RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

FTA HIGHLIGHTS OF A DECADE
2011-2021

Introduction: 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

Introduction: Ten Years of Forests, Trees and Agroforestry Research in Partnership for Sustainable Developments

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The final content remains the sole responsibility of the authors.

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List of acronyms

CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
CGIAR	Consultative Group for International Agricultural Research
CIFOR	Center for International Forestry Research
CIRAD	French Agricultural Research Centre for International Development
FTA	CGIAR Research Program on Forests, Trees and Agroforestry
ICRAF	World Agroforestry
INBAR	International Bamboo and Rattan Organisation
PES	Payment for ecosystem services
SDGs	Sustainable Development Goals

Executive summary

Forests, trees and agroforestry are part of major land-use transitions worldwide, with an impact on the balance between the global issues of planetary boundaries and local concerns about livelihoods and peoples' rights. The 17 Sustainable Development Goals (SDGs) include complex trade-offs between various local and global interests in forests or derived land uses that require effective science-policy boundary work. Use-oriented research carried out by FTA connects three knowledge systems: the various scientific disciplines, local ways of knowing, and the way public discourses and policy reforms (re)frame issues, articulate common goals and seek effective means of implementation. Place-based, context-responsive sustainable development solutions need to build on identities and core values. These interact with socially contextualized rights, knowledge, markets, local ecosystem services and global teleconnections.

This is an introduction to the FTA Highlights of a Decade series, which showcases the main findings, results and achievements of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) from 2011 to 2021. FTA, the world's largest research-for-development partnership on forests, trees and agroforestry, started in 2011. This series features the work undertaken under the FTA program by its strategic partners: Center for International Forestry Research-World Agroforestry (CIFOR-ICRAF), The Alliance of Bioversity and CIAT, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), French Agricultural Research Centre for International Development (CIRAD), Tropenbos International and International Bamboo and Rattan Organisation (INBAR); and other national and international partners.

A decade of research and action by the FTA program has deepened the understanding of the roles of trees in farms and forests on the planet and of land-use and tree-use options in context. It has supported new market connections (traditional and new tree-based food, energy, biomaterials, environmental services), contributed to the emergence of more inclusive business models for tree-based value chains, informed the agendas of national and global forest, climate and food policy and facilitated new forms of governance for the "global commons."

All the work presented in this introduction and in the FTA highlights series was undertaken as part of the FTA program. The series aims to show the extent of actual contributions of FTA to research and development challenges and solutions over a decade, and indirectly, in doing so, to also provide a perspective on the genesis, history and evolving narratives on the related development issues.

1. Forest, tree and agroforestry transitions in context

People have an ambivalent relationship with trees. More than seven billion humans share the planet with approximately three trillion trees (Crowther et al. 2015), which is 46% fewer than at the start of human civilization. The current average ratio of 400 trees per person masks a wide variation. Overall, nearly one-third of these trees are outside the world's four billion hectares of forests, which is 31% of the total land area and 0.52 hectares per person (FAO 2020). Approximately 1.36 trillion of these trees exist in tropical and subtropical regions; 0.84 trillion are in temperate regions (while 16% of global forests is in this zone); and 0.84 trillion are in the boreal region (while 27% of global forests is in this zone, with lower average tree densities per ha; Creed and van Noordwijk 2018; FAO 2016; FAO 2020). An estimated 1.6 billion people depend in part or in full on forests and trees outside forest resources for their livelihoods (Angelsen et al. 2014). More than 800 million people (30% of the global rural population) live on 9.5 million km^2 of agricultural lands (45% of the total area) with >10% tree cover; 180 million on the 3.5 million km^2 of agricultural lands with >30% tree cover; and about 350 million near or within 40 million km^2 of dense forests (Zomer et al. 2016; Chao 2012).

The remarkable success of an increase in agricultural production has come at the cost of environmental integrity. A change in the direction of development towards sustained agility that balances productivity and environmental integrity will be needed to avoid a crash (Figure 1a).

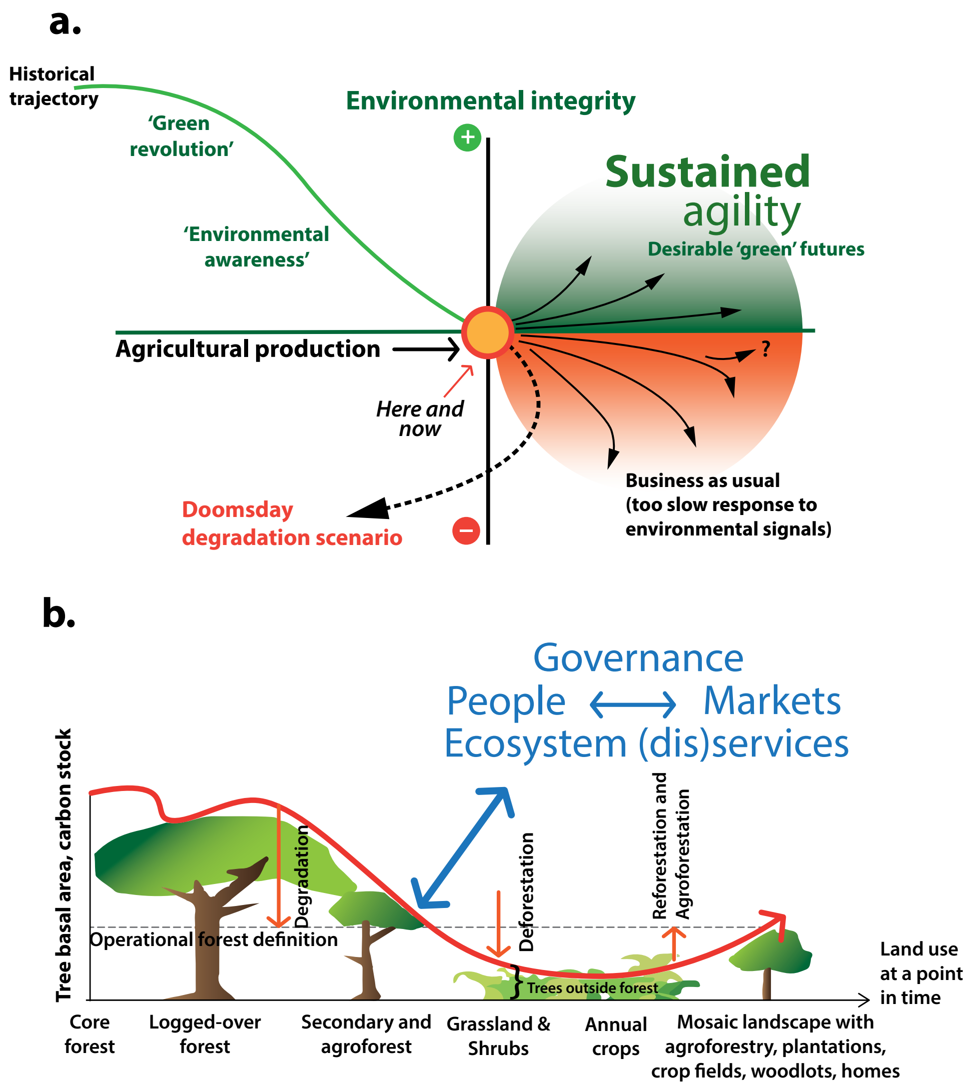


Figure 1a. Global system transition to sustained and agile balance between environmental integrity and agricultural production; **1b.** Schematic depiction of landscape-level tree cover transition (the forest transition curve) adapted from the original FTA proposal (CGIAR 2011).

