AGROFORESTRY MODELS AND BUSINESS CASES

INTERNATIONAL EXPERIENCES

Netherlands Enterprise Agency

WAGENINGEN UNIVERSITY & RESEARCH

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About This Document

This document has been prepared by Mirjam Pulleman, Elsbeth Smit and Esther Wintraecken at Wageningen University and Research as a deliverable for the RVO-funded project "Agroforestry in Tea and Coconut Plantations in Sri Lanka" in compliance with the grant agreement on 'Dutch Agroforestry Expertise' (ref nr. 202104120). This deliverable is part of the inception phase of the project and aims to inspire project partners and stakeholders to engage in the co-design of integrated agroforestry production systems and business models, based on international examples and lessons learnt.

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Photo Credits

Front cover, upper picture: Women harvest tea leaves in Northeast, India. Amit Ranjan/Unsplash (CIFOR-ICRAF). Front cover, bottom pictures: Cacao-Coconut agroforestry systems, Colombia. Nacional de Chocolates.

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SRI LANKA IS THE FOURTH LARGEST TEA PRODUCER IN THE WORLD AND THE FOURTH LARGEST COCONUT EXPORTER. THE TEA AND COCONUT INDUSTRIES ARE VITAL FOR THE NATIONAL ECONOMY AND RURAL LIVELIHOODS.

Introduction

Sri Lanka is the fourth largest tea producer in the world and the fourth largest coconut exporter. The tea and coconut industries are thus of critical importance for the national economy and rural livelihoods. In addition to smallholder tea and coconut production, Sri Lanka has a substantial area of mono-culture coconut plantations and mono-culture, degraded or even abandoned tea plantations that are privately or state owned. Over time, population growth and increasing market demand have induced a focus on maximizing yields, a strong simplification of the plantation production systems and high dependency on agrochemicals. Nowadays, many plantations face serious challenges in terms of land degradation, aging of the plantations, climate change, price volatility, labour scarcity and increasing production costs. This results in low productivity, low market competitiveness and limited capacity to adapt to new international quality and sustainability standards.

Diversification of the plantations using an agroforestry approach is seen as a promising strategy to regenerate the productivity and viability of the plantations, while generating benefits to the environment and rural populations. However, transformation of degraded plantations into highly productive and economically viable agroecosystems is not straightforward. Agroforestry models require adaptation to the specific agroclimatic and social context and may also require new market linkages and alternative business models. Yet, practical examples or guidelines for the transformation of tea and coconut plantations to agroforestry-based production models that integrate agronomic, environmental, social and economic aspects are not available in Sri Lanka.

It is in this context that the Embassy of the Netherlands in Colombo and the Netherlands Enterprise Agency (RVO) initiated the project "Agroforestry on tea and coconut plantations in Sri Lanka". This project aims to facilitate a public-private partnership to develop an integrated agroforestry approach to be piloted in one degraded coconut and one degraded tea plantation. The pilots will be used to formulate guidelines for the sustainable management of degraded tea and coconut plantations based on an agroforestry approach and facilitate upscaling to other degraded tea and coconut plantations.

The development and scaling of agroforestry interventions requires strong involvement of stakeholders at local, national and international levels. A participatory approach with active engagement of public and private sector stakeholders is essential to achieve positive environmental and social outcomes and strengthen possibilities for replication. Important stakeholders in the project are the owners, manager and workers of tea and coconut plantations on which the pilots take place, while RVO will also involve national and international stakeholders that can support piloting and scaling.

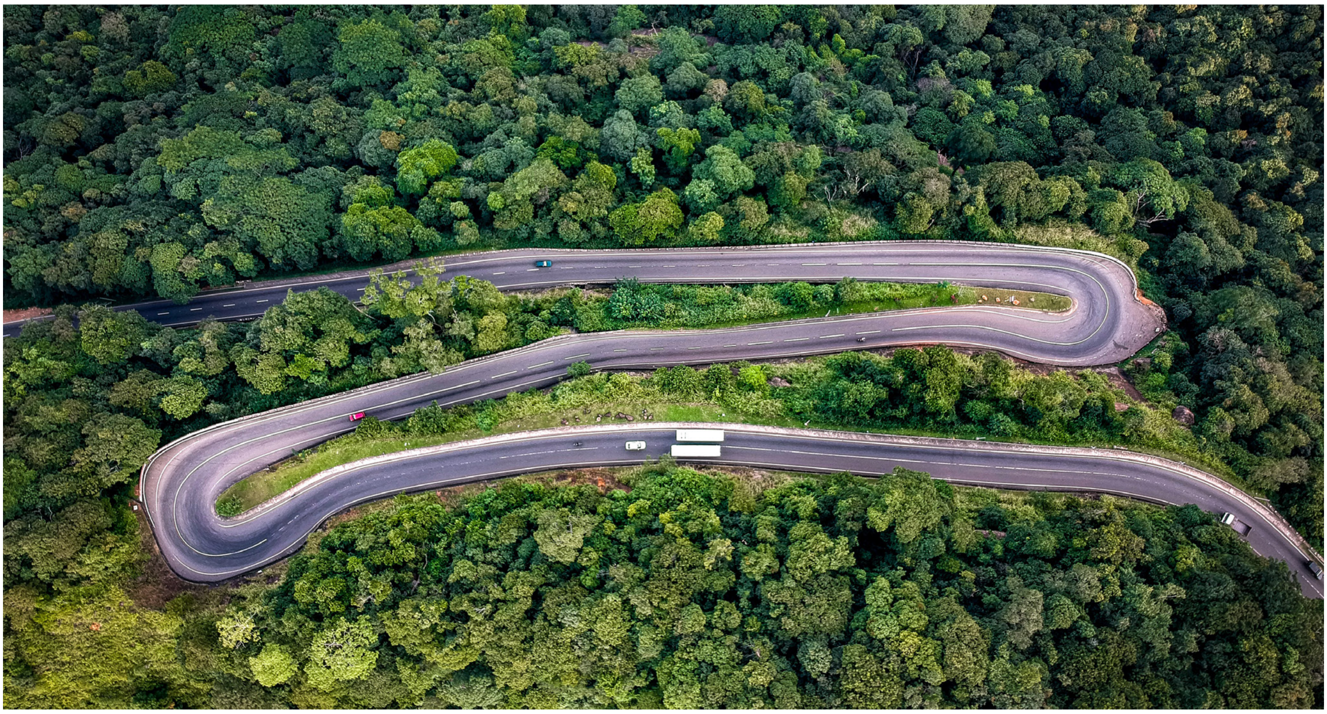
This document is targeted at stakeholders and partners involved in the RVO project. The purpose is to inspire the reader to see what can be achieved through agroforestry-based interventions in tea and coconut plantations and what aspects need to be taken into account for the successful transition to agroforestry. First, we provide an overview of the potential of agroforestry (and complementary practices) for sustainable production, with specific attention for the context of tea and coconut plantations. Second, we present a selection of international experiences with agroforestry models and business cases that could serve as inspiring examples. Finally, we synthesize key messages and recommendations to be considered for the piloting in tea and coconut plantations in Sri Lanka.

This document is based on a desk study that integrates experiences and documents available at WUR and their international networks of research organizations and private sector partners, complemented with a quick scan of scientific publications and information available through Internet. The overview presented here does not pretend to be complete, but rather provides directions and examples for inspiration. We emphasize that the examples used may represent conditions (climatic, agroecological, and socioeconomic) that differ from those of the targeted plantations in Sri Lanka. Adaptation and validation according to local conditions will be needed and requires experimentation and piloting, as will be facilitated through the project.

