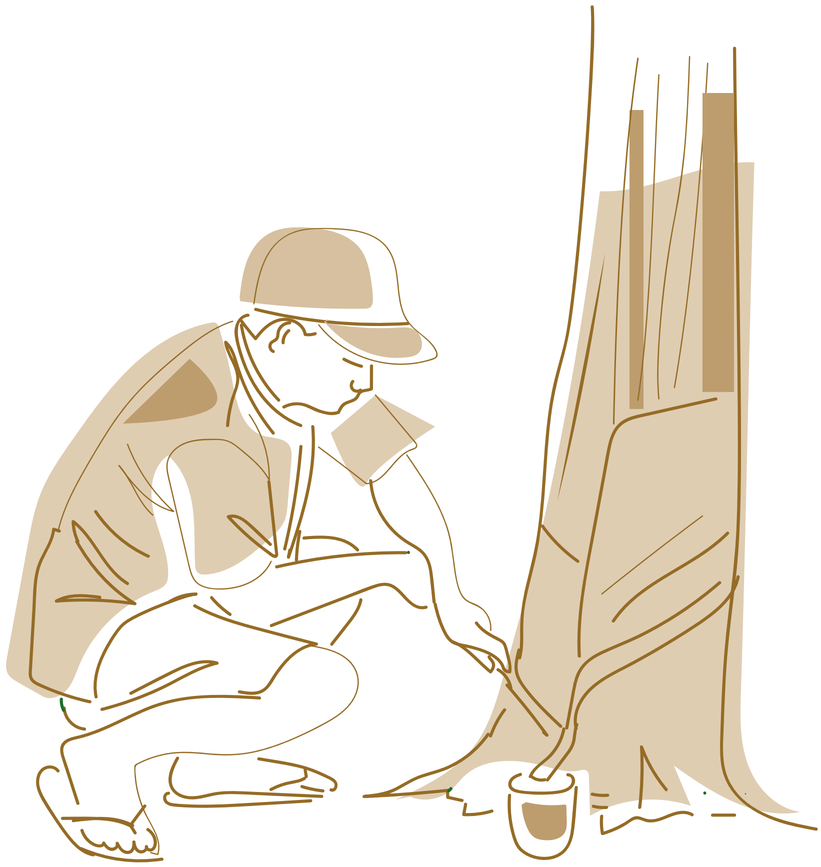
can have negative social and economic outcomes (Switzer 2014; Andersson et al. 2016; Pirard et al. 2017b; Malkamäki et al. 2018). Typologies of tree plantations (D'Amato et al. 2017; Peroches 2020) have helped to frame FTA research in this area, including disaggregating types of large-scale tree plantations into public, industrial private and smallholder private, and identifying end use as either protection or production (Peroches 2020).

Given the economic, social and environmental trade-offs of planted forests, FTA scientists have provided knowledge products and recommendations to implementers to guide sustainable plantation forestry. Central to this work is integrated principle of planting the right trees on the right site for the right purpose and also respecting community rights (Baral et al. 2016). Along this line, knowledge on the production side of plantation forestry has been advanced through modeling (Smethurst et al. 2020) and studies matching site suitability to specific species. Also key is a framework for assessing ecosystem services from planted forests (Baral et al. 2016). Forest ecosystem services assessments of planted forests have also been carried out in other FTA projects (Bonnesoeur et al. 2019; Rai et al. 2020) and for natural bamboo forests and stands (Paudyal et al. 2019).

In addition to the environmental constraints of plantation forestry, policy and social barriers to its expansion have been identified (Guariguata et al.

2017). FTA's work contributes to dialogues and discussions with government and the private sector, especially considering climate resilience (Gitz et al. 2020) and hydrological objectives (Bonnesoeur et al. 2019). FTA has provided recommendations on generating the enabling conditions for public and private investments in large-scale timber and tree-crop plantations development under economically viable, socially-acceptable and environmentally-sound practices, including finance (Louman et al. 2020) and design (Gaveau et al. 2019; Muralidharan et al. 2020; Peroches 2020).

Similar problems are associated with the production of trees for biomaterials, such as rubber, an expanding sector. FTA researchers found that the expansion of rubber tree production throughout the Mekong region has eluded sustainability goals (Kenny-Lazar et al. 2018), with corporate outgrower schemes especially compromising the food and income security of small-scale producers (Fox et al. 2014). To address sustainability in the natural rubber sector, FTA is collaborating with the International Rubber Study Group (IRSG; see Gitz et al. 2020), the Sustainable Natural Rubber Initiative (SNR-I) and the Global Platform for Sustainable Natural Rubber (GPSNR) to develop solutions, including the use of voluntary standards for sustainable natural rubber.



3.3 Farm-forestry and agroforestry

Bamboo in the Amazon rainforest, Brazil.

Photo by Neil Palmer/CIAT

The role of small-scale tree growers in woody biomass production is increasingly important as natural stocks are diminishing, extraction from natural forests is increasingly in conflict with societal and environmental needs, and industrial plantations are at odds with the needs of small landowners. FTA researchers have demonstrated how sustainable wood and bamboo production can be effectively achieved on farms in diverse environments across the globe. For example, researchers with the International Bamboo and Rattan Organisation (INBAR) identified knowledge gaps in the integration of bamboo in agroforestry systems in sub-Saharan Africa (Partey et al. 2017). Following up on an earlier review of the role of rubber in agroforestry systems across the tropics (Penot and Ollivier 2009), Penot et al. (2017) supported efforts to improve sustainability in the rubber sector in smallholder production systems in Indonesia and Thailand. ICRAF scientists contributed to the development and implementation of the world's first national agroforestry policy, in India, which also authorizes the production of bamboo on farms (Singh et al. 2016). For more information about work on trees on farms conducted within FTA, see Highlight No. 7 in this series (Somarriba et al. 2021).

Trees on farms are often considered by agricultural development institutions and researchers as secondary to the first objective of crop or livestock production, except in the case of tree-based commodity crops such as coffee and cacao. FTA research into integrated farming systems, however, has revealed the role that farmers play in wood production, but it also shows that there is considerable unrealized potential that needs technical support (Sabastian et al. 2019) and an enabling policy environment (Sears et al. 2018). FTA researchers have identified the critical enabling conditions for smallholders to grow trees (Sabastian et al. 2019; Arvola et al. 2020), concluding that the role of government is essential, particularly in ensuring tenure rights and providing knowledge and incentives to potential and existing growers. For more information about work on improving rural livelihoods through supporting local innovation at scale conducted within FTA, see Highlight No. 9 in this series (Sinclair et al. 2021).

Restoration of degraded peatland using agro-silvo-fishery approach in Perigi, South Sumatra.

Photo by Himlal Baral/CIFOR

In Indonesia, for example, conditions for smallholders' adoption of silvicultural practices for the production of trees and tree-based products on farms include access to extension services; associating through farmer groups; and spreading knowledge of relevant government policy (Rohadi et al. 2015; Sabastian et al. 2019). These and other reports (such as Pokorny et al. 2010) have illuminated the importance of domestic forestry systems to the provision of sawnwood for housing at the local and national levels, the economic importance of timber sales from farm-forestry systems through the periodic cash afforded to producers, and the sustenance of a robust value chain to support rural livelihoods.

