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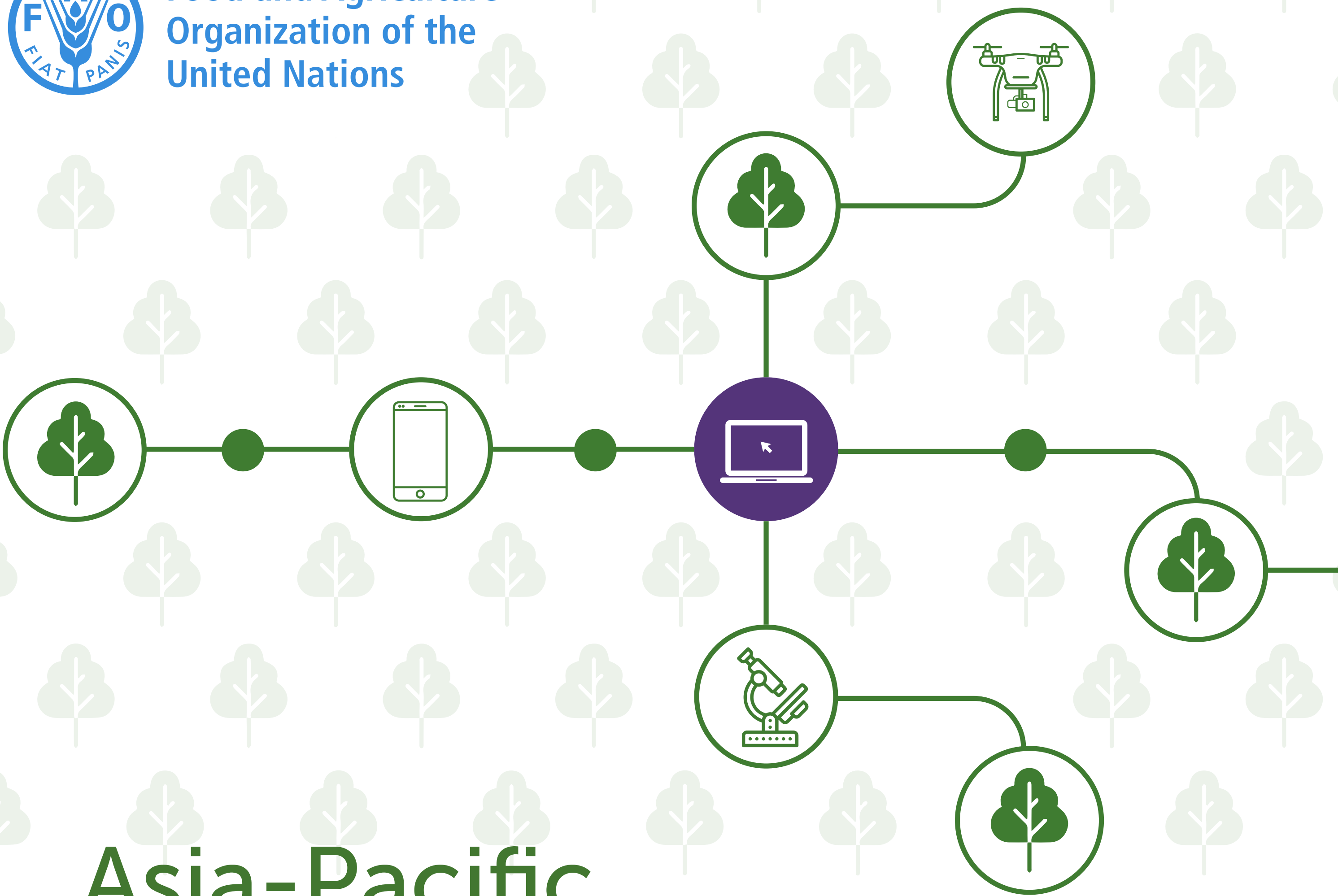