Key Messages

1. Agroforestry-based interventions have the potential to restore the productivity of degraded tea and coconut plantations, diversify production of goods and services, and improve environmental and economic performance.
2. Agroforestry systems can make the production systems more resilient to climate change while creating opportunities to reduce the C footprint of the plantation.
3. There is no one blueprint for the perfect tea or coconut agroforestry system: System designs depend on the specific conditions of the plantation (including a clear identification of the degradation issues to be tackled), the objectives for the system transformation, the available or needed resources and capabilities and the business model that will support it.
4. In addition to agronomic and environmental aspects, market connections, labor availability and mechanization are critical aspects that inform successful agroforestry designs.
5. Agroforestry and intercropping can be complemented by sustainable practices such as waste recycling to produce organic fertilizers and integrated pest management to further reduce the need for external inputs and at the same time improve land productivity.
6. The development of agroforestry models in time is dynamic. The availability of resources (space, light, nutrients, water) changes with the age or development stage of the tea or the coconut trees and allows for different crops or trees to be introduced as intercrops at different stages; labor and input needs may change over time, as well as revenues.
7. Sustainable business models may combine different incentives and mechanisms to overcome barriers to adoption, including product diversification and certification, payments for ecosystem services, tailor-made loans, training programs, impact investment. Inspiration for business cases and related incentives can be obtained from diverse international experiences and are presented in this document.
8. Public-private partnerships are important to support plantations in the transition to agroforestry and in seeking ways to valorize agroforestry products and services, while providing environmental benefits to the society and a strong platform for rural community development.
9. There is strong momentum for diversification of tropical tree crop systems such as tea and coconut, but this requires cross sectoral collaboration, participatory approaches and on-farm piloting to adapt opportunities to the local context.
10. Monitoring and Evaluation (M&E) of processes and impacts of agroforestry transitions is critical to ensure that the environmental and social benefits are achieved and to draw lessons to improve (future) interventions. Ideally M&E continues after the initial implementation of the AF system has ended as it may take several years before an agroforestry system has matured and the environmental and socioeconomic benefits are fully expressed.

AGROFORESTRY PRINCIPLES, OBJECTIVES AND OPPORTUNITIES



The Basics of Agroforestry

Agroforestry is a land use approach that combines different types of woody and non-woody plants and crop (and sometimes animal) species to provide multiple environmental, social and economic benefits. Although agroforestry has been practiced for thousands of years, especially in tropical forest regions around the world, these systems have gained renewed attention in recent years. This interest derives from their potential to overcome several adverse consequences of input-intensive mono-culture, such as loss of biodiversity, degradation of natural resources, high nutrient losses and greenhouse gas emissions (1).

Characteristics of Agroforestry

Agroforestry approaches make use of positive interactions between different species to create synergies between agronomic, environmental and social objectives. Interactions among plant species (and, where relevant animals) are important at different spatial scales, both horizontally and vertically (2). Vertically, agroforests consist of different vegetation layers. The use of (shade-tolerant) understory plants and small trees, accompanied by taller shade trees, creates a system that is biodiverse in terms of structure and species. Different species and their interactions can strengthen natural processes such as the cycling of nutrients, disease and pest suppression, soil and water conservation and can help to moderate temperature and moisture fluctuations. This way, a well-designed and well-managed agroforestry system can make production systems less dependent on external inputs and more resilient to climate change and extreme events (3). Additional benefits include a higher total productivity, increased biodiversity and storage of carbon. Shade trees also improve the working conditions for farm workers, protecting them against the intense sun light, and can positively impact on the well-being and productivity of grazing animals. Finally, the diversification of production allows for the valorization of new agricultural products and environmental services through national and international markets and provide food, energy and timber to local communities

Challenges of Agroforestry

There are also challenges. Agroforestry systems are knowledge intensive and more complex to establish and manage than mono-culture systems. Their design and management require careful planning to minimize yield loss due to competition for light, water and nutrients, while optimizing positive interactions among crop, tree and animal species to improve soil quality and ecosystem services (Fig 1). At the same time, economic and operational factors such as establishment time and costs, duration of realized results, level of degradation, valorization of the products and services, climate change impacts and labor needs and mechanization also require careful consideration.

Many different Agroforestry models exist. They differ in structure, functionality, diversity and composition as they have different objectives and require adaptation to the specific environmental, social and political contexts and market opportunities. A classification of different types of agroforestry systems is provided here.

Figure 1: Agroforestry systems, ecosystem services and design

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Table 1. Classification of an agroforestry system by components; function of trees; temporal association; pattern of trees

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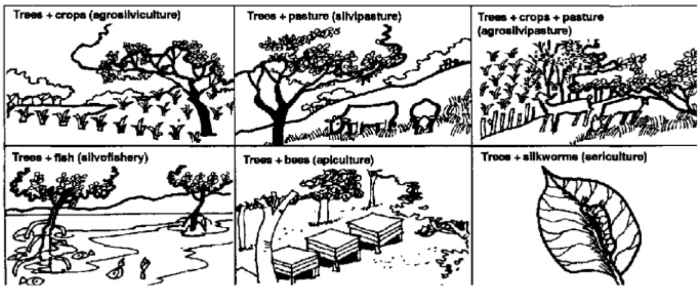
<tr><td>Classification of an agroforestry system by components</td><td>
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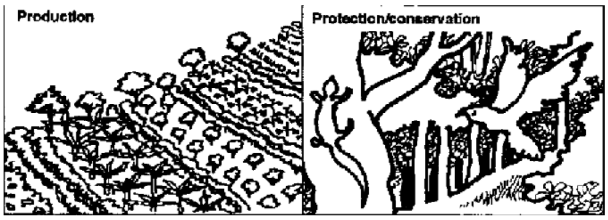
<tr><td>Classification of an agroforestry system by function of trees</td><td>
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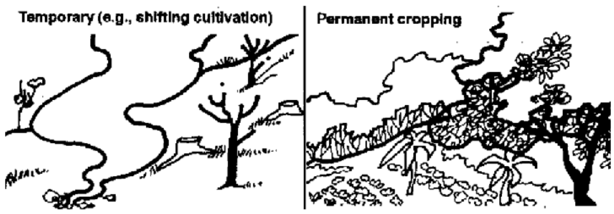
<tr><td>Classification of an agroforestry system by temporal association</td><td>
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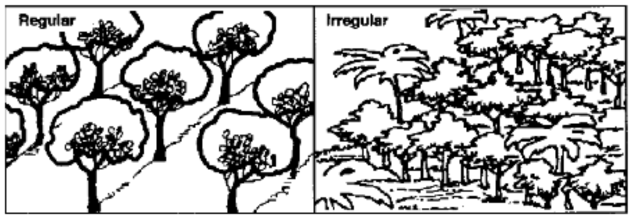
<tr><td>Classification according to different spatial arrangement</td><td>
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Importantly, the design of an agroforestry systems also shows a development over time as the availability of resources changes. Depending on the initial conditions, shade levels, nutrient dynamics and soil quality change during the development from a young agroforestry system into a mature system. Different harvestable products become available over time and it may take several years before newly planted tree crops start producing. Therefore, intercropping with annual crops or integration of livestock may be particularly important in the early years of newly established agroforests.

When planning an agroforestry intervention it is important to get a good understanding of the baseline conditions of the plantation in terms of productivity constraints. When the soil is strongly degraded, depleted in nutrients and organic matter, or suffering strong acidification or chemical contamination specific measures should be put in place to restore the soil quality and functions before other more demanding trees or crops are planted. The use of early successional plants that provide good soil cover and produce a lot of biomass even in poor soil conditions is important to protect the soil and add soil organic matter and stimulate soil life. Ideally those (cover) crops fix nitrogen from the atmosphere to add additional nitrogen to the system.

The following video (Box 1) provides a good overview of the general principles, benefits and types of agroforestry, while also addressing challenges in their establishment and management.

Box 1: Video about the basics of agroforestry.

This video explains the principles, models and benefits of agroforestry systems in general terms.

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Objectives of Agroforestry Systems

Agroforestry is a multifunctional and flexible management approach, which allows users to target a range of specific and varied environmental and social issues. Agroforestry systems are often considered as part of popular sustainable agriculture management concepts like Agroecology or Regenerative Agriculture and can or cannot meet the conditions to be considered an organic farming systems (see glossary). Agroforestry system designs can also be combined with other regenerative or agroecological practices to improve soil quality, natural pest control and recycling of nutrients from farm waste streams. Opportunities to move towards improved circularity of agricultural production systems ('circular agriculture') through enhanced recycling of locally generated organic waste streams and the possibilities for introducing sustainable energy systems can be of interest.