On-farm fuelwood production has been addressed by FTA researchers in sub-Saharan Africa, where the need for fuelwood is especially acute. An FTA scientist and colleagues found a positive contribution from using waste wood from pruning trees in agroforestry systems to meet household energy needs and provide income for women, who bear the brunt of fuelwood collection (Njenga et al. 2021a). Others

Ruth Mendum and James Gitau studying women's energy burden at Kereita village, Kiambu County, Kenya.

Photo by Mary Njenga

have shown that on-farm fuelwood production can improve household food security, income and general well-being (Jamnadass et al. 2011; Duguma et al. 2019). The key message to all stakeholders, and one that is supported by data, is that agroforestry and sustainable management of biomass for biofuels is possible. FTA work in Tanzania showed that different tree species grown under different agroforestry systems, such as intercropped or in woodlots along farm boundaries, yield different amounts of fuelwood. It also showed that integrating the use of improved cookstoves reduced fuelwood consumption, hence reducing collection effort (Kimaro et al. 2019).

3.4 Managing synergies and trade-offs and optimizing landscape approaches

A key strategy promoted by FTA to optimize the capacity of planted forests to supply woody biomass to the energy and materials sectors is to combine production with landscape restoration, establishing plantations on degraded and underutilized lands (Box 4). Marginally productive and degraded land has little value to society and provides only a fraction of the ecosystem services of natural ecosystems. FTA scientists have looked into how to transform these areas into functional landscapes with both ecological and economic value to multiple stakeholders, making the restoration of degraded lands attractive to landholders and investors alike (Baral and Lee 2016; Artati et al. 2019; Duguma et al. 2020).

Nyamplung *(Calophyllum inophyllum)* on degraded peatlands in south Sumatra.

Photo by Himlal Baral/CIFOR

Box 4. Case study on restoration and bioenergy in Indonesia

FTA has supported extensive research, policy dialogue and implementation projects in bioenergy and biomaterials in Indonesia. FTA researchers initiated the Restoring Landscapes for Bioenergy, Biomaterials and Ecosystem Services project to look for solutions to the energy-environment-livelihood trilemma.[1] A comprehensive review of the bioenergy sector in Indonesia in the early years of FTA identified the causes and consequences of the rapid development of large-scale plantations of oil palm and timber trees (Casson et al. 2015). That expansion resulted in high levels of deforestation, with mixed social and economic results and land tenure insecurity and where marginalized people were most negatively affected (Obidzinski et al. 2012). The project led to a discussion in Bonn at the 2018 Global Landscapes Forum about the integration of bioenergy into landscape restoration.

A subsequent spatial assessment of degraded lands in Indonesia was undertaken, revealing an area of 3.5 million hectares (ha) of suitable land for three multipurpose species (Jaung et al. 2018), and showing that there was potential to increase bioenergy without competing with food production. Working under the guiding 4R principle — planting the right trees in the right place for the right purpose and respecting community rights — FTA researchers set out to identify opportunities to encourage private and public investments in producing biomass for bioenergy and biomaterials. The goal was to enhance rural livelihoods through the sale of forest products while improving landscape-level ecosystem services: biodiversity conservation, climate change mitigation and water regulation.

One area of focus has been on degraded peatlands in Indonesia (Maimunah et al. 2018; Wahono et al. 2020) because of their high primary productivity for carbon sequestration, wood production and provision of edible products to enhance food and energy security at the local level.

Through farmer perception studies, FTA scientists identified the key conditions for farmers in degraded peatlands to integrate biomass production for bioenergy into their farming systems (Artati et al. 2019). These conditions include a stable bioenergy market for landowners, use of familiar bioenergy species, and agricultural extension support for capacity building. Through research and demonstration trials, as well as stakeholder engagement and capacity building, the team identified the potential for widespread adoption by farmers and for working with the private sector to support the scaling up of these restorative systems.

[1] https://www2.cifor.org/bioenergy-and-restoration.

A bioenergy research and demonstration trial in East Kalimantan. Three years old Nyamplung *(Calophyllum inophyllum).*