Asia-Pacific roadmap for innovative technologies in the forest sector

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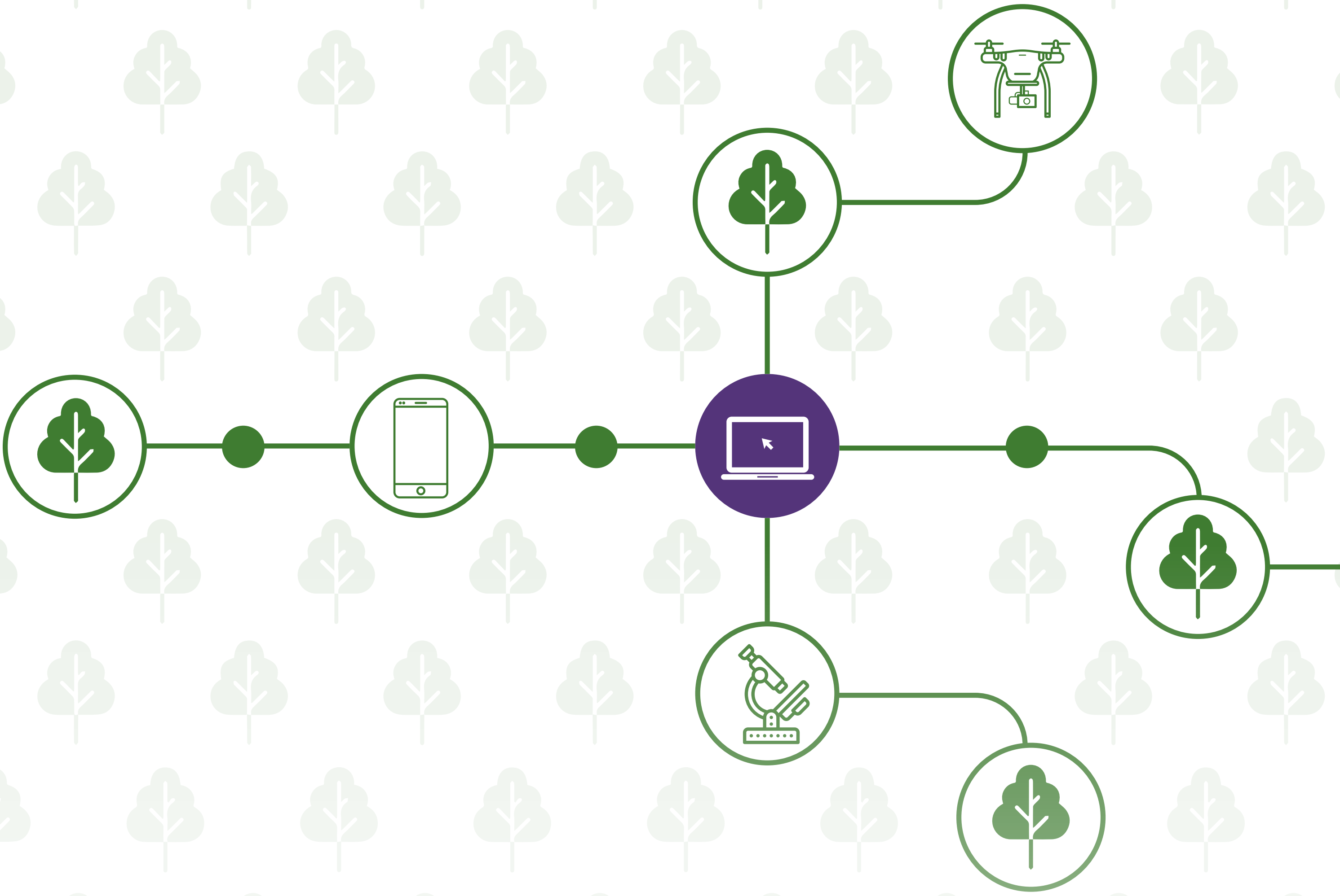

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Contents

Foreword

The preservation of forests, sustainable forest management (SFM), forest landscape restoration (FLR) and the need to make the most of precious forest resources are priority issues in the policy and sustainable development agenda of the Asia-Pacific region. Innovation will be key in the coming decades to meet an increasing demand for wood and other forest products while halting and reversing deforestation, in line with the commitment taken at COP26 in Glasgow by the international community. However, uptake of innovative technologies has been slow and uneven in the Asia-Pacific region, and there remains a gap between political commitments and the investments – in education, capacity building and infrastructure development – required to put them into practise.

As highlighted by the 'Third Asia-Pacific Forest Sector Outlook Study' (APFSOS III: FAO, 2019), the use of innovative technologies – whether digital, biological or processing technologies, new wood-based products, social innovations or innovative finance mechanisms – have the potential to revolutionize forest management and to make critical contributions to sustainable development along forest value chains.