Table 2: Glossary of related terms used

Agroforestry	Agroforestry systems include both traditional and modern land-use systems where trees are managed together with crops and/or animal production systems in agricultural settings. They are dynamic, ecologically based, natural resource management systems that diversify and sustain production in order to increase social, economic and environmental benefits for land users at all scales (Lin et al 2021).
Agroecological	Agroecological approaches favour the use of natural processes, limit the use of purchased inputs, promote closed cycles with minimal negative externalities and stress the importance of local knowledge and participatory processes that develop knowledge and practice through experience, as well as more conventional scientific methods, and address social inequalities. Agroecological approaches recognize that agrifood systems are coupled social–ecological systems from food production to consumption and involve science, practice and a social movement, as well as their holistic integration, to address Food Security and Nutrition (FSN) (HLPE 2019).
Circular agriculture	Circular agriculture is based on the principle of optimising the use of all biomass. The waste streams of one supply chain can be the raw materials for another. That also means that no more acreage or resources are used than are strictly necessary. Circular agriculture is part of the circular food system (www.IFPRI.org)
Regenerative agriculture (RA)	RA is an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production Schreefel et al. (2020).
Organic agriculture	Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasises the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system. (FAO/WHO Codex Alimentarius Commission, 1999).

In order to design an agroforestry system, it is important to have clarity about the objectives and expectations. Table 3 lists examples of possible objectives of transition to agroforestry and how agroforestry can contribute to these objectives. This table clearly shows that agroforestry contributes to multiple objectives, demonstrating that many potential synergies exist in well-designed agroforests. Additional sustainable practices can be used to further strengthen the impact of such interventions are also listed.

Considerations for Design and Replication

An important aspect of agroforestry design is the choice of plant species combinations and their arrangement in time and space. Depending on the agroclimatic conditions and the farming objectives (e.g., improvement of microclimate, improving soil health, storage of carbon, provision of fodder to animals) combination of trees and crops (or animals) that provide different functionalities can be selected. Important criteria for the selection of agroforestry species include:

- The demand for the product(s) in the market
- The productivity
- Availability of a water source
- Topographic conditions and terrain
- The availability of quality seeds and propagating material
- The morphological and phenological characteristics of the species
- Nutrient requirements
- Adaptation of the species to the climatic conditions
- The soil characteristics
- Ease of management and labor requirements (e.g., pruning)

Climatic conditions are particularly important for the design of agroforestry systems. For example, in humid climates with little air movement shade trees can be favorable to the development of diseases. In regions with high radiation a denser shade cover may be optimal, than in regions that tend to be more clouded. For this reason, it is also very important to consider the morphological (height, size of the canopy, root system architecture) and phenological characteristics (leaf shedding and timing) of the shade trees and the understory crops, because this determines competition with the main crop for space, light, water and nutrients. Here, the development of the system over time also plays an important role. For example, understory tree crops like cacao or tea need more shade during the early years, but less shade when the cacao trees or tea bushes are bigger and partly provide their own shade. Therefore, a distinction is made between temporary and permanent shade crops. Databases and digital tools are becoming increasingly available that allow users to explore which agroforestry species and species combinations could be considered depending on agroecological zone and production system objectives (e.g., Diversity for Restoration D4R tool; (26).

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Besides agronomical and environmental aspects, a match with market opportunities, local policies and labor availabilities is crucial in designing a successful agroforestry system. Therefore, a clear understanding of the specific context and a strong participation of key actors is critical. Local actors include farmers/plantation management, farm workers and communities in and around the plantation need to be involved to fully understand the expectations, limitations and opportunities that can drive a transition towards agroforestry-based production systems and can contribute with important knowledge and experiences on locally available plant species and practices. An example of a participatory shade tree advice tool that integrates local knowledge can be found here.

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Using a gender approach is important as knowledge on local plant species and preferences and uses can differ depending on gender roles.

Stakeholder engagement is also critical to overcome constraints or barriers and to pave the road for replication and scaling of potentially successful designs. Here, private sector actors such as certifiers, traders, input suppliers, impact investors and public policy makers and research and education systems can play an important role. Solutions can be explored based on collaboration and require co-development of innovations. Examples of such innovations are the valorization of environmental services and other financial incentives, accompanied by enabling policies that stimulate agroforestry, or the development of novel mechanization technologies suitable for agroforestry systems (4)(1).

Table 3: Examples of possible objectives of transition to agroforestry and how agroforestry and other complementary practices can contribute to these objectives

Objective	How can agroforestry contribute?	What additional sustainable practices could be explored?
Restore landscape quality and biodiversity	Promote ecological corridors between fragmented habitats, acting as an intermediary between natural forests and intensive agriculture. Reforestation	Improve habitat quality, restore contaminated areas
Reduce soil erosion and soil compaction	In sloping areas, trees or shrubs act as a physical barrier to reduce nutrient loss from erosion. Use of permanent soil cover (residues, cover crops)	Erosion buffers, terracing, trenching Contour planting Reduce grazing density or duration (regenerative grazing) Avoid use of heavy machinery
Improve soil fertility	Recycling of prunings and plant litter Recycling nutrients from deep soil layers by deep rooting trees or crops Use of leguminous trees or (cover) crops	Use of biobased fertilizers (composts, biochar, digestate) from organic waste streams Improve manure management Correct soil acidity (liming)
Reduce dependency on synthetic/external fertilizer inputs	Improved nutrient uptake efficiency through intercropping Include of legumes (in case of nitrogen) and deep rooting crops	Correct soil acidity (liming) Adequate fertilization (amount, balance, timing, placement)
Reduce use of chemical pesticides or herbicides	Improved soil cover (weed control) Diversification of plant species reduces pest and disease outbreaks Use	Push-pull system and other forms of integrated pest control
Diversify income through valorization of different products	Agroforestry systems typically yield different products (different crops, herbs, fruits, fibre, timber, fodder, medicinal plants) Agroforestry could provide better opportunities for ecotourism	Honey production
Reduce carbon footprint, offset GHG emissions	C storage in tree biomass and soil carbon Improve fertilizer use efficiency	Fertilizer type and application Solar or wind energy Circular use of waste streams for energy production
Improve water use efficiency/ water storage	Reduce runoff by improved soil cover	Water harvesting
Adapt to impacts of climate change (changing rainfall and temperature regimes, extreme events)	Agroforests moderate temperature extremes Agroforests can improve water retention and reduce evaporation	Use of well adapted varieties Water harvesting
Diversify/improve income through compensation for ecosystem services	Agroforests contribute to carbon storage and biodiversity and may be used to restore landscapes and secure water provision to downstream users	Restoration of natural forest areas
Improve local food, fuel, timber security	Intercrop food crops with commodity crops. Use prunings as fuel.	Biogas production from harvest residues, prunings or manure
Improve pollination and natural pest control	Intercropping or introduce field hedges with species that support pollinators	Hold bees, use traps for pest insects
Improve livestock production	Improved shading for livestock Intercropping of fodder crops or trees	Rotational grazing, fodder banks