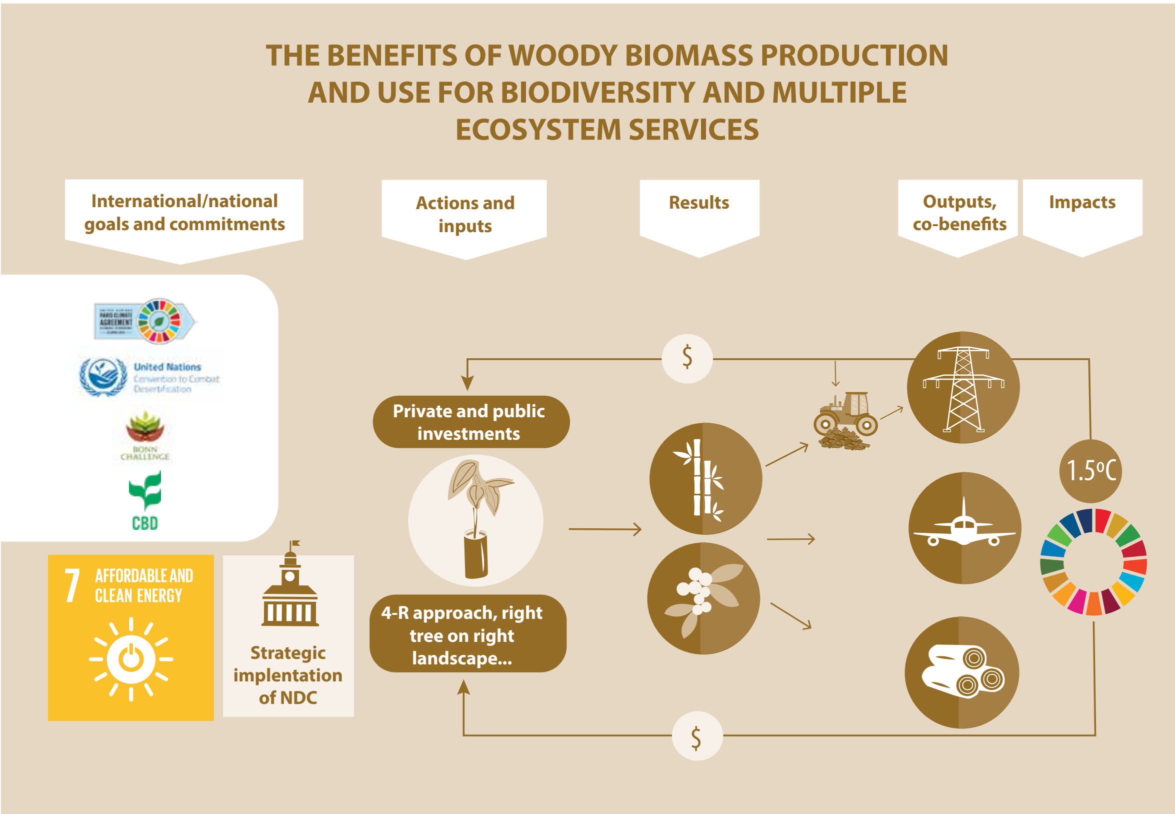
Photo by by Himlal Baral/ CIFOR

Research in southeast Asia on multipurpose tree and bamboo species for degraded land restoration and economic benefits (Borchard et al. 2018) has shown promising results for nyamplung (*Calophyllum inophyllum*; Leksono et al. 2018b), balangeran (*Shorea balangeran*), jelutung (Dyera lowii), pongamia (*Pongamia pinnata*; Leksono et al. 2018a) and others (Jaung et al. 2018; Maimunah et al. 2018; Samsudin et al. 2018; Rahman et al. 2019; Rahman and Baral 2020). *Calophyllum* and *Pongamia* are especially attractive due to their fast growth and the high levels of oil in their seeds, making them ideal for biodiesel production and thus for income generation through land restoration (CIFOR 2021a). In addition, their waste and by-products can be used as a raw material by the pharmaceutical and cosmetic industries, and as compost for soil enrichment (Leksono et al. 2018b).

At the core of the FTA approach to tree and bamboo production on degraded lands are two principles: first, to make restoration attractive to local farmers by improving access to resources and income opportunities; and second, to identify the right species to plant in the right place for the right purpose and respecting community rights (the 4R principle) (Baral and Lee 2016). Biomass is a key output of such restoration, but not the only one. In Viet Nam and other Asian countries, reforestation efforts through tree planting, which were primarily designed to meet the demand for industrial-use timber and boost income in rural areas, have also increased forest cover and enhanced many forest ecological functions (Paudyal et al. 2020).

INBAR has focused on bamboo for landscape restoration, advancing knowledge on species selection, nursery propagation, biomass assessment, and sustainable management. Scientists have successfully tested the use of bamboo in Indonesia for the dual purpose of restoring vegetation on degraded land and providing feedstock for electrical power plants to supply reliable rural bioenergy in remote and off-grid locations. (Sharma et al. 2018). As a result of demonstration projects of restoration with useful tree and bamboo species in Asia, two private companies have reached out to FTA researchers for advice on and partnership in forest landscape restoration (FLR) initiatives. They are interested in collaborating with local communities, who will benefit from the goods and services provided by FLR with multipurpose trees and energy production.

Based on this and other research, the FTA has concluded that considerable opportunities exist for effectively integrating biomass production and restoration of degraded landscapes. It is recommended, therefore, that significant effort be made by national governments, corporations and private actors to establish planted forests on deforested or otherwise degraded sites, and to actively avoid new deforestation and other natural ecosystem conversion, thereby conserving natural capital (Sharma et al. 2018; Rahman et al. 2019; Harvey and Guariguata 2021).



4. Use

FTA researchers have highlighted the many opportunities and challenges related to the use of wood and bamboo biomass for bioenergy and biomaterials.

Increasing demand for wood materials has seen FTA research on both traditional and innovative wood use, specifically in four key areas:

- First, support more efficient wood processing to reduce waste, thereby alleviating some of the need for increasing production.
- Second, up-cycle wood waste by converting it into biomaterials and bioenergy, as demonstrated by Korean partners in their research into the effectiveness of biomaterials as binders to produce wood pellets (Ahn and Lee 2014).
- Third, use wood as a substitute for energy-intensive and inorganic materials such as steel, concrete and plastic.
- Fourth, promote the development of new products and approaches, such as using bamboo as a substitute for plastic (Li 2020b). It should be noted that bamboo is at the forefront of innovative biomaterial research, such as in medical science, led by FTA partner INBAR.

A key debate about using woody biomass as feedstock for bioenergy — especially with regard to the shift from fossil fuel energy to woodfuel — relates to equity of access to energy resources; wealthy nations are adopting the use of woody biomass for large-scale electricity generation and heating as a replacement for fossil fuels (Haddad et al. 2019). FTA researchers have

Kitchen laboratory at Kereita village, Kiambu County, Kenya

Photo by Mary Njenga

explored the up-scaling of electricity production from woody biomass (Ackom et al. 2013; Pirard et al. 2017a), which is seen by the global development agenda as an integral part of the shift towards a forest-based bioeconomy.

The global development agenda, especially those elements concerned with climate change and human health, has promoted a rapid transition from traditional highly polluting forms of bioenergy, such as burning wood and dung in open fires, to modern energy systems based on liquid and gas biofuels and non-biomass-based renewable resources such as hydro, wind, geothermal and solar radiation. The International Energy Agency's 2021 report *Net Zero by 2050* (IEA 2021) outlines a strategy to achieve net zero in cooking energy by entirely phasing out traditional biomass (woodfuels) by 2030, replacing them primarily with modern bioenergy and electricity. This is unlikely to occur, especially since woodfuel is a main source of energy for 40% of the world's population (Sola et al. 2016); in sub-Saharan Africa, for example, the demand for wood-based biofuels by rural and urban users is expected to remain steady in the near future (Haddad et al. 2019).

Despite expectations that modernization would make traditional woodfuel obsolete (Sola et al. 2019) through a transition to clean-combustion bioenergy technologies for power generation and transport fuels, certain barriers and constraints have resulted in the persistence of woodfuel use, with negative outcomes (Table 2).

Table 2. Reasons for the persistence of biomass for bioenergy and related FTA research

Push factor	Local response	Negative outcomes	FTA research
High price or low availability of modern fuels (e.g. liquefied petroleum gas)	• Use of woody biomass feedstock for energy	• Depletion of local wood resources • Degradation of forest ecosystems emission reductions • Conflict over access to resources	Yonemitsu et al. 2014
Energy poverty	• Increasing effort by fuelwood collectors to collect biomass farther afield • Preparation of less nutritious, less energy-intensive food	• Depletion of wood resources • Nutritional insecurity • Low productivity of household members	Njenga et al. 2014; Jamnadass et al. 2015; Sola et al. 2016
Rural unemployment	• Increasing charcoal production enterprises	• Forest and woodland degradation and deforestation • Conflict over resources	Sola et al. 2017; Ndegwa et al. 2020
Market and policy incentives for large-scale biomass energy feedstock	• Investor land grabs • Conversion of food production to biofuel production	• Smallholders' loss of farms, farmland and livelihoods • Weakening of local resource governance • Food insecurity	German et al. 2011; Sola et al. 2019
Singular focus at the national level on the development of modern energy systems	• Diversion of development and investment away from improving traditional energy systems	• Inefficient stoves resulting in poor indoor air quality, leading to health problems • High GHG emissions • High demand for biomass feedstock	Mendum et al. 2018

Thus, FTA researchers in sub-Saharan Africa have delved deeply into identifying the socioeconomic, technological and environmental inputs needed for and the potential outcomes of improving woodfuel combustion technologies and energy recovery from woody residues. Of particular concern are the high burden on fuelwood collectors and the health risks associated with smoke emitted by inefficient wood combustion for cooking and by charcoal kilns; both burdens are disproportionately borne by women and children (Duguma et al. 2014; Njenga et al. 2021a).