Forests, trees and agroforestry have to play a key role in this transition. When forests disappear, with time and the action (or inaction) of men and women over land, selected trees come back to the landscape (Stibig et al. 2014). Trees play very diverse roles in a range of natural and modified ecosystems worldwide, including of course forests. The concept of "forest" tends to have both particular biophysical-ecological and social-institutional connotations; part of the empirical literature prefers the term "tree cover transitions" rather than "forest transition" to stay close to what is observed. The tree cover transition (Figure 1b) has been at the centre of attention of the Forests, Trees and Agroforestry (FTA) program over the past decade. When represented in national statistics, the tree cover transition pattern reflects a switch from a stage of dominance by deforestation and conversion of forests to other land categories, to a stage of net increase in forests, often as a result of plantation forestry, with forests that aren't as green on the ground as they may appear to be in the statistics (Xu 2011). But, beyond what is covered in national forest statistics and global forest resource assessments (Köhl et al. 2015), trees also occur outside forests and as intricate parts of agricultural landscapes. This tree density outside forests is increasing globally (Zomer et al. 2016), while forests are being lost in tropical regions and plantations increase elsewhere.

Box 1. Forests, Trees and Agroforestry (FTA): an integrative research program

The FTA program was built around three overarching hypotheses:

1. There is scope for major increases in income, food and nutrition security and resilience for millions of people in the face of climate change through more inclusive and gender-equitable access to and better utilization and management of forests, trees and agroforestry systems.
2. Making nature-based solutions work and optimizing productive and environmental benefits from nature at scales from the farm to the globe requires innovative, evidence-based, integrative, inclusive and people-centered approaches.
3. Public and private governance and institutional arrangements must be transformed and aligned to create the necessary enabling environment that allows forests, trees and agroforestry systems to fully contribute to achieving the SDGs.

FTA works across four main production systems: natural forests, plantations, pastures and cropping systems with trees. It deals with a number of locally and globally important commodities, including timber, palm oil, rubber, coffee, cocoa, coconut, wood fuel, bamboo, rattan and fruits. FTA approaches multifunctional landscapes as systems – where people interact through forestry, agriculture, fisheries, food and energy systems, water management, conservation, value chains and infrastructure, all at the core of the global climate and development agendas. FTA worked in many countries, in very different situations. The highlights that are presented in this series are supported by a lot of work that could not be covered in the space available.

The FTA program (Box 1) has sought to research this transition, not just to be better aware of it and understand its drivers, but primarily to better anticipate the consequences (positive, negative, synergies and trade-offs) of economic development on forests, land use and the environment, and conversely what forests and trees can bring to sustainable development. Trees often outlive human generations. Because of this, investigating the roles of trees means being able to look at the past as much as finding ways to project into the future. The program aimed to engage with those who seek new ways to learn from and avoid past lose-lose outcomes for local livelihoods as well as environmental quality, and to combine forward-looking interventions on a positive, synergetic (win-win) path to sustained agility. Forest protection and trees are seen in FTA as drivers of sustainable development that need to be better known, investigated and leveraged.

Place-based analyses are needed to understand context, and potentially relate it to generic patterns of land-use change. Land-use transitions in various countries have been matched to a pattern of forest (or tree cover) gain after a phase of historical forest loss (Meyfroidt and Lambin 2011). Such a transition, however, can apparently be triggered across a wide range of thresholds of human population densities and stages of economic development (Dewi et al. 2017). Several studies also showed that increases in total forest (or tree) cover at national scale can hide ongoing loss of natural forest within a country, compensated (in terms of the metric used) by increased plantations within the area accounted for. National forest transitions often involve “outsourcing” of the production of food and/or timber to other countries; this leads, often outside the accounting systems used, to “imported deforestation”, from areas where a net loss of forests continues, or is even being accelerated (Meyfroidt et al. 2014). Thus, scale matters for the way transition processes are understood, with moral responsibility not restricted to agreed accounting systems.

The national pattern of losses and gains that may be reported in forest statistics can mask a wide range of conditions within a country, with a coexistence of different stages of tree cover transition such as conversion of natural forest, subsequent land degradation, restoration and increase of agroforestry and (peri)urban forest cover (Dewi et al. 2017). For example, within Indonesia the full set of forest transition stages is currently found between Papua and Java islands, challenging uniform policy development. In the forest and landscape restoration debate, the relative focus on ongoing drivers of degradation versus repairing past damage can be understood in this light (van Noordwijk et al. 2020a; Guariguata et al. 2021). Detailed patterns within countries interact with international policies, such as those on Reducing Emissions by Deforestation and (forest) Degradation (REDD+)and the internationally agreed agenda on Sustainable Development Goals (SDGs).

The tree cover or forest transition concept has served as a recognizable spatial pattern (theory of place) that can be used as a lens to look at landscapes worldwide, in order to describe phenomena as related to a stratified geographic space. It has led to defining landscape categories[1] that are critical to assess the degree of representativeness of any geographic data sampling (Dewi et al. 2017). The concept of tree cover transition also embeds, as its drivers, a set of social-ecological processes that jointly trigger changes at the system level ('Theory of Change'), and enable the identification of key "actionable" leverage points to modify pathways of change and development ('Theory of Induced Change'). See Figure 2.

The theory and empirical evidence behind tree cover transitions offer a framework to understand the complexity of options for action and interventions at a certain place and at a certain time, as 'Options in Context'. This offers a safeguard against overgeneralizations of interventions that have a good local track record in a context that is insufficiently 'unpacked'. It also enables a better understanding of how options of tree use over land interact with peoples' choices, and contribute to better-informed consent (Coe et al. 2014; Sinclair and Coe 2019).