AGROFORESTRY IN TEA AND COCONUT PRODUCTION SYSTEMS

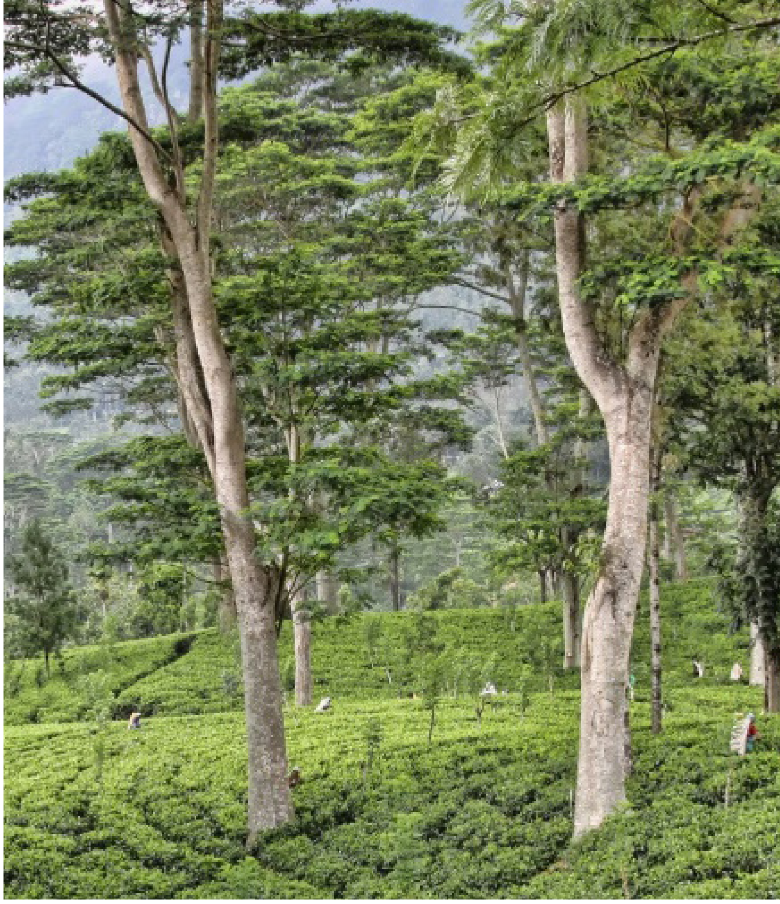
Tea and coconut, like other tropical tree crops (e.g., coffee, cacao, oil palm, rubber) possess good potential for ecological and economic diversification based on agroforestry principles, allowing for regeneration of degraded land, improved resilience to the impacts of low and volatile market prices and climate change. Below we present a mini-review of international documentation (scientific and grey literature) on tea and coconut agroforestry designs and benefits, illustrated with videos on their practical implementation in different contexts.

Tea

Tea is a shade-loving plant and therefore thrives best in a system where it is grown under a tree canopy. Many species of shade trees are used across tea-growing areas of the world. Examples of tea-based agroforestry systems and projects to stimulate their adoption (Box 2) are found in tropical and sub-tropical regions of south-east Asia, India and China and are also common in smallholder farms in Sri Lanka (5)(6). Tea-based agroforestry systems often intercrop tree bushes with fruit or timber trees. Besides benefits of diversification for farm revenues and food security, there are important agroecological benefits of shade trees such as microclimate regulation by moderating radiation, temperature, and wind speed and increasing the relative humidity thereby mitigating climate change impacts. Reduced soil erosion on steep slopes and other ecosystem services have been reported whereas shade cover also positively affects the yield and quality of tea (7).

Smallholder tea farms in Sri Lanka include intercropping with a variety of species including native or introduced fruit trees and fruit palms like Caryota urens, areca catechu, artocarpus heterophyllus (jack fruit tree) or native and introduced species of timber trees like Michelia Champaca, Swietiana Macrophylla (mahogany). Larger scale plantations tend to be less diversified. Here, common shade trees are the introduced timber trees Albizia Moluccana (an N fixing tree), Grevillea Robusta (silver oak) and eucalyptus grandis in different arrangements such as dispersed intercropping of shade trees, wind breaks, contour and hedge planting. Several species of trees, shrubs and grasses can be used for contour planting and hedges (8). Pre-planting for rehabilitation of strongly degraded land has been done with grasses like Cymbopogon confertiflorus that can be used for oils, fragrants and other cosmetic or industrial uses, similar to vetiver (Chrysopogon zizanioides), a deep rooting crop that is often used for erosion control in tropical regions around the world.

Tea plantations can thus diversify their tea crop with trees and crops that (i) provide alternative income sources (ii) support soil conservation or rehabilitation, (iii) provide fuel wood for the workers and tea processing (iv) provide fodder for farm animals, (iv) fix atmospheric nitrogen, among other uses. The contribution of trees and intercrops to local food security can also be of interest as a source of non-timber forest products (NTFPs). For example, Inga edulis trees produce pods with delicious seeds locally known as ice cream beans and have the additional benefit of being a leguminous tree, i.e. it fixes nitrogen. For further suggestions of species to be used for the diversification or rehabilitation of tree plantations in Sri Lanka see (8).



Box 2 : Tea agroforestry in Darjeeling, India.

Two agroforestry models were used to transform tea plantations in Darjeeling: 1) trees planted every 3 meters around the fields, 2) within plantations, every 10x10m a tree is planted (100 trees per ha). Tea was intercropped with various fruit- and timber trees, among which orange and avocado. Farmers first indicated their interest in specific trees and the project guided them by advising which of the preferred trees would fit in the agricultural system so that diversification would result in increased yields. So far, 50.600 trees have been planted by 529 organic and fair trade tea farmers who joined the project.

Local partners, such as a tea cooperative and an NGO, were included in the project to empower local farmers' organizations with trainings and field workshops. The project aims to be a socio-ecological model for other communities and tea plantations in Darjeeling district. The projects is sponsored by Ushuaia Beauté, a French brand for natural body care products and implemented by PUR projects.

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Table 4 shows some examples of common tree species and non-tree crops that have been intercropped with tea in other countries, including China, India. For shade tree species intercropped with tea a distinction is made between temporary and permanent shade based on the following recommendations for the development of the agroforestry system over time (ref Tea world).

1. first plant temporary shade tree species at high density, together with the slow-growing permanent tree species
2. remove temporary tree species to lower density
3. remove temporary tree species when permanent tree species reach preferred size.

Table 4: Common intercrops with tea in China (trees and non-tree crops; source: NZDL) and India (temporal and permanent shade trees intercropped with tea; source: Tea World).

Country	Plant Type	Species common name	Species scientific name
China	Shade trees	Jujube Peach Pear Persimmon Plum Masson's pine Slash pine Loblolly pine Chinese fir Chinese tallowtree Tung tree Paulownia Poplar Sassafras	*Ziziphus jujuba* *Prunus persica* *Pyrus pyrifolia* *Diospyros lotus* *Prunus salicina* *Prunus simonii* *Pinus massoniana* *Pinus elliottii* *Pinus taeda* *Cunninghamia lanceolata* *Triadica sebifera* *Vernicia fordii* *Paulownia tomentosa* *Populus euphratica* *Populus lasiocarpa* *Sassafras tzumu*
	Non-tree crops	Alfalfa Barley Vetch Corn Horsebean Pea Soybean Wheat	*Medicago sativa* *Hordeum vulgare* *Vicia spp.* *Zea Mays* *Vicia faba var. Equina* *Pisum sativum* *Glycine max* *Triticum aestivum* *Triticum durum*
India	Temporal shade	White hoary pea Gliricidia Leucaena/ White lead tree/ Ipil ipil Chinaberry tree/ Pride of India/ Bead-tree/ Cape lilac/ Indian lilac/ White cedar Sisu/ Indian Rosewood White siris/ Karoi tree Silk tree/ Sirises/ East Indian walnut	*Indigofera teysmanii* *Gliricidea maculeata* *Leucaena lecucephala* *Melia azedarach* *Dalbergia sisoo* *Albizia procera* *Molucca albizia (Falcataria moluccana)*
	Permanent shade	Ceylon rosewood Sauce tree Lebbek tree/ Flea tree/ Frywood/ Koko - - Red Lucky Seed/ Madatiya Silver Bush/ Cork Bush/ Sheesham Tree	*Albizia odoratissima* *Albizia chinensis* *Albizia lebbek* *Derris robusta* *Acacia lenticularis Benth.* *Adenanthera pavonina* *Dalbergia sericea*

An exhaustive number of studies on the effects of the use of shade trees or intercrops, as well as different fertilization methods can be found in scientific literature, especially from China. For example, in Hunan, a subtropical region in south China, a study comparing 14 years old tea tree agroforests with different tree species showed that increased plant diversity resulted in increased soil fertility and positive changes in the microbial structure in comparison with the tea monoculture (10). Another study (11) showed how caterpillar host tree species can favor pest suppression in tea. In south-west India (Kerala) root characteristics of tea and silver oak were studied in a mixed tea plantation, showing that silver oak shade trees are tapping into deeper soil layers (below 45 cm) for water uptake and do so we can expect that competition with tea roots (0-45 cm rooting depth) for water and nutrients would be limited. Tea and silver oak were also found to have different nutrient demands further adding to the compatibility of the two species (12). (13) reported that intercropping of tea with peanuts as a cover crop enhanced soil nutrient status and had a positive effect on soil conservation. Another study from China showed that intercropping of tea with the fruit trees loquat, waxberry and citrus improved soil nutrient status, decreased heavy metal content and improved the soil amino acid profile which was related to green tea quality. Intercropping with citrus was found to be superior to the other two fruit varieties (14).