Following up on APFSOS III, the present study, co-published by the Food and Agriculture Organization of the United Nations (FAO) and the Center for International Forestry Research (CIFOR – the lead centre of the CGIAR Research Program on Forests, Trees and Agroforestry or FTA), helps shatter the image of forestry as a low-tech sector. It illustrates with specific examples how innovative technologies can help to: improve forest monitoring and forest management; reduce waste and increase resource-use efficiency, productivity and profitability along forest value chains; enable the development of a bioeconomy contributing to climate change mitigation and SFM; create new skilled job opportunities, making the forest sector more attractive for youth, in particular; provide new products and services, and develop new uses for previously underutilized and undervalued wood species; enhance traceability and transparency along forest value chains; support participation, capacity development and information sharing; and enable new governance and investment models.

Innovative technologies are often considered as inherently beneficial, with advantages largely outweighing the risks. However, innovative technologies can also generate significant negative social, economic and environmental impacts, including: the loss of unskilled jobs; the destruction of natural ecosystems; and the loss of access to natural resources. These collateral damages are likely to disproportionately affect the most vulnerable groups and communities, which risk being further marginalized by new technologies and thus need targeted support. When considering the adoption of an innovation, it is essential to consider its potential impacts – whether positive or negative, intended or unintended – as well as all potential synergies and trade-offs with other development objectives. This can support the establishment of environmental and social safeguards or, as appropriate, the design of compensatory or accompanying measures to ensure no one is left behind.

SFM involves a series of functions along forest value chains, from monitoring, management and harvesting to transformation and final utilization of forest products and services. SFM also requires stakeholder engagement and strong governance mechanisms. Innovative technologies may not only perform existing functions better than current technologies but may also provide completely new functions, products and services. The present study suggests a framework to assess the strengths and weaknesses of innovative technologies in performing these different functions, thus helping decision makers to identify the most appropriate technologies to match specific objectives in a given context and address the specific needs and priorities of various stakeholder groups.

Based on the evidence gathered in this study, and upon extensive consultations that involved over 425 key regional stakeholders and technical experts (from governments, intergovernmental organizations, the private sector and civil society, as well as from academia and research institutions.), this report suggests a set of 10 overarching evidence-based recommendations with 59 specific options for policy- and decision makers to facilitate the dissemination and adoption of innovative technologies as well as to overcome the two main barriers identified in the study, namely: (i) lack of capacity in infrastructure and equipment, human capital and financial resources; and (ii) rigid legal frameworks (policies and regulations) that often lag behind rapidly evolving technologies. These recommendations and options are organized around the two following questions: (i) Why do we need to harness the potential of innovative technologies? and (ii) How can we overcome the current constraints and support the uptake and scaling up of innovative technologies in the forest sector?

Such broad recommendations can show the direction and delineate the main areas of work for the decade to come. However, the way one technology performs one function, as well as its positive or negative impacts for people and the planet, may vary significantly across contexts in the very large and diverse Asia-Pacific region. Even within one context, impacts may be perceived differently by different stakeholder groups. In addition, the social, economic and technical contexts evolve quite rapidly. Hence, to be useful for policy and decision makers on the ground, recommendations and options need to be actionable and adapted to the national and local contexts. They need to cover the 'how', not only the 'why'. They need to go beyond general principles and consensual objectives, and suggest clear targets, impact-assessment mechanisms, and concrete means of implementation.

To address this need, this document also contains two complementary tools that can help governments and other actors to consider these overarching recommendations and specific options develop their own roadmap, adapted to their own context, priorities and needs. First, this report proposes a four-step practical process, suggested to be led by the Asia-Pacific Forestry Commission (APFC) at the regional level, to implement a shared roadmap for innovative forest technologies and articulate it at different scales. Second, a detailed table links the overarching recommendations and specific options to evidence and case studies presented in the study, showing how they can be concretely and successfully implemented in a given context, or how they can be adapted to various situations, as well as to the priorities and needs of various categories of actors.

Students and young people involved in forest sector-related activities in the region were given a central role in the collective process of elaborating this roadmap. As technology enthusiasts and forest managers of the future, young people have a leading role to play in the uptake and scaling up of innovative technologies. They can bring to the debate their unique forward-looking, 'out-of-the-box' perspectives. A collection of 13 selected youth contributions from Asia and the Pacific on 'innovative forestry for a sustainable future' was published during the Global Landscapes Forum (GLF) hybrid climate conference (Glasgow, United Kingdom, 5–7 November 2021) as part of this roadmap.

It is our hope that the publication of the present document will mark the beginning of a collective process, possibly led by the APFC and its member countries, to further support and accelerate the uptake and scaling up of innovative technologies and advance SFM in Asia and the Pacific. We also hope that this roadmap will fuel a revived agenda for international and regional cooperation in forestry. In the coming months, we stand ready to support the implementation of the roadmap and articulate it at different scales, including by organizing presentations of the roadmap at country level, by collecting and analysing additional successful examples of innovations, and by organizing exchanges of knowledge and experience across countries and actors at regional and national levels.