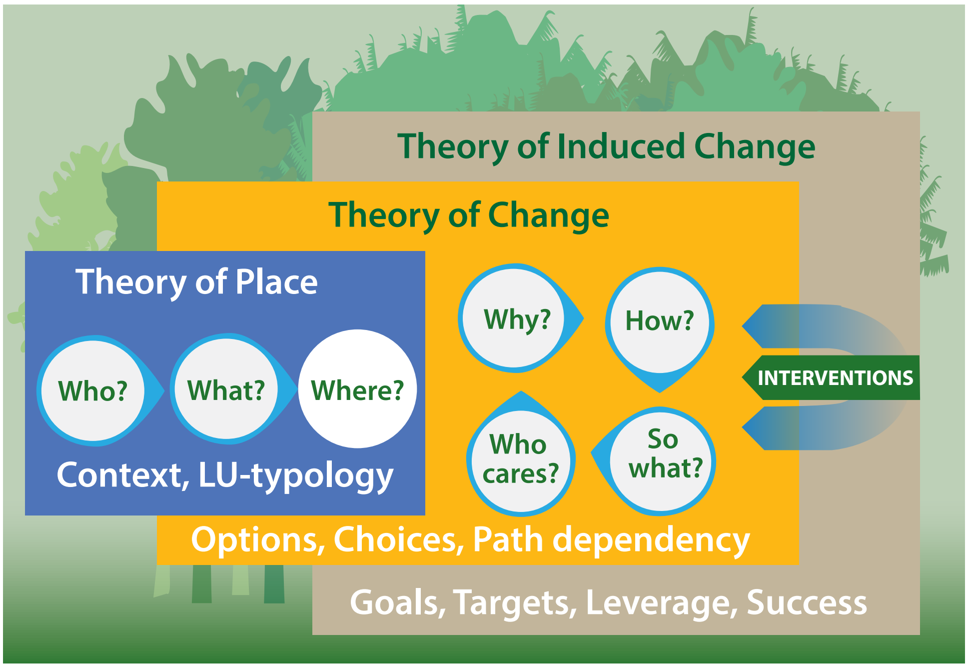


Figure 2. Theories of place, change and induced change and the key questions and concepts with which they are associated in use-oriented research (van Noordwijk 2021c).

[1] Land cover (what is observable by remote sensing) and land use (what people do) come together in landscape typologies, along with the ways in which water flows and biodiversity influence human decisions, roles and rules.

The efforts of FTA, associating CGIAR international agricultural research organizations and key program partners has led to the support of local and national stakeholders in slowing deforestation and in the meaningful and purposeful return of trees to the landscapes. This was based on two key interacting knowledge and decision cycles. The first is the "underlying causes and effects" cycle, linked to the theory of change, with FTA providing increased understanding of the underlying drivers (D), pressures (P), system states (S), impacts on lives, livelihoods and well-being (I), and response options (R) for coherent subnational, national and international programs (Figure 3). Secondly, the "issue attention cycle" (a-to-e) zooms in on the multiple entry-points for responses triggering change by stakeholders and their institutions that can be adaptive, mitigative, transformative and reimaginative, depending on the main point in the DPSIR cycle that it targets. Research-in-development work can contribute in multiple ways to stages a-to-e in the issues attention cycle (van Noordwijk 2021c). Taken altogether, these stages and their entry points can jointly lead to policy reform, institutional change and means of implementation, defining in fact a "theory of induced change."

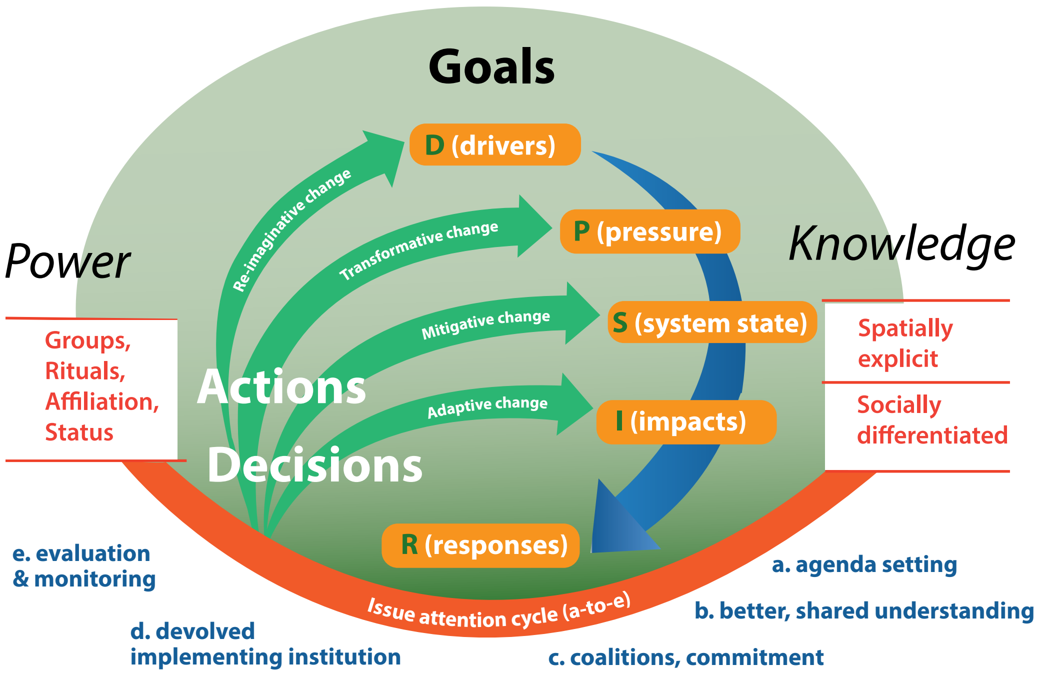


Figure 3. Tree cover transitions may need to be understood at the levels of D: drivers, P: pressure, S: system state, I: impacts and R: responses in which the issues attention cycle (a-to-e) of responses can lead to decisions and actions that induce change, at an adaptive, mitigative, transformative and/or reimaginative level that aligns with goals and is constrained by power and knowledge (van Noordwijk et al. 2020b).

2. FTA, the SDGs and national partners

The FTA program was shaped while the discussions were starting on Rio+20 (2012), which led to the Sustainable Development Goals (SDGs) of the Agenda 2030 of the United Nations, agreed by 193 countries in 2015 (see Figure 4a). While most international agricultural research focuses on crop productivity, which is key to the income and food security goals (SDG 1: No Poverty and 2: Zero Hunger), FTA from the start aimed to balance (Figure 4b) these fundamental goals with those aiming at environmental protection (climate change, life on land, life in water), and those dealing with human development deficits, especially where they relate to forests, forest margins and rural areas (Katila et al. 2019).

Acacia plantation near the village of Moussa, Yangambi - DRC.