An interesting source of information about agroecological practices for tea producers, including intercropping, use of different types of organic inputs, integrated pest and disease management can be found here (15). Focusing on aspects of soil health, tea productivity, and quality this paper discusses the potential benefits of agroecological tea management in the Vietnamese context using a more integrated approach combining crop diversification with additional sustainable (soil) management practices (Fig 2).

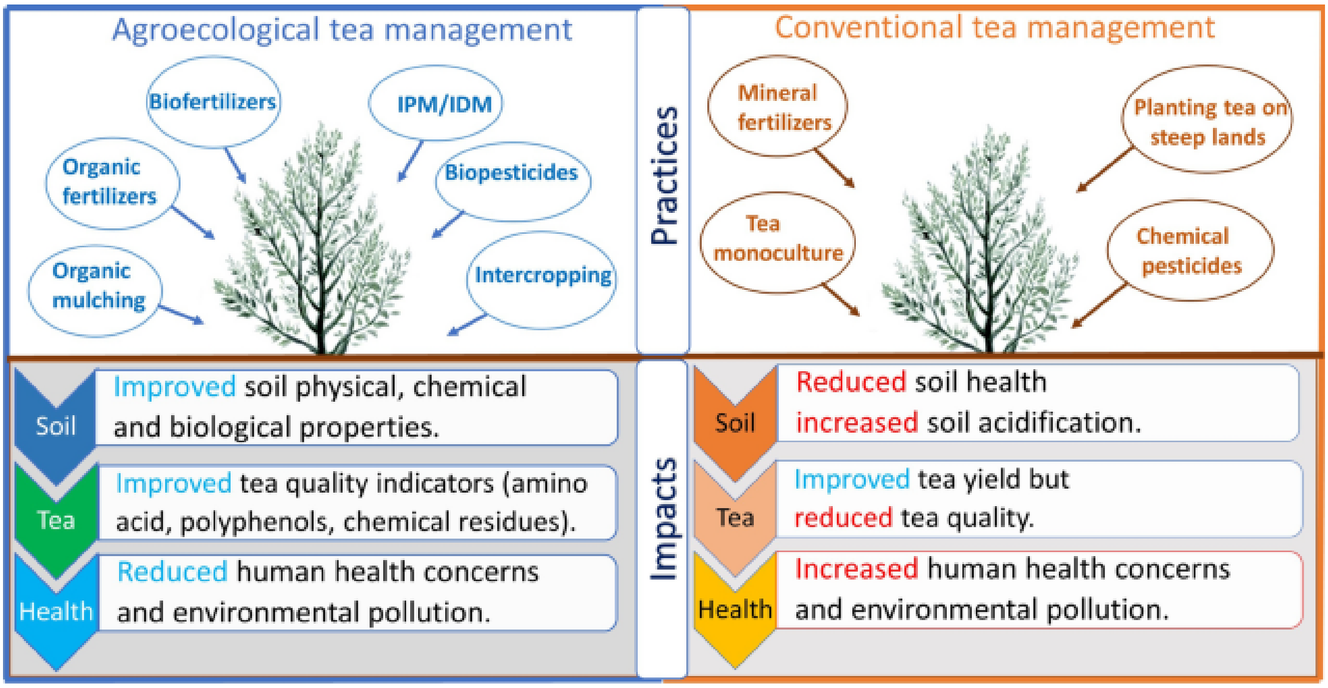

Figure 2: Potential benefits of Agroecological versus Conventional tea management according to (16)

Coconut

Coconut plantations offer good opportunities for diversification because there is a lot of space between the coconut trees in order to meet the resource requirements of the trees as they reach their full size. During the first few years, similar to rubber, coconut allows for intercropping with annual crops or for animal grazing. After about eight years other (shade tolerant) crops can be cultivated under the coconut canopy (8) . Trees are thus grown in layers; coconut trees at the highest level then shorter fruit trees, such as mango and coffee or cacao, with pineapples, tuber and root crops like cassava, potato, and peanut at the lower level as shown in the Philippines (17). Advantages of intercropping are weed reduction, soil improvement, improved microclimate improved coconut yields, provision of ecosystem services and income diversification (17) (18). For example, (18) reported that coconut yields were higher when grown in combination with cacao than when grown as monoculture. Moreover, different parts of the coconut tree, from leaves to fruits to flowers, can be used to produce marketable goods, including kernel, coconut water, coconut fiber, coconut shell, coconut sap and coconut peat-based products. Therefore, coconut does not only allow for diversification of the production systems itself, but also for economic diversification in the form of different marketable coconut tree products.

Different trees or crops that are intercropped with coconut in Sri Lanka are cacao, pepper, avocado and some fruit trees, along with ginger and turmeric in the mid country, and fruits like papaya, pineapple and banana at lower altitudes, along with yams such as colocasia. Trees and shrubs like tectonea grandis, berrya cordifolia, swietiana macrophylla and alstonea macrophylla can be cultivated along the field

Table 5: Crops used as intercrop with coconut. Adjusted from Nair et al. (1993)

Common intercrop with Coconut		**Country**
Cereals	Rice Finger millet (and other millets), Maize	India India, Sri Lanka
Pulses	Green gram (mung bean), Black gram (urd), Pigeon pea Cow pea Soya bean, Groundnut	India Sri Lanka Philippines
Root crops	Cassava Sweet potato, Yams Taro, cocoyam	India, Sri Lanka and Philippines India Philippines
Spices and Condiments	Ginger, Tumeric, Cinnamon Chillies, Clove, Black pepper	India Sri Lanka
Fruits	Pineapple Mango Banana Papaya Breadfruit	India Sri Lanka Philippines Malaysia Pacific Islands
Tree crops	Arecanut Cacao Coffee	India India, Malaysia Philippines, Oceania
Other crops	Cotton, Sesame Abaca, Sugar cane	India, Sri Lanka Philippines

borders. Some species that are to be tried in rubber plantations can also be tried out in coconut (8). In coconut plantations, the shade cast of the palms is a decisive factor in determining the area and selection of the intercrop and depends on the planting distance between the palms and the size of the palm trees. Although the intercrop is likely to face competition for light, several crops can produce relatively well under the conditions of shade. Examples of crops that have been associated with coconut are provided in Table 5. In these examples, tree species for intercropping were successfully selected in order to achieve complementary use of resources such as of water, light and nutrients. Choosing tree species that result in complementary use of resources rather than competition is crucial for the success of an agroforestry system (18).

Several scientific studies that have evaluated the effects of coconut agroforestry and intercropping have found positive effects of intercropping on soil quality and coconut yields, for example when using leguminous crops as green manures (Table 6). In Sri Lanka, coconut has also been intercropped with green manure trees and shrubs like Gliricidia, a fast growing leguminous plant, on both wet and dry sites. The leaves and twigs were cut twice a year and used as a green manure, applied around the palms with the onset of rain with positive results on soil fertility (soil organic matter, nitrogen, potassium). Therefore, this study identified Gliricidia as a high potential crop to restore soils in coconut plantations (19). Similar results were found for crops like Tithonia diversifolia or Leucaena (20)(21). For further detail on those studies the articles reporting these studies can be consulted.