FTA scientists have pursued an agenda for improving the "traditional" use of woodfuel and securing the sustainable production of woodfuel, as discussed above. Key work has been carried out on increasing the heat productivity of wood-based fuels. FTA partner INBAR has carried out research on the use of bamboo as an alternative and highly efficient feedstock for charcoal production (INBAR 2017; Sharma et al. 2018; Brand et al. 2019; Nti Acheampong et al. 2020), briquettes (Brand et al. 2019; Marafon et al. 2019), and pellets (Ackom et al. 2020). Research on the production and use of briquettes made from charcoal dust recovered from the charcoal supply chain has shown that, depending on the binding agent used, they can have a lower global warming potential than traditional charcoal and provide 16% more cooking fuel to the household (Njenga et al. 2013b) and savings in fuel costs (Njenga et al. 2013c).

In parallel, work in Africa has been conducted on improving the combustion efficiency of charcoal kilns and biomass cookstoves, which reduces the quantity of wood resources needed and the emissions during charcoal production and charcoal and firewood use. It also alleviates the labour burden for women, and improves health outcomes in households (INBAR 2017; Gitau et al. 2019; Njenga et al. 2019; Harvey and Guariguata 2021; Njenga et al. 2021a; Schure et al. 2021a). For scaling up sustainable charcoal FTA scientists developed a practical guide on charcoal production using improved kilns in their work in Kenya (Wanjira et al. 2021) and trained more than 380 charcoal producers. Research on the adoption of improved cookstove technology in Kenya showed that gasifier cookstoves were effective at reducing indoor air pollution and fuel consumption in cooking, but required added labour for choosing specific sizes of wood and were preferred only for cooking certain food types and during certain times of the day (Njenga et al. 2016; Gitau et al. 2019). A complete transition from traditional practices hasn't been achieved after decades of work on cleaner cookstoves and fuels. Instead, the new stoves and fuels are added to the traditional fuels and stoves in a practice referred to as stacking (Gitau et al. 2019; ESMAP 2021; Njenga et al. 2021a), reemphasizing the need for research on biomass energy. Implementation of these new technologies and practices, and their sustained use, requires a keen understanding by researchers and implementers of local sociocultural conditions, including cooking culture, power dynamics and gender aspects (Hollada et al. 2017; Gitau et al. 2019; Sundberg et al. 2020).

5. Value chains

A third dimension of the biofuel and biomaterials sectors, and one that is critical to achieving sustainability and contributing to the shift towards the forest-based bioeconomy, is the value chain. The value chain for many of these commodities originates on farms and in adjacent forests and woodlands, and is initiated by small-scale and often marginalized actors. The value attributed to their work is often undercut by disparities in the power dynamics among supply chain actors, smallholders' lack of access to the necessary capital to improve their operations, and the discriminatory rent-seeking behaviours of other actors. Efforts to uplift marginalized and oppressed actors along the value chains is essential (Rosa and Martius 2021).

This is why FTA has promoted their better integration through involving smallholder producers in multistakeholder discussions; for example, in the Global Platform for Sustainable Natural Rubber (GPSNR). FTA has also promoted production on smallholder farms and degraded lands in villages; supported local enterprises to add value to raw materials; and developed greater entrepreneurial capacity for smallholders in general and women and youth in particular (Essougong et al. 2019; Boissière et al. 2020).

Early FTA work on wood-based value chains included an evaluation of sustainability frameworks for biofuels (Guariguata et al. 2011). More recently, a synthesis was produced that evaluates the multiple initiatives and sustainable frameworks to promote sustainable supplies of forest-risk commodities such as palm oil and plantation timber (Wardell et al. 2021). Both studies signal that producer countries can respond to international or extra-regional policy shifts and to corporate and other private-sector demands for the sustainable production of biomass. Other studies show that the success of sustainability schemes lies in their implementation. For example, FTA researchers and partners evaluated the use and utility of forest certification schemes on the ground in Cameroon, finding that an awareness of certification, a demand in domestic markets for certified wood products, and the presence of policy incentives were essential for widespread adoption (Nukpezah et al. 2014). Piketty and Garcia Drigo (2018) found that the quality of auditing for timber certification had a strong influence on outcomes in Brazil.

Sustainability standards and guidelines are essential for promoting the accountability of actors in the production and trade of biomass, and FTA scientists have been active in helping to produce, shape and implement production and trade standards and guidelines for wood, bamboo and other materials. FTA participates in a working group of the Sustainable Biomass Programme (SBP) with a particular focus on promoting the SBP certification system[2] across the Global South for woody biomass, mostly in the form of wood pellets and woodchips used in energy production. FTA scientists have also advised on the sustainability of planted forests. They provided the scientific evidence base for the discussion of plantations in the UN Committee on Food Security. FTA research on restoration principles and standards (Gann et al. 2019) was used by a CIFOR scientist to co-lead a draft procedure for implementing the Forest Stewardship Council (FSC) policy on forest conversion.

Timber on an arduous journey along the supply chain.

Photo by Robin R. Sears

[2] https://sbp-cert.org.

In 2019, the partners in the SNR-I and GPSN launched the "International Rubber Study Group (IRSG) Sustainability Agenda: A vision for sustainable rubber economy partnership for shaping the value chain of the future." IRSG, in collaboration with CIFOR/FTA, CIRAD and the International Rubber Research and Development Board (IRRDB), held a workshop in June 2020 on Climate Change and Natural Rubber Systems (Pinizzotto et al. 2021), to share information and strategically plan the next steps.

Value chains in the charcoal sector have been well studied by FTA scientists, who have demonstrated that the sector provides critical employment and income for multitudes of rural and urban poor people, especially women (Njenga et al. 2013a; Bennett et al. 2018; Sola et al. 2019; Ndegwa et al. 2020). COVID-19 has put at risk the nutrition and incomes of millions of people, especially in some countries in sub-Saharan Africa, such as the Democratic Republic of Congo, by disrupting supply chains for charcoal (Schure et al. 2021b). The FTA team in Cameroon was able to build on their previous work on local forest governance (Piabuo et al. 2018) to quickly assess the impacts of the global COVID-19 pandemic on community forest enterprises, recommending that adding more local value would help buffer these enterprises from disruptions (Piabuo et al. 2021). Further, both studies found that additional challenges affecting the supply and transport of essential charcoal during the pandemic have made it harder to promote sustainability in the sector.

FTA scientists have empirically described the complexity in the value chains for traditional biomass used for energy and materials (Sola et al. 2019; Sears et al. 2021); in some cases, paying specific attention to gender (Ihalainen et al. 2020). Others have highlighted the critical importance of appropriately coordinated policy interventions in multiple sectors to motivate sustainable outcomes at the charcoal-agriculture connection (Iiyama et al. 2017).