Photo by Axel Fassio/CIFO

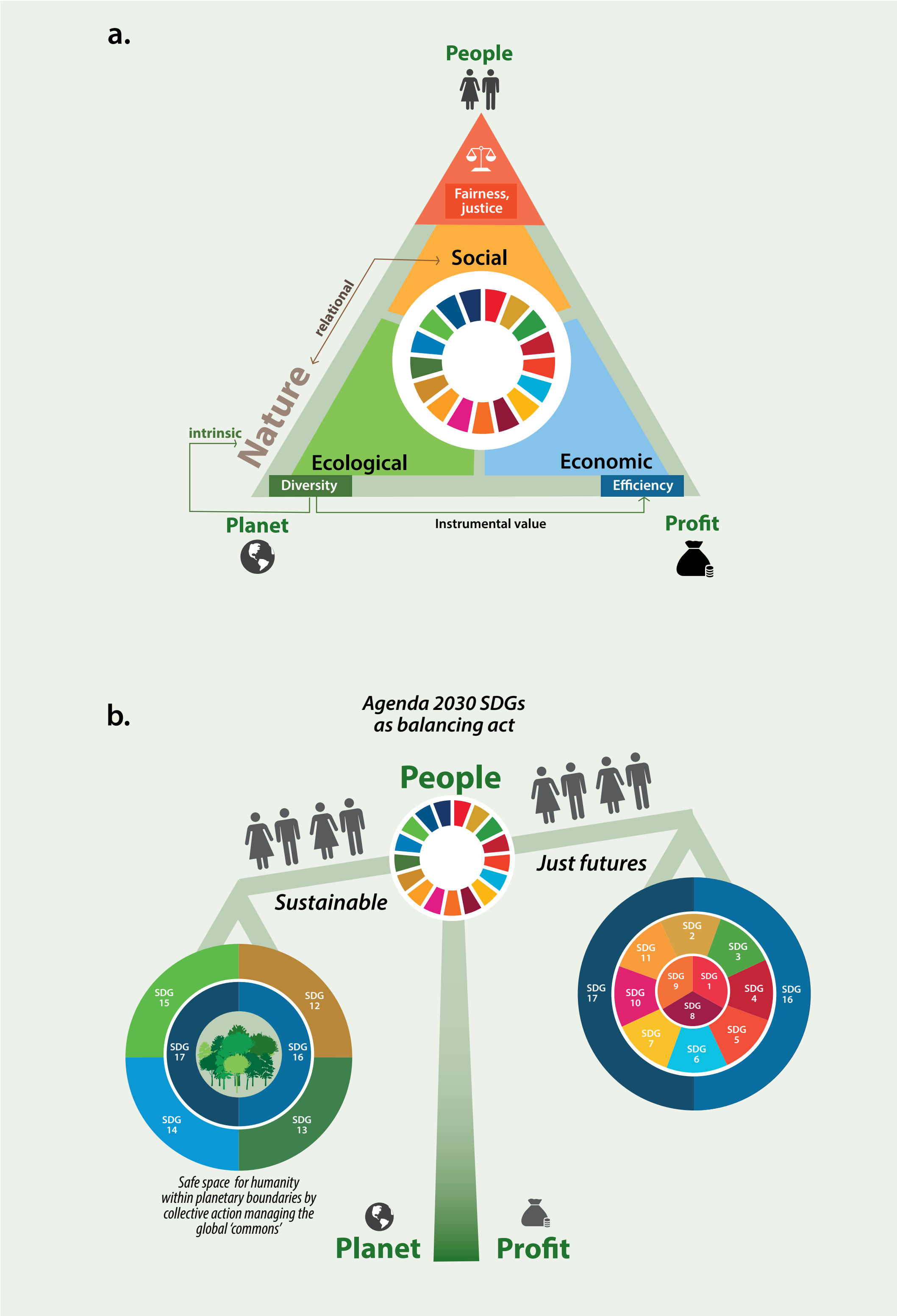


Figure 4a. The triple bottom line of planet, people and profit is reflected in the 17 SDGs and in the instrumental, relational and intrinsic values of nature to people (van Noordwijk 2021c)
4b. Forests, trees and agroforestry connect the two sides of the SDG balance: staying within planetary boundaries of human environmental impact and addressing the development deficits, ensuring that nobody stays behind, with SDGs 12, 16 and 17 as connectors between the two sides.

Aerial view of a Transition Forest area in Bokito, Cameroon.

Photo by Mokhamad Edliadi/ CIFOR

At the heart of this balance of goals, agroforestry can be seen both from the perspective of agriculture and from that of forestry. On the agricultural side of the spectrum, the formal recognition of agroforestry four decades ago was rooted in critiques of the loss of agrobiodiversity in "green revolution" perspectives on agricultural intensification and in recognition of age-old practices that had fallen through the cracks between agriculture and forestry (van Noordwijk 2019). Agroforestry research has since supported the articulation of agroecology principles (Leakey 2010; Prabhu et al. 2015; Wezel et al. 2020; HLPE 2019) that align well with the new "making peace with nature" concepts (UNEP 2021). From the perspective of forestry, agroforestry offers people the opportunity to leverage the extremely wide diversity of tree and non-tree genetic resources originally found in forests in order to shape diverse, productive systems that can coexist in harmony with forests, within mosaic landscapes.

As "the future is now", science for achieving sustainable development (IGS-UN 2019) needs to step over the shadows of the past and the way the past partitioned and segregated different sectors and scientific disciplines. One of several differences between "agriculture" and "forestry" in most institutional traditions is the separate roles of associated ministries. While ministries of agriculture, and the research that they sponsor, generally focus on means of production and productivity such as improved seeds, soil fertility and pest control, and on the way markets and value chains function, the primary function of ministries of forestry is generally oriented towards land stewardship, often managing a substantial part of the nation's land area as state property, especially in places where forests — unlike cropland or pastures — have historically been defined as lands outside of local control. The challenges that agriculture and forestry ministries face in dealing with the more holistic rural development and SDG agenda thus differ quite substantially.

Agriculture is challenged by an environmental agenda, including the fundamental concern that agricultural expansion is a major driver of deforestation, and the trend to simplification of production systems, and by a nutrition agenda, with all the countries in the world affected by combinations of persistent food insecurity, malnutrition and growing obesity. This fundamentally changes the perception of how agriculture relates to both food systems (beyond food supply alone, linked to the quality and diversity of diets) and rural systems (with next generations opting out of agriculture).