Table 6. Effects of agroforestry and intercropping in coconut on soil quality and ecosystems services as reported in scientific literature

Intercrop	Study Results	Country	Source
Leucaena	Intercropping coconut with Leucaena resulted in an increase in carbon content, increased water holding capacity and a decrease in soil compaction. Fresh Leucaena cuttings placed around unproductive palms on degraded soils gave a 29% increase in coconut production	Sri Lanka	Lyanage et al. 1992
Cocoa	Coconut was intercropped with cocoa under different tree densities. High density cocoa under widely spaced coconuts can be a profitable intercrop system. However, cacao was the main crop in this case.	Ghana	Osei-Bonsu et al. 2001
Gliricidia	Gliricidia was identified as a high potential crop to restore soils in coconut plantations in dry and wet regions, even at early ages.	Sri Lanka	Ranveendra et al. 2021
Tithonia diversifolia	When intercropped with coconut and cuttings used as green manure, Tithonia diversifolia had a great potential to improve soil properties as well as nutrient levels in palm organs	Sri Lanka	Senarathne et al. 2018
Calliandra calothyrsus Leucaena leucocephala Acacia auriculiformis Gliricidia sepium	Four nitrogen fixing tree species were intercropped with 38 years old coconut palm. During the dry period, all plots with intercropped trees had a higher soil water content than plots with coconut only. Gliricidia and Acacia performed best in terms of water conservation.	Sri Lanka	Vidhana Arachchi and Liyanage 2001

Similar to tea agroforestry, the intercropping of coconut with trees and non-tree crops can be complemented with other sustainable practices to enhance soil quality, diversify income, reduce dependency on external inputs and the carbon footprint at the plantations, among other benefits (Box 3).

Box 3 : Regenerative practices and diversification of coconut farms in Thailand.

This video (12 minutes) provides a practical explanation about an ongoing piloting project to transform conventional monoculture coconut farms into diversified, organic coconut farms using a range of practices such as intercropping (among which chili pepper), cover cropping. Beekeeping (stingless bees) has been adopted to improve the pollination of coconut flowers and honey production, different composting techniques are implemented to increase circular use of coconut residues, and biological pest control is stimulated by releasing (and growing) natural predators. The aim of these pilots, 10 in total, is to learn what works and what does not and share these results with large groups of farmers. The project will also develop a training curriculum on coconut farm management, soil health, organic input, pest management, and regenerative organic practices The project, running from 2020-2023, is commissioned by the Danone Ecosystems Fund and Harmless Harvest and implemented by GIZ.

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AGROFORESTRY BUSINESS CASES

Cost-benefits and Economic Incentives for Agroforestry

Agroforestry systems often allow for a better cost-benefit ratio in the longer term, provided they are well-designed and different marketable products and services generated by the system can be valorized (3). Diversification of farming systems through intercropping and agroforestry generally leads to a higher overall productivity and often these systems require less external inputs compared to monocropping systems due to a more efficient use of resources such as nutrients, water, energy (light) and space. Agroforestry systems also remain productive for a longer time because of maintenance of soil quality and slower aging of the trees. Improved resilience to climate change, crop failure and market fluctuations are other benefits that translate into improved economic performance (1). Agroforestry helps to moderate climatic extremes allows for a better protection of crops and soils against extreme climatic events, while the production of multiple products and environmental services can mitigate economic losses through price fluctuations or crop failure.

However, important challenges for the transition to agroforestry systems are the higher knowledge and labor requirements in the first years, and the need for financial investments in plantings, training, inputs, new farm infrastructure or equipment, etcetera, while it may take several years before the productivity benefits are achieved. Transformation may also require new commercial relations and business models to be developed to tap into new markets and finance opportunities.

Cost-benefits of agroforestry systems are strongly crop and context specific and therefore it is difficult to make any generalized predictions on the financial benefits. Additionally, agroforestry models typically show a strong temporal variation in profitability especially in the early stages of development until a more mature system has developed. Therefore, analysing the impact of specific agroforestry interventions on farm economics is essential to understand how revenues change over time and build a sustainable business case for the transition. Economic modelling can help to estimate the cost-benefits of agroforestry designs and compare alternative agroforestry designs and scenarios (Box 4). Other important aspects to be considered are the changes in risks and transaction costs along the value chain and how they can be mitigated (1).

Box 4: Example of cost-benefit analysis for different agroforestry scenarios.

The following example from Ivory Coast illustrates the economic results at plantation level for two different cacao agroforestry scenarios. In the first scenario, a mix of 40 trees (timber, fruit and wood-energy) is introduced in a 20 yrs old cacao plantation. The second scenario includes the introduction of a similar mix of trees while old cacao trees are being replaced as well. In this model, 20 more cacao trees can be included in the plot due to spatial optimization and during the first years intercropping with food crops can help to overcome the loss of income from cacao beans. Cacao becomes profitable from year 6 onwards. Regeneration of the old cacao, scenario on the right, and the addition of food crops, on the other hand, greatly increases the revenue of the farmer in the medium to long term.

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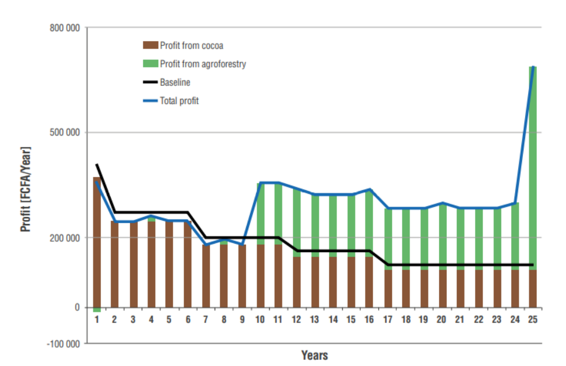


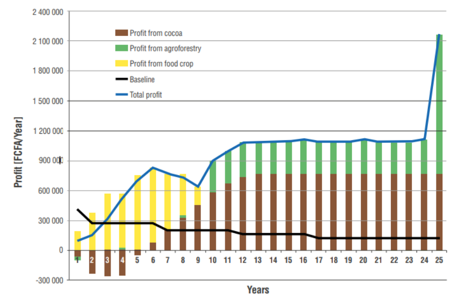


Figure 6. Model 4- Agroforestry coupled with cocoa rejuvenation compared to the baseline scenario – food, timber, fruit trees or fast-growing trees for bioenergy are combined with new generation of cocoa trees. Profitability increases greatly.

Agroforestry-based production and business model generally allow for more diverse options for value creation but also require investment costs to make the transition from monoculture plantations to a more complex farming model (FAO 2021). In this context, a number of interrelated global trends are relevant to help create enabling conditions for the adoption and scaling of agroforestry models:

1. The strong push for agroforestry and regenerative agriculture among public and private sector institutions globally
2. The growing consumer demand for high quality and sustainably produced products
3. The growing number of national and international policy commitments to mitigate impacts of global change such as climate change, biodiversity loss and land degradation.

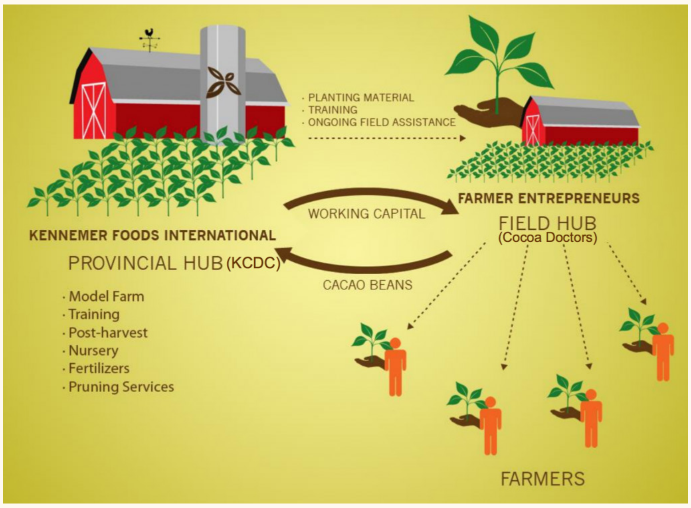
Financial Mechanisms and Examples of Agroforestry Business Cases

Public-private partnerships that cover the whole value chain and that are based on high-value products offer an interesting source of inspiration. A growing number of impact investors is involved in partnerships focusing on forest landscape restoration (FLR) that promote agroforestry-based approaches to restore degraded farmland, develop sustainable production systems and improve livelihoods. Alternative business models that integrate innovative financial mechanisms that can support transitions towards environmentally sustainable and climate friendly farming systems are currently being developed. Several practical examples of such finance mechanisms and integrated business models are provided below.

Box 5 describes an example of an innovative financial mechanism that includes tailored credits that have more flexible conditions for loan repayment based on future cash flow, taking into account that increased revenues from agroforestry are not immediate. Such loans can also be part of so-called Service Delivery Models (SDM) that can provide farmers with finance and other services such as training and access to inputs and information (22) to sustainably increase the performance of farms while also providing business opportunities for service providers thus creating innovations in supply chain structures.