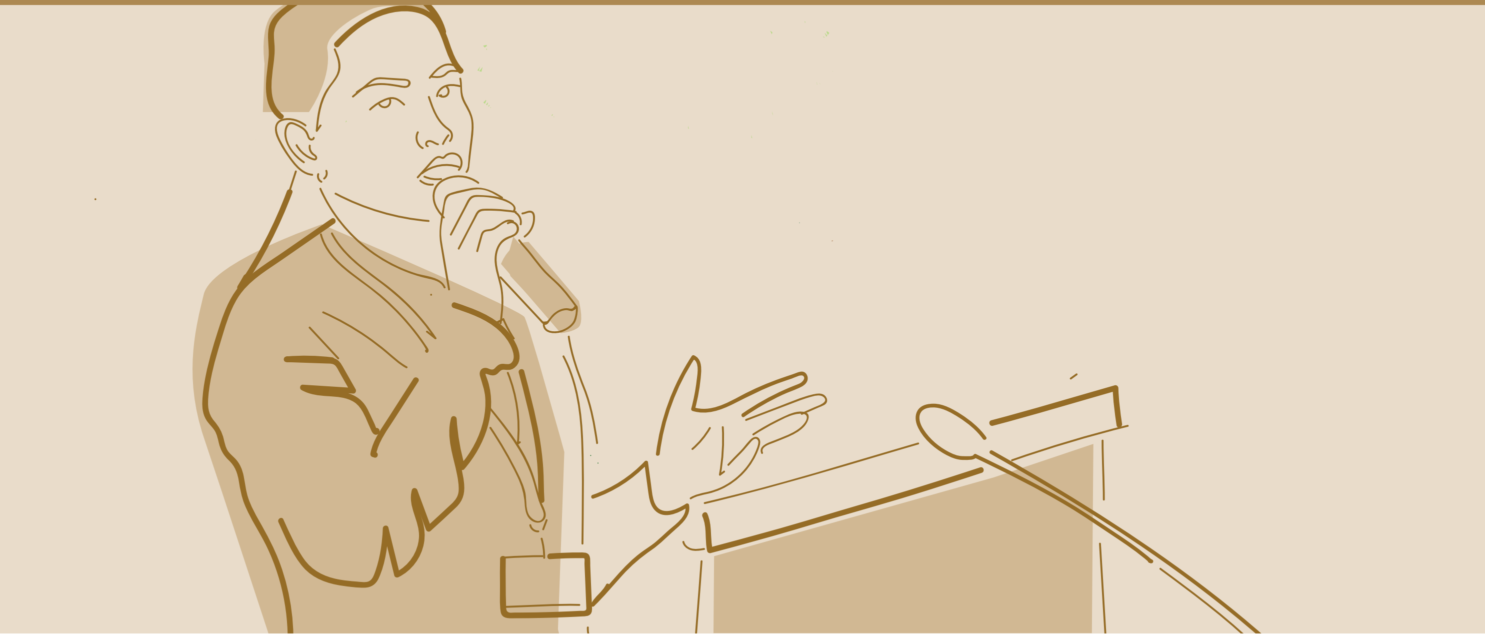
FTA research on value chains for biomaterials has focused on traditional uses of wood for lumber for construction and furniture; on bamboo and rattans for furniture (Kahindo et al. 2015; van der Lugt and King 2019; Li 2020a); and for non-timber forest products such as rubber tree latex (Gitz et al. 2020) and agroforestry outputs (Degrande et al. 2014). With the goal of motivating policymakers and forest authorities to address inequities for and risks to smallholder producers on an informal supply chain of farm-based timber through policy reform, FTA researchers produced a series of papers describing multiple dimensions of the value chain in Peru (Putzel et al. 2013; Sears et al. 2021) and southeast Asia (Putzel et al. 2012). Purnomo et al. (2011) explored scenarios for upgrading small-scale producers and workers in the teak furniture value chain in Indonesia, focusing on women workers. The team followed up on this initial work with action research to help strengthen the position of small- and medium-scale enterprises in furniture value chains (Purnomo et al. 2014).

Processing fallow timber into boards for the Lima market.

Photo by Robin R. Sears

From fallow timber to housing, bolaina boards make their way to a family on the outskirts of Lima.

Photo by Robin R. Sears



6. Policies to support sustainability and equity

The promotion of sustainable wood-based biomass production, use and value chains for bioenergy and biomaterials must be underpinned by appropriate policy, institutional and organizational arrangements, and by investments and finance (Louman et al. 2020). Because each of these dimensions of biofuels and biomaterials involve multiple sectors — including forestry, agriculture, health, energy, materials, industry and trade — policy coherence across sectors is crucial.

Woodfuel biomass, for example, is poorly regulated precisely because it crosses sectors and is largely informal (Sola et al. 2019; Harvey and Guariguata 2021). Furthermore, traditional use of woodfuel — charcoal, fuelwood for cooking and heating in the home — is viewed by national authorities, for example in Cameroon, as a backwater technology with little relevance to providing for the energy needs and income streams of rural residents (Amugune et al. 2017). FTA scientists have called out this view as a double standard, since the use of wood for electricity generation is promoted in the developed world as a modern, climate-smart technology, especially in the European Union (Sharma et al. 2022). In sub-Saharan Africa, policies and incentives related to wood-based bioenergy are highly related to the energy, agriculture and food security agendas (Sola et al. 2016; Mendum et al. 2018).

To this end, FTA researchers have conducted critical analyses on the carbon balance and GHG emissions associated with bioenergy (Bird et al. 2012) and how bioenergy can be used to achieve national goals for renewable energy (Widayati et al. 2017; Widayati et al. 2022). They have been working to inform woodfuel policy and to shift the paradigm related to the modernization of energy systems (Box 5); showing, for example, how innovations in woodfuel production on farms and in cookstove and charcoal kiln efficiency reduce GHG emissions, among other benefits (Njenga et al. 2020).

Box 5. Shifting the paradigm on traditional bioenergy in sub-Saharan Africa

FTA scientists have disseminated key findings associated to bioenergy and biomaterials at numerous global events such as the World Forestry Congress, Global Landscape Forums, and IUFRO World Congress. The 2015 World Forestry Congress in Durban, South Africa, highlighted opportunities for promoting wood as a fuel for the future and for engaging women in rural areas in entrepreneurial woodfuel-based activities, and the need for increased investment in research and development for woodfuel innovation (IISD 2015). Supporting this theme, CIFOR-ICRAF scientists and partners have promoted a paradigm shift in bioenergy in sub-Saharan Africa, effectively expanding the global narrative on SDG 7 (affordable and clean energy). Such a shift is urgently needed; a forest-based bioeconomy approach could stabilize sustainable natural resource use while enhancing social sustainability (Rosa and Martius 2021). FTA scientists have encouraged stakeholders to pursue an agenda that promotes decarbonization through transforming woodfuel systems, rather than phasing them out, suggesting scalable solutions for achieving carbon neutrality in farm-based woodfuel:

1. supporting sustainable raw material production through coppicing, woodlots, intercropping and short rotations with fast-growing species in agroforestry systems;
2. reducing GHG emissions and increasing charcoal yield by improving the efficiency of carbonization (converting wood into charcoal under limited oxygen);
3. improving combustion efficiency and human health by shifting to efficient cookstoves;
4. contributing to a circular bioeconomy through the use of woody residues and agricultural waste as bioenergy and biochar feedstock (Njenga et al. 2020).