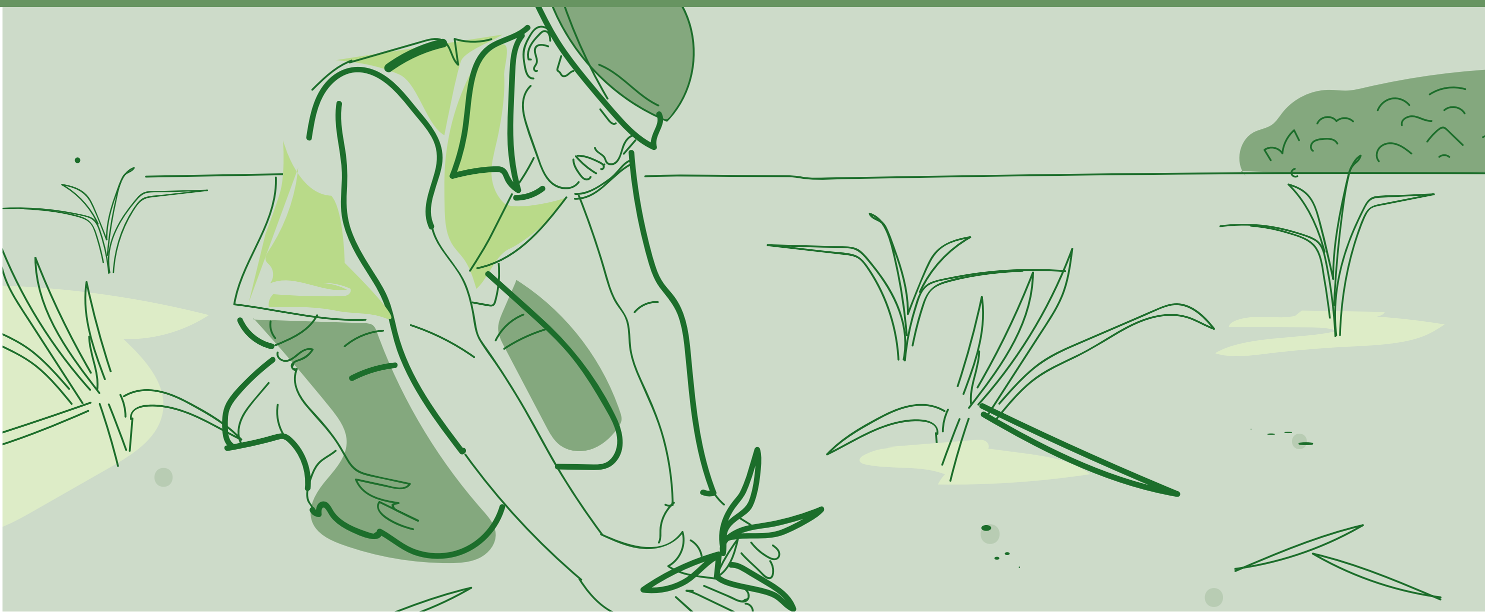
For forestry, in many countries the challenge came first from a confrontation of competing social and economic agendas. The sector is on the one hand a "landlord" of a social agenda (dealing with the "rich forest, poor people" syndrome, and the critical issue of Indigenous Peoples), but forests on the other hand play a critical role as income earners for the state's development agenda, through logging concessions and other ways to extract forest rents. The environmental agenda was initially seen by ministries as externally imposed and a threat, but it helped in finding a new rationale for maintaining forests under state control as providers of water, conservers of biodiversity and resources for mitigating climate change.

Since the Rio conference in 1992 new contexts and objectives led to the sustainable development agenda, and in many ways called for more integrated (not siloed) responses. But, given agricultural and forestry's separate roles and identities, it remained a challenge for agricultural and forestry research organizations to work together with each other and with (academic) social scientists and ecologists to understand the wider interactions in social-ecological systems contributing to economic development under a continuously changing policy environment. International research programs, such as the Alternatives to Slash and Burn (ASB) program that was initiated at the 1992 Rio conference, helped the national research systems in at least some countries take steps in that direction.

FTA built on the initial experience in the ASB program, of science-policy-farmer boundary work in tropical forest margins (Clark et al. 2016). It took on a facilitator role for national partners, within constantly changing donor and investment priorities. It tried to establish an integrated, long-term program built on trust and the comparative advantages of complementary partners and on research being bold, not predominantly risk-averse or driven by short-term performance metrics. From its design phase a central tenet was that a strong, well-designed coalition of disciplines and partners can be robust, by both thinking fast and thinking slow, reaching goals together and valuing shared learning at science-policy interfaces. Diversity was also important in many (diverse) ways (Box 2).

Box 2. Diversity

Where other international agricultural research programs deal with one or a few crops, for FTA diversity is both a strength and a challenge. By current synthesis (Slik et al. 2015) the Indo-Pacific region and the Tropical America region each have a range of 19,000–25,000 tree species. Continental Africa is relatively poor, with a minimum of 4,500–6,000 tree species. Very few species are shared among the African, American and Indo-Pacific regions, and the total number of tropical tree species is at least 40,000. Beyond trees, forests are home to a major share of nearly all terrestrial taxa of plants and animals. Forests also harbor a rich ethnic and linguistic human diversity, with many values, views and voices about desirable futures that relate to the full spectrum of SDGs and beyond. While priority setting is a common part of research management, with expectations of subsequent scaling out or up, new approaches are needed that truly value diversity in all its aspects and avoid the false appeal of one-size-fits-all solutions.



3. Making peace with nature; rediscovering the commons

3.1 Cross-scale relationships

FTA was designed with an ambitious agenda to (i) contribute by research and evidence generation to designing and orienting major global and national agricultural, land, environment and climate policies; and (ii) deliver robust, place-based, context-specific solutions (including technical, social and institutional innovations, and innovations in governance) in response to these issues. To confront and understand diversity, FTA recognized that a cross-scale analytical framework was needed to recognize similarities, appreciate differences, understand the path dependency of historical choices, and explore current options. This forms the basis for a theory of change for socio-economic and ecological systems (Figure 5), which FTA's theory of induced change was subsequently grounded on (the latter theory links FTA's and other external actors' interventions to the changes they "induce" inside the social-ecological system).

Coffee near Yangambi, DRC.

Photo by Axel Fassio/CIFOR

In building such a theory of "induced" change with explicit assumptions that can themselves be tested and where relevant modified, it is critical to be very humble and recognize that – as experience shows — whatever the specific entry point for change-oriented interventions (technology development, value chain support, tenure reform, ecosystem service payments, restoration or global carbon markets, for example), any of the other (contextualized) aspects may emerge as a dominant factor in the subsequent dynamics, and this may necessitate a revision of the original theory of induced change of the program with stakeholders. This is why learning processes are so important, not only as a part of FTA research methods, but as a principle for action by stakeholders. For more information on capacity development for use-oriented, integrative and transdisciplinary science conducted within FTA, see Highlight No.16 in this series (Wardell et al. 2021).