Box 5: Example of a public-private partnership project to support coconut farmers in the Philippines to convert to agroforestry-based production models.

In 2017, a public-private partnership (PPP) between the Dutch development bank (FMO), IDH, Kennemer Foods and Agronomica Finance developed a project to provide loans to support coconut farmers to convert to coconut-cacao agroforestry systems. The project projected that that coconut farmers that integrate cacao can increase their income by up to 400%. The project aimed to reach out to 30.000 coconut farmers and provide them with a tailor-made finance program. Instead of traditional microloans with monthly interest and principal payments, the loan repayment is based on future cash flow. Planting materials, inputs and training are also provided by the project. By providing technical and financial support, the project aims to transform smallholder farmers into successful entrepreneurs thereby creating an example to encourage other financial institutions to independently invest in other farmers that want to convert to agroforestry.



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Third-party certification for products that meet environmental and/or social standards is another financial mechanism that can offer interesting avenues for value creation. Some examples of programs that certify good agricultural practices or agroforestry products according to different models and commodity types are provided in Table 5. In addition to international certification programs, agroforestry farms may also have access to national certification schemes for agricultural and forestry products (1).

Table 7: Examples of international programs that certify good agricultural practices or agroforestry products (Source Lin et al 2021)

Certification programme	Provision related to agroforestry
Forest Steward Council Forest Management Certification (FSC)	Among the international and national standards (Indonesia, Viet Nam, and Malaysia), FSC seems to be neutral on TOF as long as it complies with the requirements of natural forests, plantations and small, low-intensity managed forests. The latter system excludes plantations of non-timber forest products such as oil palm and cacao plantations. Starting in 2018, forest managers who demonstrate their contribution to ecosystem services can claim additional benefits for their forest products.
Programme for the Endorsement of Forest Certification (PEFC)	In their sustainable forest management framework, PEFC has broadened the scope of management activities to include TOF in 2018. According to scientific and traditional knowledge, the maintenance and enhancement of tree cover and ecosystem services are at the core of the guidelines. Agricultural components are advised to adhere to good agricultural practices. Agriculture- and settlement-extensive systems are excluded from the land-use management categories.
Rainforest Alliance Sustainable Agriculture Standard (Rainforest Alliance)	In the 2020 Rainforest Alliance Sustainable Agriculture Standard, farmers are recommended to adopt agroforestry using native trees to achieve 10–15% canopy cover on farms with shade-tolerant crops. Rainforest Alliance establishes minimum requirements of the number of native tree species per hectare based on the region for these systems. Planting trees favourable to the natural ecosystem is noted under the mandatory requirements related to ecosystem services. This standard also applies to UTZ Certified products, following the merger between the two organizations in 2018.
GLOBALG.A.P. (GLOBAL-G.A.P.)	The GLOBALG.A.P. is a farm assurance programme that focuses on sustainable farm management to promote environmental sustainability, food safety and product traceability. Although agroforestry is not mentioned in the general requirements and rules, farmers carrying out GAP are eligible to apply for this programme to certify their crop, livestock and aquacultural products. This programme initially targeted the European market and has now expanded globally.
Bird-Friendly Coffee (Smithsonian Migratory Bird Center)	The GLOBALG.A.P. is a farm assurance programme that focuses on sustainable farm management to promote environmental sustainability, food safety and product traceability. Although agroforestry is not mentioned in the general requirements and rules, farmers carrying out GAP are eligible to apply for this programme to certify their crop, livestock and aquacultural products. This programme initially targeted the European market and has now expanded globally.
Organic Guarantee System (IFOAM)	Under the IFOAM standards (2014), farmers must implement measures to maintain and improve the ecological health of the landscape through on-farm wildlife corridors. Agroforestry is not mentioned in the standards but may be used to address many of the socio-ecological requirements of the organic production of farm products.

Other mechanisms that offer potential to create incentives for agroforestry include Payments for Ecosystem Services (PES), including carbon credit schemes (1). By linking agroforestry to national and international climate change commitments SDGs such as NDCs and net zero emission pledges, carbon sequestration in tree biomass and soils can be valorized (1), although there are still challenges related to the monitoring and to the complexity of the whole trading process (25). In Sri Lanka, CIFOR-ICRAF and partners across government with support from the Green Climate Fund are introducing PES to sustain highland restoration to protect the water storage capacity of reservoirs that are vital for irrigating lowland rice (2). Also worth mentioning here is the development and establishment of mini-hydros on the plantations as a potential to implement PES as part of AF.

Box 6 shows an examples of how an impact investor combines different mechanisms into a more integrated business model to support large-scale agroforestry systems.

Box 6: International example of a large-scale agroforestry production and business model by impact investor 12TREE in the Dominican Republic

The integrated business model aims at supporting large-scale sustainable agroforestry by simultaneously delivering returns to investors and stakeholders, while protecting biodiversity and other natural resources, mitigating climate change and improving livelihoods of rural communitues (12Tree Finance). Agroforestry farms include crops like coconut, banana, cocoa, coconut, coffee, cardamom, ginger, honey, and plantain. At their plantation in the Dominican Republic, 12Tree grows coconuts in an integrated agroforestry system, with coconut palms acting as the canopy layer, providing shade for cacao as well as vegetable and root crops underneath.

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One final example (Box 7), shows how investment from the Land Degradation Neutrality Fund is used to consolidate and expand agroforestry-based land restoration through partnerships between a large scale plantation company, an out grower program and local communities to regenerate degraded and unproductive land. This initiative started in 2014 and the main lessons that have reported from this experience so far are:

- The business and investment case for agroforestry systems exists but requires extensive on-the-ground experience from a project developer that has the technical farming background to operate an agroforestry plantation.
- It should ideally be based on proven pilots under the same climatic and local conditions as the planned expansion/growth.
- Agroforestry is a good way to connect with local communities and have them take ownership.
- If an agroforestry project is succeeding in one location, it does not mean that it can be easily replicated to another context. Although lessons learnt can be applied, it would still require a thorough understanding of the local context, climatic conditions, soil health, and an experienced project operator.

Table 8: KPI's often mentioned for the monitoring of PPP initiatives

Key Performance Indicators
Ha restored land: soil health, reforestration, agrofreostry
Ha forest protected
Mt CO_2 emissions reduced
Producers/farmers reached
Adoption of the model outisde of the project
Increased income
Increased job opporunities
Gender issues addressed
Improved livelihoods

Box 7: Example of an initiative that supports the rehabilitation in Nicaragua through implementation of large scale cocoa and coffee agroforestry in partnership with local communities.

The commercial company Cacao Oro de Nicaragua was founded in early 2014 to produce sustainable and certified agroforestry-grown cocoa and coffee on those 3.000 hectares of degraded land. The company targets international markets, primarily the United States and Europe. The current farm operations are divided into 5 Productive Units of approximately 400 hectares, each headed by a head technician who is responsible for all operational aspects on their Productive Unit. The idea behind the work in farm units is to instill a sense of teamwork and ownership of the results between all the workers in the Unit.

The cocoa-farming operation was developed under an agroforestry model to help the restoration of the landscape and promote the diversity of the region's flora and fauna. With 2,000 hectares planted by the end of 2018 – and approximately 1,000 hectares of the farm are considered natural reserve and protection zones for waterways and will not be developed. Through an investment by the Land Degradation Neutrality Fund, the company aims to consolidate its current operations, as well as expand its current production area through an out grower program. Cacao Oro is also exploring a partnership with an indigenous community to replant part of the degraded and unproductive land owned by them with agroforest. More information can be found in the report that can be downloaded through the link above.