FTA scientists emphasize that these solutions should be locally appropriate and supported by investment, technology transfer, capacity development and enabling policies.

Ruth Mendum, Mary Njenga and village women studying womens' cooking energy burden in Kibugu village, Embu County Kenya.

Photo by James Kinyua Gitau

In parallel, FTA researchers began to assess the role of biofuel production, use and value chains from a multifunctional landscape perspective, promoting pathways to ecosystem-based approaches to bioenergy generation by building on the regenerative economy concept (Duguma et al. 2014, 2020). Both teams have applied scientific findings in their contributions to the development of the Kenya Bioenergy Strategy (2020–2027). That strategy is explicit on gender and inclusion; for instance, it considers the gendered needs and aspirations of the community and the roles in and benefits of commercialization, and has a section on mainstreaming gender and youth in bioenergy (MoE 2020). FTA also contributed to the development of standards for sustainable charcoal and carbonized briquettes and exception/removal/zero rating of value added tax on sustainable briquettes, bioethanol and biogas in the country. The role played by FTA scientists in transforming bioenergy policy and regulating instruments in Kenya illustrates the need for scientific evidence and effective participation in dialogue.

In the materials sector, the role, risks and benefits of small-scale material production is often overlooked by policies, programmes and incentives. They fail to recognize its contribution to meeting the domestic demand for timber and to sustaining rural employment and income (Cerutti et al. 2013; Lescuyer et al. 2016; Sears et al. 2018). An FAO-CIFOR study on domestic timber production and demand in Cameroon contributed to the development of an inter-ministerial directive that all public procurement of timber should require legal timber (Cerutti et al. 2014; Lescuyer et al. 2017).

FTA researchers have identified some of the barriers to smallholder farmers' formalizing their engagement in domestic timber value chains (Robiglio and Reyes 2016; Sears et al. 2018). For example, in the Peruvian Amazon, the natural regeneration of fast-growing timber (such as *Guazuma crinita* and *Calycophyllum spruceanum*) in swidden fallows feeds a robust domestic supply chain for small-dimension lumber (Sears et al. 2021). Extensive FTA research on these systems, and engagement with Peru's policymakers and forest technicians, is helping to open up pathways for these local timber producers to legally harvest, process and sell this woody biomass. The goal is to provide incentives and pathways for smallholder farmers to opt to sell the timber rather than burning it as biomass when clearing the land for subsequent cropping.

An example of how to address the cross-sector nature of biomaterials comes from a series of FTA projects on bamboo production and use (Box 6). INBAR scientists produced an information package, including a manual on bamboo biomass and carbon assessment (Bao and Trihn 2019). They guide investments in bamboo plantation establishment and management that support climate change mitigation, money savings and energy provision. Likewise, INBAR researchers have developed a voluntary standard for the establishment of rattan plantations (Muralidharan et al. 2020), and are working with partners to make this an international standard.

The bamboo plant stabilizes soil on slops and high risk landslide prone zones. "Vegetative propagation of bamboos at COBAM project nursery in Rwanda".

Photo by Alba Saray Pérez Terán/CIFOR

Box 6. Bamboo development as a strategic bioenergy resource

The International Bamboo and Rattan Organisation (INBAR) is the driving force for the development and transfer of data, information and technology on bamboo-based production technologies and smallholder bamboo value chains across Africa, Asia and Latin America. INBAR has raised awareness and influenced households to plant bamboo on farms and degraded lands to provide an alternative biomass-based energy source, meet material needs, and improve rural livelihoods, targeting women and youth in particular. INBAR researchers first identified two primary factors that prevent bamboo energy development: limited community knowledge and skills to adopt bamboo planting and energy products; and gaps in national policymakers' awareness of the benefits of bamboo energy. They then set out with a comprehensive research, outreach and capacity-building campaign in several African countries to increase bamboo production and use. They conducted marketing campaigns to increase awareness and built community capacity via training in farm field schools and workshops. Through this work, INBAR has trained 6,000 individuals, mainly women and young people, in bamboo cultivation, carbonization and briquette production and use. More than 10,000 households were engaged, 600 ha of new bamboo were planted, and 10,000 ha of existing stands are being sustainably managed (INBAR 2014).

At the national level, INBAR engaged Ethiopian and Ghanaian policymakers in policy dialogues to inform decision-making regarding the benefits of bamboo for sustainable development and green economies to improve rural livelihoods. INBAR also generated scientific evidence and engaged government officials across sectors via meetings and policy workshops to position bamboo as a strategic resource for national climate change strategies and for economic and energy strategies. The outcomes of this concerted research programme and campaign include the adoption of bamboo in Ghana's national biomass energy policy; a 25-kilowatt (kW) gasifier in Madagascar that generates electricity from bamboo biomass and farm waste, benefiting 173 rural households; and a bamboo power plant in Indonesia that provides 700 kW of reliable energy for 1,200 households in three remote villages.

Another example of how FTA has addressed the cross-sector nature of biofuels and biomaterials is through the Sustainable Wood for a Sustainable World Initiative (SW4SW),[3] a joint initiative (2018–2022) of FAO, CIFOR, ITTO and other partners. The initiative's goals are to strengthen sustainable wood value chains from the local to the global level, and to conduct and promote collaborative activities that enhance the contribution of wood-based products to the sustainable development goals and to the nationally determined contributions to the Paris Agreement. Operating at four levels — policy, operational, scientific and political — the initiative will support the formulation of policy frameworks and approaches and will innovate and promote market solutions. FTA contributed to several SW4SW workshops in Africa (FAO 2019b) and Asia (FAO 2019a), and to a survey of the impacts of COVID-19 on wood value chains and the forest sector's response (FAO 2020).

[3] https://www.fao.org/forestry/sustainable-wood/en/.

7. Towards a forest-based bioeconomy

The cost of unprecedented progress in the global economy and human well-being has been environmental degradation that is pushing many of the earth's systems beyond their boundaries (Steffen et al. 2015). The common misconception — that achieving environmental sustainability requires compromising economic progress — is answered by the movement towards a circular bioeconomy. The widespread use of green technologies, renewable energy and bio-based materials can solve a wide range of issues without putting further burden on the environment. By appropriately managing the modes of production, societies can continue to enjoy the multitude of goods and services provided by the earth's natural systems, and, yes, without compromising economic prosperity. Forests are one of the critical ecosystems that support the bioeconomy, and the term "forest-based bioeconomy" encompasses the subsector of the bioeconomy in which forest biomass constitutes the key renewable biological resource (Rosa and Martius 2021).