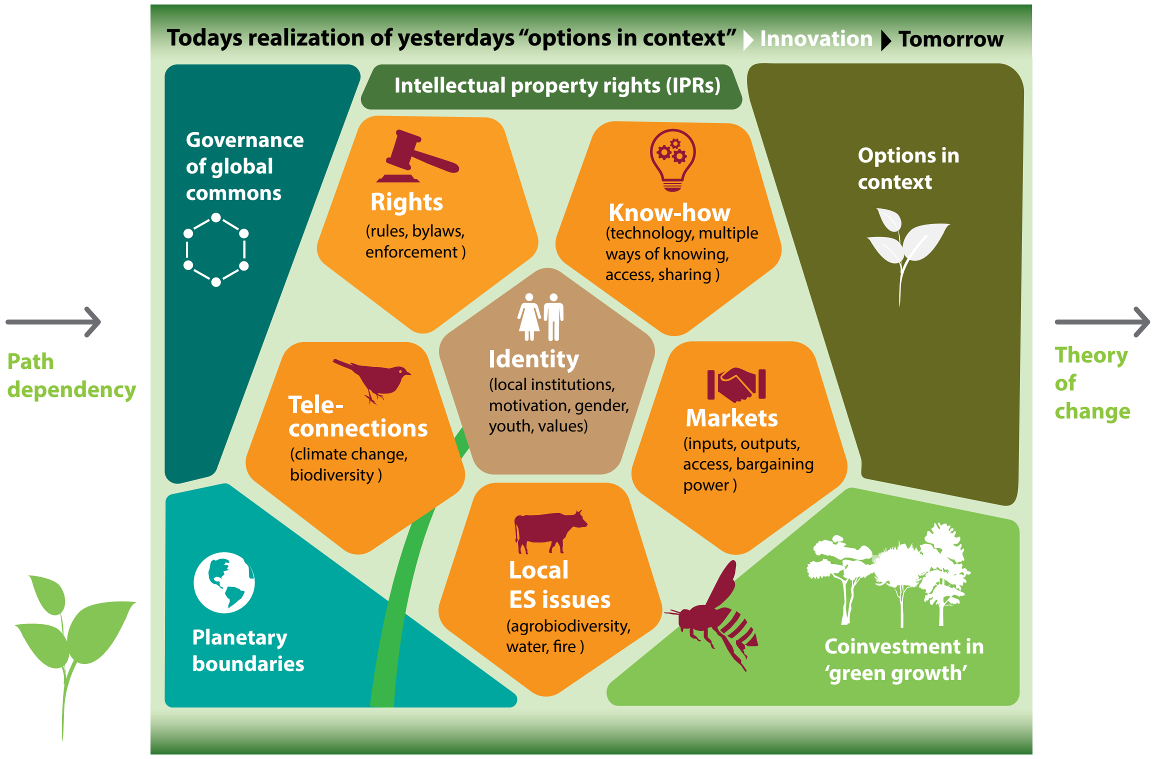


Figure 5. Analytical framework for understanding people (centre) in landscapes interacting with livelihoods and policies, as part of a process in time where today's options lead to tomorrow's choices; ES = ecosystem services

The remainder of this section discusses some highlights and examples for the six pentagons in Figure 5. These represent at the same time a typology of key intervention domains and building blocks with which to construct typologies of contexts.

3.2 Identity, local institutions, gender

The way that identity (at the centre of Figure 5) is expressed depends strongly on cultural context, language, religion, rural-urban gradients and intergenerational dynamics. Individuals may see themselves at the intersection of various ways of grouping people (Colfer et al. 2018). Gender aspects of tree preferences (Sari et al. 2020), value chain development (Kiptot and Franzel 2012), migration (Mulyoutami et al. 2020) and climate change adaptation (Djoudi and Brockhaus, 2011) have, for example, been described, but gaps remain (Colfer et al. 2015). For more information about work on gender equality and social inclusion conducted within FTA, see Highlight No.15 in this series (Elias et al. 2021).

Food sovereignty has been qualified as the fifth pillar of food security, beyond supply, access, utilization and stability (Jemal et al. 2018) and is linked to identity. Nutrition can be derived from forests, landscapes, homegardens and markets (Vinceti et al. 2013; Ickowitz et al. 2014; Powell et al. 2015; Vira et al. 2015; Fungo et al. 2016; Jemal et al. 2021). Storable staple foods, such as rice in Asia, can be more easily "outsourced" in exchange for marketable forest and agroforestry products than other complements of healthy diets (van Noordwijk et al. 2014a). For more information about work on food security and nutrition conducted within FTA, see Highlight No.5 in this series (Ickowitz et al. 2021). Other aspects of identity emerge when values of the natural elements of landscapes are mapped, with the rationality appeal of instrumental ("ecosystem service") values complemented by the relational values that appeal to sociality (Zafra-Calvo et al. 2020; van Noordwijk 2021b). Ostrom (1990) reappreciated the "commons" as a domain where local institutions can emerge and prevent tragedies (Araral 2014). This resonates strongly within the forest and agroforest literature. It blends the sociality perspective on human decision making (Hofstede et al. 2021) with the bounded rationality perspective of behavioral economics (Thaler and Ganser 2015).

3.3 Rights, governance

In many countries forests are still defined by restricted rights of access, use, transformation, inheritance and sale (Galik and Jagger 2015), rather than by their vegetation and tree cover. The nation state claims to be the owner

A view of primary rainforest in Honitetu village, West Seram regency, Maluku province, Indonesia on August 22, 2017.

Photo by Ulet Ifansasti/CIFOR

in many cases, although the constitutional basis of such claims has been successfully contested in some forest-rich countries (Myers et al. 2017). In the last decades forms of community forestry have emerged as types of co-management, as documented for example in Cameroon (Piabuo et al. 2018; Duguma et al. 2018; Minang et al. 2019) and in the Maya Reserve in Guatemala (Millner et al. 2020). Control over forests has shifted from central to more local governments in some countries, but this trend was reversed in other countries (Capistrano and Colfer 2005; Colfer 2012; Agung et al. 2014). Social forestry initiatives remain under pressure where ambitions cannot easily be reconciled (De Royer et al. 2018; van Noordwijk 2020). Emerging recognition of agroforestry in the policy domain (de Foresta 2013; FAO 2013; Singh et al. 2016) is more challenging for the "farmers in the forest" aspects than for the "trees on farm" aspects (van Noordwijk 2019). Where private tenure control has long been seen as essential for economic progress, de facto local community institutions have resurfaced in various contexts (van Noordwijk 2017; He 2021). The observation that around 15% of oil palms in Indonesia are growing within the state forest zone, while there is no legal way this could happen (Purwanto et al. 2020), indicates a challenge for all involved. For more information about work on governing forests, agroforestry and trees for delivering on the SDGs conducted within FTA, see Highlight No.14 in this series (Minang et al. 2021a).

3.4 Know-how, trees, options in context

Constraints to and opportunities for tree diversity management (Ordonez et al. 2014) along the forest transition curve (Figure 1b) (see) have been the basis for tree domestication (Leakey et al. 2012; Ofori et al. 2014) and genomic characterization of African orphan (or underutilized) crops (Hendre et al. 2019). For more information about work on seeds and seedlings conducted within FTA, see Highlight No. 2 in this series (Graudal et al. 2021). Interventions to mainstream nutritious orphan crops into African food systems are mostly in the social domain, however (McMullin et al. 2021). A global analysis found contextual differences in rural livelihoods and specifically in forest-derived environmental income (Angelsen et al. 2014). Cacao (Somarriba et al. 2013), coffee (Carsan et al. 2013; Nguyen et al. 2020) and rubber (van Noordwijk et al. 2012b) agroforestry are some of the best studied systems at the interface of farmer and science-based knowledge. For more information about work on trees on farms conducted within FTA, see Highlight No.7 in this series (Somarriba et al. 2021).

Reconciling bottom-up participation with the production of widely applicable research outputs is a form of systems science working at the scale of impact (Sinclair 2017). It includes examples such as understanding patterns of tree adoption on farms in the local context (Iiyama et al. 2017a); farmers' knowledge of soil quality indicators (Kuria et al. 2019); tree regeneration in farmers' fields (Bayala et al. 2020); and evidence that blending farmers' knowledge and external knowledge can yield more diverse and inclusive agroforestry options (Dumont et al. 2019). 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).

Women of the Perigi Village travelling along rubber gardens.

Photo by Rifky/CIFOR

3.5 Markets, co-investment in green growth

Markets as physical locations for social exchange are hot spots for knowledge sharing, and they form the basis of value chain development for forest and agroforestry products (Nang'ole et al. 2011; Donovan et al. 2015). Specific attention has been given to wood energy value chains (Cerutti et al. 2015), including illegal charcoal trade (Iiyama et al. 2017b). For more information about work on biomass, bioenergy and biomaterials conducted within FTA, see Highlight No.8 in this series (Baral et al. 2021).