On behalf of FAO

Sheila Wertz-Kanounnikoff

Senior Forestry Officer
Module Leader - Forestry and Biodiversity
Secretary - Asia-Pacific Forestry Commission
FAO Regional Office for Asia and the Pacific

On behalf of CIFOR

Robert Nasi

Director General of CIFOR

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Acronyms and Abbreviations

ACIAR	Australian Centre for International Agriculture Research
ADPC	Asian Disaster Preparedness center
AFoCO	Asian Forestry Cooperation
AFOLU	Agriculture, Forestry and other Land Use
AFPA	Australian Forest Products Association
AGB	aboveground biomass
AI	artificial intelligence
APAFRI	Asia Pacific Association of Forestry Research Institutions
APFC	Asia-Pacific Forest Commission
APFNet	Asia-Pacific Network for Sustainable Forest Management and Rehabilitation
APFSOS	Asia-Pacific Forest Outlook Study
app	application for a mobile device
ARIES	Artificial Intelligence for Environment and Sustainability
ASM	Academy of Science Malaysia
ATSAL	Agroforestry Tree Seeds Association of Lantapan
BJC	builder, joinery and carpentry
BNPP	BNP Paribas
BT	biological technologies
CCB	Climate, Community and Biodiversity Standard
CCO	Creative Commons
CBD	Convention on Biological Diversity
CBFM	community-based forest management
CBI	Climate Bonds Initiative
CF	community forestry
CFUG	community forest user group
CIRAD	Centre de Coopération Internationale en Recherche (French Agricultural Research Centre for International Development)
CLB	cross-laminated bamboo
CLT	cross-laminated timber
CGIAR	Consultative Group for International Agricultural Research)
CIFOR	Centre for International Forestry Research

CNC	computer numerical control
COP	Conference of the Parties
CPI	Clean Power Indonesia
CSO	civil society organization
CSR	corporation social responsibility
CST	conservation surveillance technologies
DBH	diameter breast height
DIFA	Degree of Integration of Focal Areas
DNA	deoxyribonucleic acid
DSS	decision support system
EC	European Commission
EOS	Earth Observing System
ESAP	Environmental and Social Action Plan
ESG	environment, social and corporate governance
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAORAP	FAO Regional Office for Asia and the Pacific
FAOSTAT	FAO Corporate Statistical Database
FECOFUN	Federation of Community Forest Users Nepal
FIPI	Forest Inventory and Planning Institute of Viet Nam
FIRMS	Forest Information and Reporting Management System
FLR	forest and landscape restoration
FRA	FAO Global Forest Resources Assessment
FRC	Forestry Research Center (Viet Nam)
FREL	forest reference emission levels
FRI	Forest Research Institute (PNG)
FRIM	Forest Research Institute Malaysia
FRL	forest reference levels
FSC	Forest Stewardship Council
FST	a fixation index; a measure of population differentiation due to genetic structure
FTA	Forest, Trees and Agroforestry (CGIAR research programme)
FTE	full time equivalent
GDP	gross domestic product
GEE	Google Earth Engine
GFG	Global Forest Goals
GFW	Global Forest Watch
GGGI	Global Green Growth Initiative
GHG	greenhouse gases
GII	Global Innovative Index

GIIN	Global Impact Investing Network
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation)
GIS	geographic information system
GLAS	Geoscience Laser Altimeter System
GPS	global positioning system
GSMA	Global Systems for Mobile Communications
Gt	Gigaton
GTTN	Global Timber Tracking Network
HLPE	High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security
HS	harmonized system (code)
ICCN	Institut Congolais pour la Conservation de la Nature (Congolese Institute for Nature Conservation
ICESat	Ice, Cloud and land Elevation Satellite (NASA)
ICRAF	International Center for Research in Agroforestry (World Agroforestry)
ICMA	International Capital Market Association
ICT	information and communication technologies
IF	innovative finance
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IFSA	International Forestry Students Association
INBAR	International Bamboo and Rattan Organisation
INSEAD	Institut Européen d'Administration des Affaires (European Institute of Business Administration)
inVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPB	Institut Pertanian Bogor (Bogor Agriculture University, Indonesia)
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service
IPCC	Intergovernmental Panel on Climate Change
IPR	intellectual property rights
IPTIM	Integrated Planning for Timberland Management
IRRDB	International Rubber Research and Development Board (Malaysia)
IRRI	International Rice Research Institute
ITTO	International Timber Trade Organiation
ITU	International Telecommunication Union
IUCN	International Union for Conservation of Nature
IUFRO	International Union of Forest Research Organizations
kLAB	knowledge laboratory (ARIES)
kWh	kilowatt hour
LDC	least developed countries