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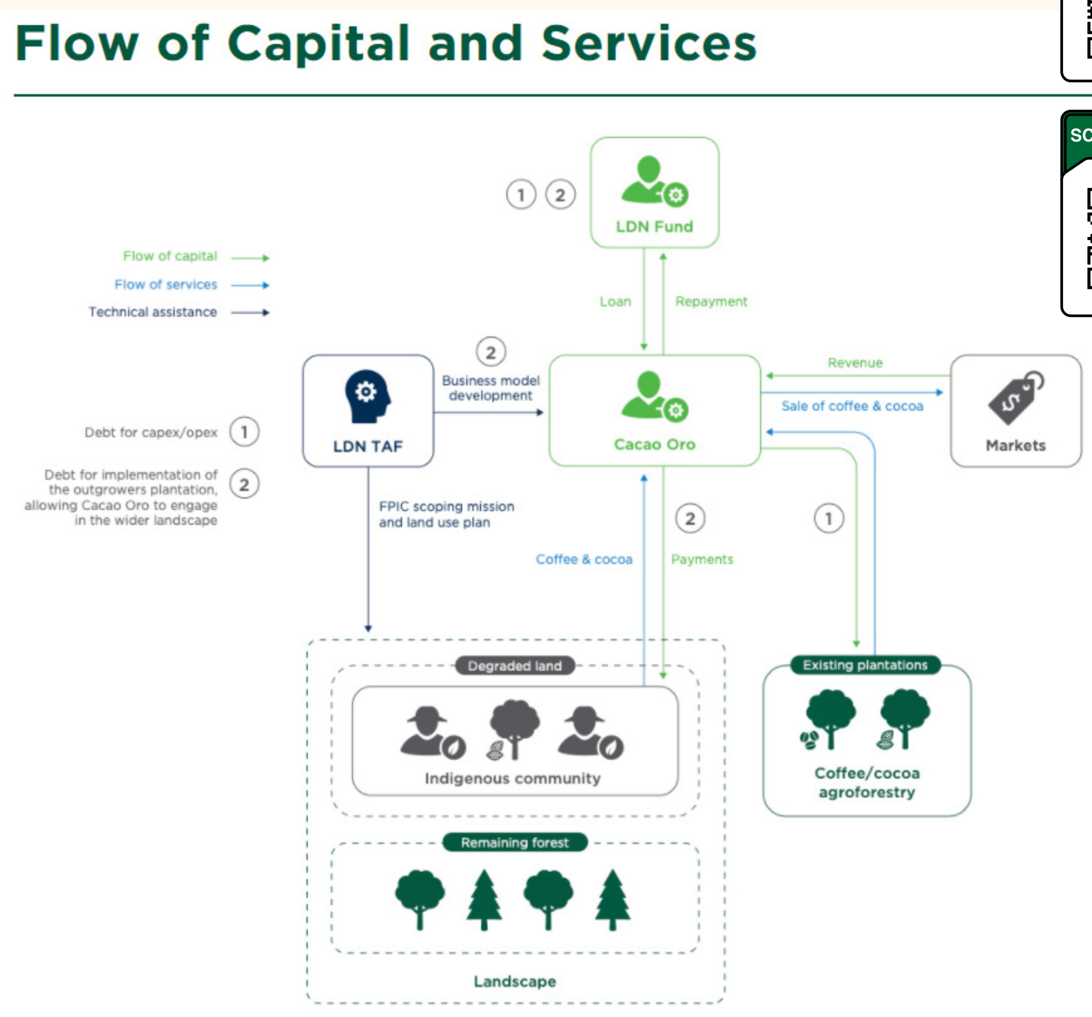

CONCLUDING REMARKS

What stands out based on the examples of the business cases presented in the previous section is that Public–private partnerships are essential for connecting models for sustainable production systems with agri-food value chains and other sustainable finance mechanisms. The role of the private sector in financing agroforestry has strongly increased in recent years, due to the surge in corporate social and environmental responsibility (1). Public-private partnerships can support plantations in the transition to agroforestry and seek ways to valorize agroforestry products and services (i.e., tea and coconut, other agricultural goods and services like carbon storage), while providing environmental benefits to the society and a strong platform for rural community development. This can enhance the value of the land and the profitability of the plantations.

Nevertheless, the importance of the national political context, political priorities and environmental and agricultural policies in shaping the enabling environment should not be overlooked, while regional collaboration can also strengthen opportunities for agroforestry. Through cross-sectoral cooperation, diverse stakeholders can reduce barriers for scaling-up agroforestry. The development of sustainable business models that are economically profitable, ready for investment and being socially inclusive requires the alignment of the parties participating in the business, and the support of other actors involved in the value chain. There is a need of micro-financing, soft loans and attractive interests rates offered by the government and state banks (or other financial institutions) to motivate plantations to choose for an AF model. Monitoring of the processes and the envisaged social and environmental impacts of the interventions is critical to ensure that the business model is achieving the proposed environmental goals (Fig 3), but also to draw lessons on the factors that determine success and failures to be used to improve future interventions.

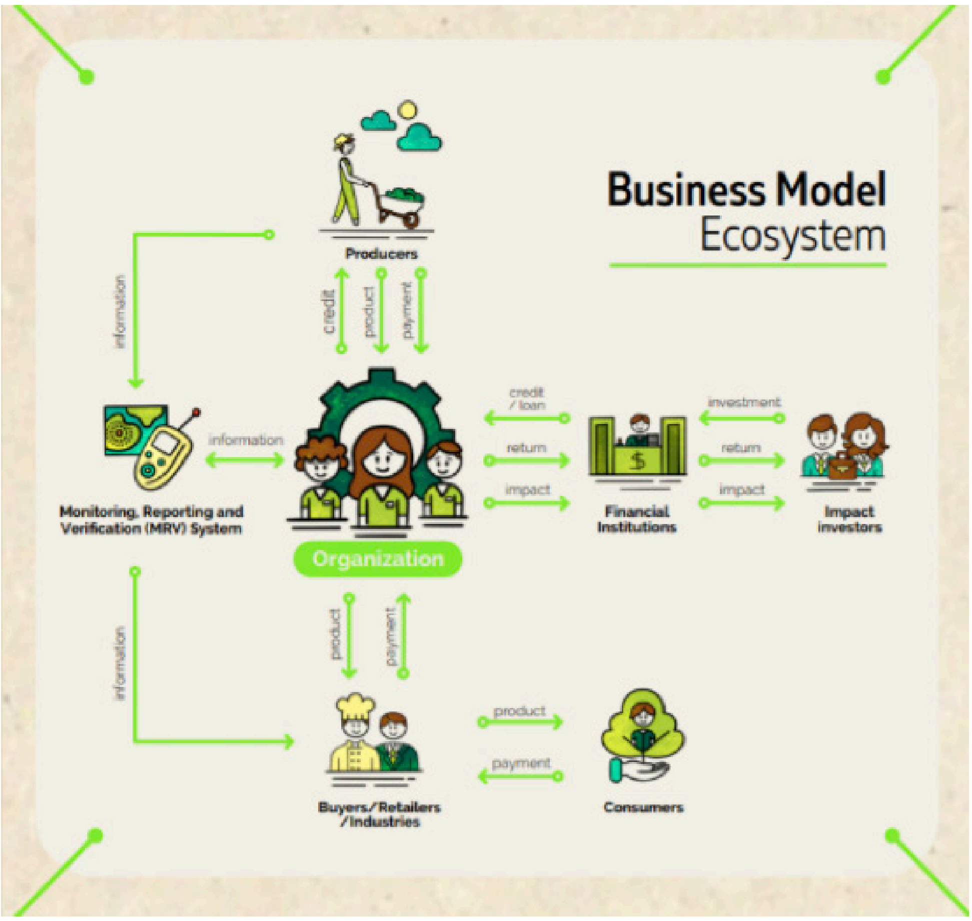

Fig 3. Schematic representation of an integrated business model that seeks to give added value to sustainable agricultural production, in this example the business model aims to contribute to the conservation of forests and the reduction of GHG emissions. The development of sustainable business models that are economically profitable, ready for investment and socially inclusive requires the alignment of the parties participating in the business, and the support of other actors involved in the value chain. Monitoring of the envisaged social and environmental impacts of the interventions is critical to ensure that the business model is achieving the proposed environmental goals.

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Contact

Dr Mirjam Pulleman
mirjam.pulleman@wur.nl

Mrs. Maaike Snel
maaike.snel@rvo.nl

Mr. Naalin Perera
naalin.perera@iucn.org

Professor Gamini Pushpakumara
ngpkumara63@gmail.com

Mr. Nalin Munasinghe
nalin.munasinghe@iucn.org