A key component of the landscape approach (Freeman et al. 2015; Minang et al. 2014b, 2015; Sayer et al. 2017; Zinngrebe et al. 2020) has been to reconcile value chains, economic actors, governance systems and local communities. Impacts of international timber procurement policies were studied; for example, in Cameroon (Atyi et al. 2013), as were impacts of timber certification in a number of countries (Cerutti et al. 2011; Romero et al. 2017). A comparative study on the certification of timber versus that of tree crops (Leimona et al. 2017; Mithöfer et al. 2017a,b; Purnomo et al. 2020) focused on consumers' awareness of their social and environmental footprints as the start of moral and economic pressure on value chains, leading to the emergence of voluntary standards and certification of compliance with standards. For more information about work on sustainable value chains and finance conducted within FTA see Highlight No.10 in this series (Brady et al. 2021).

3.6 Local environmental service issues

As the "provisioning" part of ecosystem services has been described in 3.4 and 3.5, the focus here is on environmental (especially regulating) services. Among those services, the impacts of land use and its spatial organization on the quantity, quality and regularity of water flows has nearly universal importance (van Noordwijk et al. 2016a; van Noordwijk 2021a). Over the past two decades the perspectives on forest-water interactions have changed (Creed and van Noordwijk 2018), from a binary view that associated forests with positive impacts on all aspects of water, to a quantitative one where the green water[2] use by trees (or other vegetation) is seen to compete with downstream (blue) water availability (Figure 6). More recent studies suggest that the pendulum has partially swung back, as positive effects of forests and trees on atmospheric water availability and rainfall downwind (rainbow water) became better understood and acknowledged (Ellison et al. 2017, 2019). Understanding the conditions under which and the degree to which forests reduce downstream flood risks has, similarly, shifted from categorical to context-dependent assessments, with distinctions based on infiltration rates rather than tree cover (van Noordwijk et al. 2017). Tree roots, depending

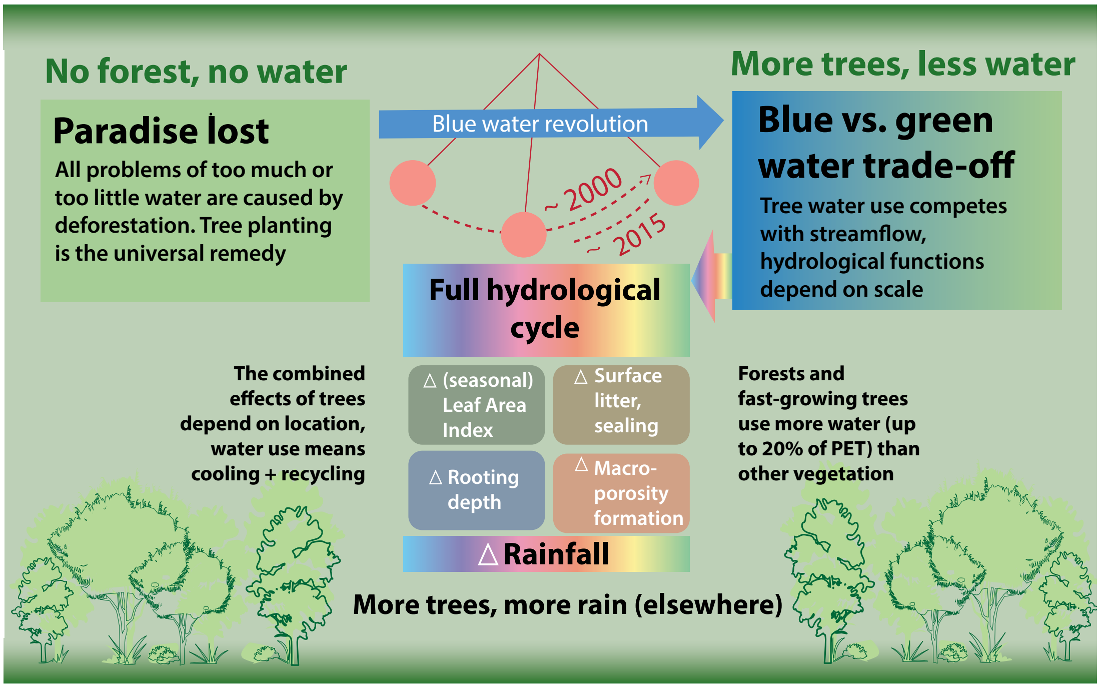


Figure 6. Paradigm shifts in the way forest-water-people relations have been understood and translated to policy instruments (van Noordwijk et al. 2018a); PET = Potential evapotranspiration; Δ = variation.

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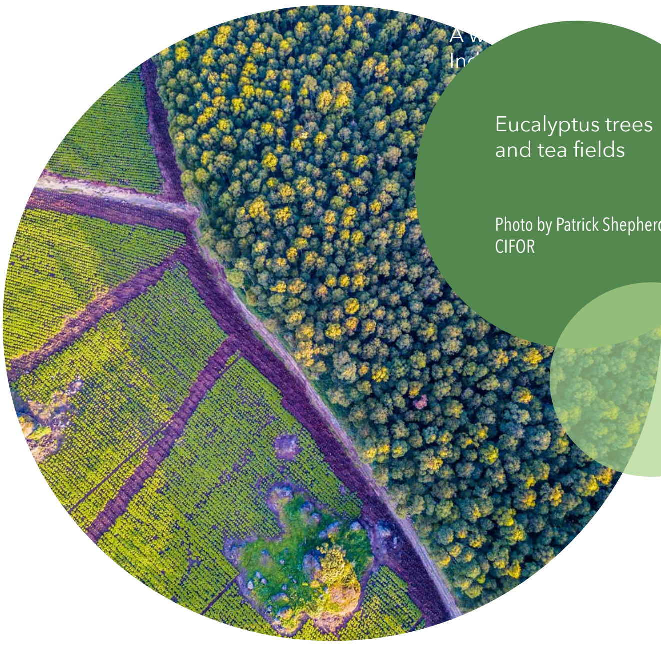
[2] Green water is precipitation on land that does not run off or recharge the groundwater but temporarily stays as waterfilms on the vegetation or is stored in the soil. Blue water is surface water and groundwater in streams, rivers, lakes and reservoirs, the traditional focus of hydrology and of downstream stakeholders. Rainbow water is atmospheric moisture that can become downwind precipitation (rainfall) (van Noordwijk et al. 2014b).