While there is no universally accepted definition of bioeconomy, it can be defined as "production, utilization and conservation of biological resources, including related knowledge, science, technology and innovation, to provide information, products, processes and services across all economic sectors aiming towards a sustainable economy" (Global Bioeconomy Summit 2018, 2). The FTA program continues to refine research agendas, directions, questions and activities related to biomass and biomaterials. The sustainable production, use and trade of forest- and tree-based products, markets, enterprises and policies are linked to global discourses relating to the fuelwood crisis in Africa (Arnold et al. 2003; Hiemstra-van der Horst and Hovorka 2009; Munro et al. 2017), renewable energy opportunities in Asia, and global climate change discussions (de Jong et al. 2017; Iiyama et al. 2017). The aspirational goal of a circular bioeconomy is to contribute to decarbonizing the global economy, reducing the use of unsustainable raw materials, and restoring biodiversity while providing jobs and achieving inclusive growth.

In recent years, FTA partners have actively promoted the concept of a forest-based bioeconomy, with a special focus on the Global South. In March 2021, FTA partners convened a conference (CIFOR 2021b)[4] that explored the shift from an economy based on extraction of natural resources and exploitation of human labour to a regenerative circular bioeconomy that invests in building natural capital and human capacity for sustainability. FTA researchers emphasized the fundamental requirement to achieving circularity in the forest-based bioeconomy: recognition of the interconnected nature of the political, social, economic, technological and ecological dimensions of the production, trade and use of woody biomass (Rosa and Martius 2021). Speakers outside of the FTA program validated much of the research in this area, suggesting that economic and business models shift from an extractive to a regenerative relationship with nature; that more attention be placed on the demand side of biomass for bioenergy and biomaterials; and that the demand for wood and bamboo and other natural biomaterials will increase as economies shift away from high GHG-producing materials such as steel and concrete.

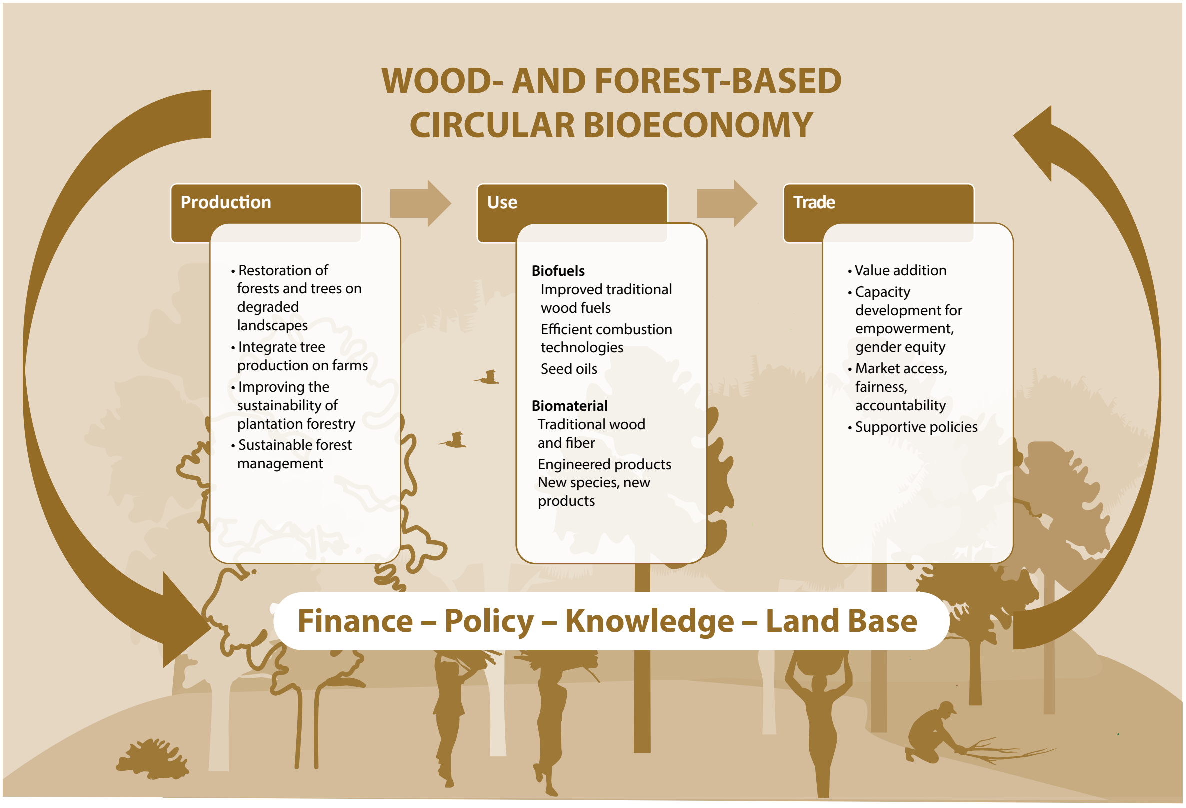
Social equity must be at the core of this shift, and FTA researchers have provided evidence of the need to resolve persistent underlying problems in the social dimensions of the wood sector, especially in forest-related policy, land and resource tenure, and value chains (Rosa and Martius 2021). For example, INBAR researchers presented a case in rural China where bamboo contributes to a circular bioeconomy, showing how its production and use benefits women and household economies, and results in land restoration (Li 2020a).

Furthermore, FTA researchers emphasize the need to approach forest conservation and rural development through ecosystem and landscape approaches (Freeman et al. 2015; Duguma et al. 2020). Restoration in human-dominated areas should be regenerative in multiple dimensions,

[4] On March 19, the European Forest Institute (EFI), the recently merged Center for International Forestry Research (CIFOR) and World Agroforestry (ICRAF) and the Finnish Innovation Fund Sitra, in collaboration with the Global Landscapes Forum (GLF) and the Sustainable Markets Initiative Circular Bioeconomy Alliance (SMI CBA), hosted the world's first conference to examine the forest-based bioeconomy with a focus on the Global South.

including the provision of biofuels and biomaterials to local people and the reestablishment of multiple ecosystem services, and should resolve conflicts related to resource access and land use. Recognizing the high cost of shifting to sustainability, especially for small-scale producers, Louman et al. (2020) have explored the role of innovative finance. For example, CIFOR scientists are exploring the ways by which the sale of agroforestry products — including fruits, honey and woody biomass as feedstock for bioenergy — can subsidize the cost of restoring degraded landscapes.