Eucalyptus trees and tea fields

Photo by Patrick Shepherd/ CIFOR

on their architecture, can reduce landslide risks (Hairiah et al. 2020b). Since dealing with water-related risks (droughts and floods) is a major part of climate-change adaptation (van Noordwijk et al. 2021), as well as forest landscape restoration (Guariguata and Evans 2020), local issues spill over to the global teleconnections category. Local knowledge and ways of interpreting tree-cover transitions need to be reconciled with those of downstream stakeholders, if effective feedback mechanisms and landscape governance are to be established (Leimona et al. 2015a; van Noordwijk et al. 2020b; Seijger et al. 2021). While a large share of existing payment for ecosystem services (PES) initiatives are based on water, the extent to which realistic assessments of likely impacts informed the institutional PES design remains contested (van Noordwijk et al. 2012a, Leimona et al. 2015b; Wunder 2015; Börner et al. 2017; Namirembe et al. 2017). For more information about work on multifunctional landscapes for sustainable development conducted within FTA, see Highlight No.13 in this series (Minang et al. 2021b).

At the interface of local ecosystem services and global climate change, the soil carbon stocks in agroforestry (Shi et al. 2018; Hairiah et al. 2020a), mangroves (Sasmito et al. 2020) and land affected by grazing and fire (Aynekulu et al. 2021) have received attention, as has quantification of the additional water buffering by soils with higher soil carbon levels (Gusli et al. 2020), as specific example of the synergy between mitigation of and adaptation to climate change (Duguma et al. 2014; Cardinael et al. 2021). Climate change is predicted to shift tree crop ranges, through changes in temperature and hydroclimate (de Sousa et al. 2019). For more information about work on adaptation to climate change conducted within FTA, see Highlight No.12 in this series (Meybeck et al. 2021).

3.7 Teleconnections (Climate change, Biodiversity)

Tele-connections, one-way effects at distance, can become institutional, two-way 'tele-coupling' if stakeholders become aware, have shared understanding of how it works, agree on common goals and effective means of implementation and monitoring (Fig. 3). At the interface of local and global concerns about forest and tree cover transitions the loss and possible restoration of (agro)biodiversity is a major topic of research. For more information about work on conservation of tree biodiversity and sustainable forest management conducted within FTA , see Highlight No.3 in this series (Vinceti et al. 2021). Expanding rubber plantations in mainland Southeast Asia threaten both biodiversity and livelihoods (Ahrends et al. 2015), similarly to oil palm expansion in insular Southeast Asia (Meijaard et al. 2018) and cacao expansion across the humid tropics (Dewi et al. 2017). Contributions of biodiversity to the sustainable intensification of food production (Dawson et al. 2019) and the "empty forests, empty stomachs" relationship (Nasi et al. 2011) connect back to food security (Section 3.2). For more information about work on wild meat conducted within FTA, see Highlight No.6 in this series (Nasi et al. 2021). Also, the origins of the Covid-19 pandemic have been attributed to human-wildlife interactions (Duguma et al. 2021).

Policies and interventions for the conservation of global biodiversity haves historically focused on maintaining enough areas without human access or interventions (so called "protected areas") - thereby segregating lands and seas between areas with human activities and areas (mostly) devoid of direct human presence or influence (apart from global change). Such international and national policy focus on "protected areas" does hide the fact that the integration of biodiversity in forest management and in productive landscapes can make substantive contributions as well (van Noordwijk 2012a). Protected areas often had social externalities and led to conflicts with local communities and indigenous peoples, making the ongoing discussion on the next 2030 CBD targets for conservation very controversial (Ellis and Mehrabi 2019). Translating the science of forest biodiversity and the delivery of ecosystem goods and services into policy has remained a challenge (Thompson et al. 2011). Although expectations have been high for landscape approaches that include protected areas but also provide livelihood and development options elsewhere, in practice learning has been uneven and often slow (Reed et al. 2019). For more information about work on monitoring, evaluation, learning and impact assessment conducted within FTA, see Highlight No.17 in this series (Belcher et al. 2021). At the start of the REDD+ process there was hope that lessons could be learned from previous integrated conservation and development programs (Minang et al. 2013; Lambin et al. 2014), but there

Pilot farm in Yangambi - DRC.

Photo by Axel Fassio/CIFOR

is little evidence that this happened (Angelsen et al. 2017, 2018; Duchelle et al. 2019). REDD+ institutions and project proponents remains quite focused on forests as such, rather than on landscape-level carbon accounting and accountability (Minang et al. 2014a,b), and have been overtaken by the shifts of policy focus to regional planning for low-carbon development and green growth strategies, with the inclusion of subnational jurisdictions as active partners in the discussion (Minang et al. 2014b). REDD+ progress was studied by FTA in relation to deforestation and forest degradation drivers (Hosonuma et al. 2012), land allocation, land tenure, power, beneficiaries and land-grab conflicts (Brockhaus et al. 2012; Larson et al. 2013; Brockhaus et al. 2014; Luttrell et al. 2013; Carter et al. 2017; Duchelle et al. 2017; Sunderlin et al. 2017, 2018). 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).

3.8 SDG governance of commons

Finally, the SDG framework allows the discussion to return full circle to issues of governance, the local and global commons, and synergy between agriculture and forestry in the food, energy, water and income nexus (Mbow et al. 2014; van Noordwijk et al. 2018b; Rosenstock et al. 2019; van Noordwijk 2019). In the process the understanding of forests (Moeliono et al. 2017; de Royer et al. 2018; Polinko and Coupland 2021), trees (Leakey 2014; Cloke and Jones 2002) and agroforestry (van Noordwijk et al. 2016a) has evolved: theories of change can lead to changes of theory. People-centric nature-based land restoration through agroforestry will, for example, have to be tenure responsive (van Noordwijk et al. 2020a; McLain et al. 2021). For more information about work on forest and landscape restoration conducted within FTA , see Highlight No.4 in this series (Guariguata et al. 2021).

Woman carrying a solar pannel near Yangambi, DRC.

Photo by Axel Fassio/CIFOR

4. Structure of the series

This introduction to the results and achievements of a decade of FTA activities draws attention to issues starting with trees and forests, rural livelihoods and national policy agendas. Of course, the three overlap, and realistic theories of induced change will probably have to include elements of all of them. See Figure 7.

1. Introducing FTA Highlights: Ten Years of Forest, Trees and Agroforestry Research in Partnerships for Sustainable Development

TREES, AGROFORESTRY, FORESTS

2. Tree Seed and Seedling Systems for Resilience and Productivity
3. Conservation of Tree Biodiversity and Sustainable Forest Management
4. Forest and Landscape Restoration

CROSS-CUTTING

16. Capacity Development
17. Monitoring, Evaluation, Learning and Impact Assessment

LIVELIHOODS

5. Food Security and Nutrition
6. Wild Meat
7. Trees on Farms to Improve Livelihoods and the Environment
8. Biomass, Bioenergy and Biomaterials
9. Improving Rural Livelihoods through Supporting Local Innovation at Scale
10. Sustainable Value Chains, Finance and Investment in Forestry and Tree Commodities

SDGs

11. REDD+: Combating Climate Change with Forest Science
12. Adaptation to Climate Change with Forests, Trees and Agroforestry
13. Multifunctional Landscapes for Sustainable Development
14. Governing Forests, Trees and Agroforestry for Delivering on the SDGs
15. Advancing Gender Equality and Social Inclusion

18. The Way Forward

Figure 7. Structure of the highlights series in view of the various roles that FTA science plays in societal processes of change at interacting scales.

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