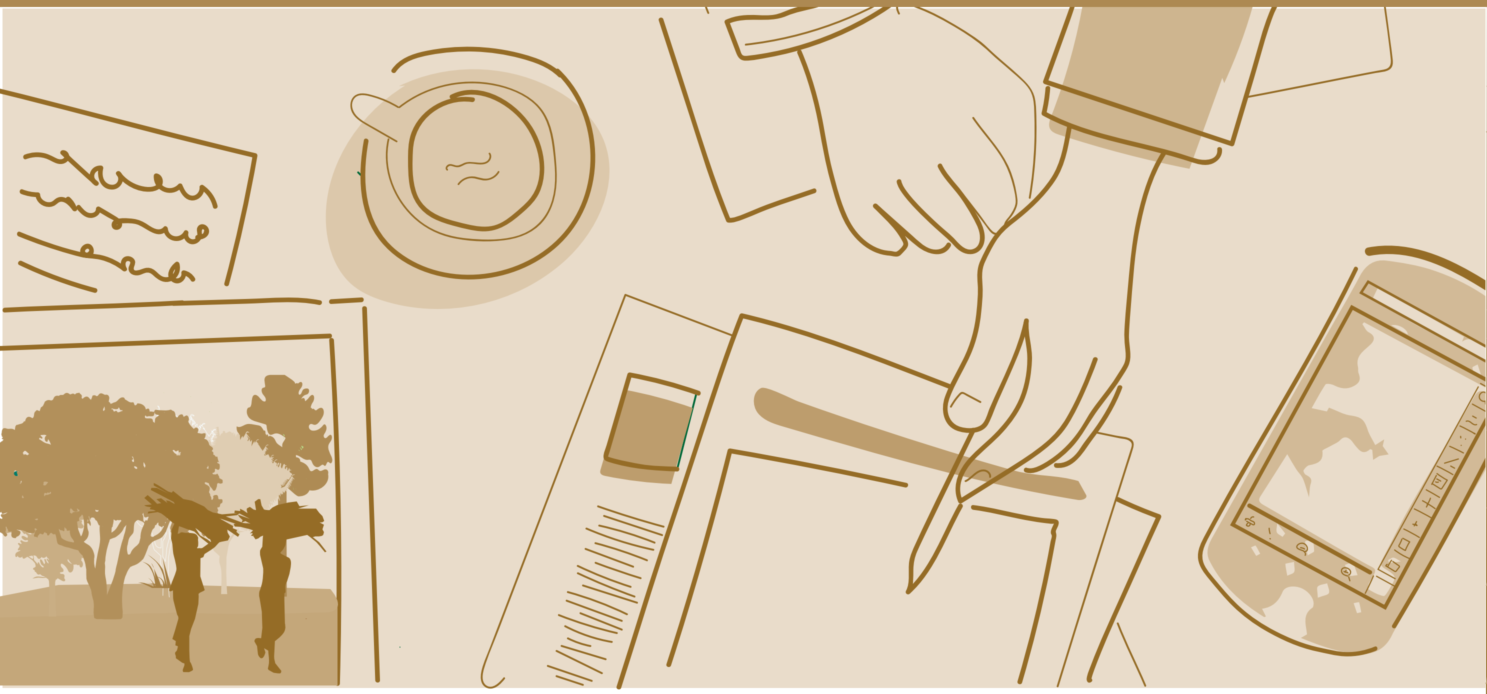
Promotion of a forest-based bioeconomy requires simultaneous advances in all aspects of society and the economy, starting fundamentally with social organization and institutions (Rosa and Martius 2021). The first advances, therefore, must be in the area of social equity, including improvement of living conditions for both current and future generations. This requires sustainable income creation, increasing the quality of life through addressing the inequalities pertaining to benefit sharing, and resource conservation for future generation.



Second, the shift towards a forest-based bioeconomy requires a reversal of trends in deforestation and forest degradation in order to conserve the natural capital that provides the foundation of all life on earth, and is the basis of economies, from local to global. Therefore, production of the resource base must be optimized, balancing production and conservation. Global wood production must shift from a high dependence on extraction from natural forests to more reliance on wood production in diverse systems, including planted forests, agroforestry systems and farm-forestry. This is not easy, given the context of an increasing demand for wood, particularly in Africa (e.g. Kebede et al. 2010, Ndayambaje and Mohren 2011), the long-overdue recognition of land and forest resource rights of Indigenous communities, and lagging implementation of related laws. Increasing production in a sustainable and equitable manner will require targeted private and public investment.

The sustainable production and use of wood resources will necessarily require the management of synergies and trade-offs among development goals and economic sectors. Central to the process of optimization is the point that the wood-based bioenergy and biomaterials agendas must be aligned with the goals of forest landscape restoration (Baral and Lee 2016; Duguma et al. 2020; Harvey and Guariguata 2021).

Third, the development of innovative, inclusive and efficient bio-based value chains is needed. Attention should be paid to the original resource, since there is variability in the recycling properties and environmental sustainability of different products. The third element requires innovation related to adding value in forestry, natural resources and related value chains to improve the livelihoods of rural producers (Rosa and Martius 2021). It also requires recognizing the value of wood processing by-products and co-products. An example of this occurs at the nexus of bioenergy and soil restoration and climate change mitigation, where biochar is co-produced to provide thermal heat for cooking and is used for soil amendment to improve crop productivity (Njenga et al. 2021b).



8. Conclusions and way forward

The FTA program has provided a platform of research on biomass, bioenergy and biomaterials, unique in CGIAR, whose outputs and project outcomes have advanced the state of knowledge about the contribution of woody biomass to the bioenergy and biomaterials sectors. At the core of the research program is the question of how to meet the increasing demand for woody biomass in a sustainable manner, without compromising global food production and forest and tree conservation, and while promoting social and economic equity at all levels and inclusion in value chains.

FTA scientists and partners have illuminated both synergies and trade-offs related to the traditional uses of wood and bamboo (such as fuelwood and lumber) as well as local and external innovations in their transformation and use. They initially produced evidence for unsustainability in the production, use and trade of woody biomass and its products, and subsequently have contributed to building sustainability in these areas.

Ultimately, the goal of FTA program is to contribute knowledge, data, analysis and demonstration projects to integrating bioenergy and biomaterials in a sustainable manner in the transition to a green economy. Research must continue to identify sustainable pathways for the development of green economies, recognizing that these pathways may be different in the Global South than in the Global North.

In service of this goal, FTA partners have launched a new initiative to serve as an umbrella for broad-based change in these sectors: the Transformative Partnership Platform (TPP) Circular Bioeconomy. At the centre of the TPP are three transformational steps.

- First, going green with new biomaterials from forests, plantations and agriculture, leading to innovations in production, use and trade at all scales.
- Second, finding common ground on goals through global dialogues and decisions on diet, products, land use and GHG emissions.
- Third, weaving these together by pooling human and financial resources, blending ideas and creativity, learning together, and adding value across portfolios of diverse forest and tree product value chains.

Future work by FTA partners in the production, use and trade of woody biomass for bioenergy and biomaterials will focus on developing and strengthening the forest- and wood-based circular bioeconomy through the platform.

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2011-2021

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Over the last decade, the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) has undertaken innovative basic and applied research across different scientific disciplines on how woody biomass production and use can be reconciled with biodiversity protection, climate change resilience and mitigation, and inclusive prosperity for local communities. This publication presents key FTA outputs on biomass, bioenergy and biomaterials from 2011 to 2021.

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