LIDAR	Laser Imaging Detection and Ranging or Light Detection and Ranging
LQ	location quotient
LTC	latex-timber clones
LUMENS	Land-Use Planning for Multiple Environmental Services
LUP	land use planning
MAAF	Ministry of Agriculture and Forestry (Viet Nam)
MapIT	a mobile GIS application
MAV	manned aerial vehicles
MDF	medium density fiberboard
MOOC	massive open online courses
MRB	Malaysian Rubber Board
MYR	Malaysian ringgit (currency)
MYSA	Malaysian Space Agency
NAFRI	National Agriculture and Forestry Research Institute (Laos)
NAFRI	National Agriculture and Forestry Research Institute (Viet Nam)
NASA	National Aeronautics and Space Administration (US)
NDC	Nationally Determined Contributions
NFI	National Forest Institution (Bhutan)
NGO	non-government organization
NIES	National Institute for Environmental Studies (Indonesia)
NOAA	National Oceanic and Atmospheric Administration
NWFP	non-wood forest products
NWS	National Wildlife Survey (Bhutan)
OBM	own brand manufacturing
ODM	original design manufacturing
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturing
OISCA	Organisation for Industrial, Spiritual and Cultural Advancement (PNG)
OSB	oriented strand board
PEFC	Programme for the Endorsement of Forest Certification
PES	payment for ecosystem services
PGK	Papua New Guinea Kina (currency)
PhD	Doctor of Philosophy
PNG	Papua New Guinea
PP	process and product innovations
PPP	public-private partnerships
PT	Perseroan Terbatas, foreign investment limited liability company in Indonesia
QGIS	a desktop GIS application
QS	Quacquarelli Symonds world university ranking system

R&D	research and development
RECOFTC	The Center for People and Forests
REDD	Reducing Emissions from Deforestation and Forest Degradation
REDD+	REDD, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks
RIL	Reduced Impact Logging
RLU	PT Royal Lestari Utama
RRIM	Rubber Research Institute Malaysia
RTMS	Remote Tree Management System
S&T	science and technology
SEPAL	System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring
SDG	Sustainable Development Goals
SDSS	Spatial Decision Support System
SED	small end diameter
SEEA	System of Environmental-Economic Accounting
SFM	sustainable forest management
SI	social innovations
SMART	Spatial Monitoring and Reporting Tool
SME	small- and medium-sized enterprises
SNP	single nucleotid polymorphic
SPC	South Pacific Commission
SRTM	Shuttle Radar Topography Mission
SSM	steep slope machines
TESSA	Toolkit for Ecosystem Service at Site-based Assessment
TID	tree inspection drones
TLFF	Tropical Landscape Finance Facility
TSM+	tree structural model
UAV	unmanned aerial vehicle
UK	United Kingdom
UN	United Nations
UN Comtrade	United Nations Commodity Trade Statistics Database
UNCCD	United Nations Convention to Combat Desertification
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention for Climate Change
UNGA	United Nations General Assembly
UNRE	University of Natural Resources and Environment (PNG)
UNSPF	United Nations Strategic Plan for Forests
UPF	urban and peri-urban forests

UPM	Universiti Putra Malaysia
US	United States
USC	University of the Sunshine Coast
USA	United States of America
USAID	United States Agency for International Development
USD	US dollar
VAFS	Viet Nam Academy of Forest Sciences
VC	venture capital
VCS	Verified Carbon Standard
WAM	winch-assist machines
WBI	World Bank Institute
WCED	World Commission on Environment and Development
WDI	World Development Index
Wi-Fi	wireless technology
WIPO	World Intellectual Property Organization
WRI	World Resources Institute
WWF	World Wildlife Fund for Nature
3D	three-dimensional
5G	fifth generation of cellular networks

Executive summary

Innovative technologies for the forestry sector in Asia and the Pacific are a priority issue identified by the 'Third Asia-Pacific Forest Sector Outlook Study' (APFSOS III: FAO, 2019). In response to this outlook study, FAO and CIFOR, lead center of the CGIAR research programme on Forests, Trees and Agroforestry (FTA), have developed a roadmap on innovative technologies in support of sustainable forest management in Asia and the Pacific. This roadmap was developed through an inclusive and participative process associating a wide range of key regional forest decision-makers and technical experts, from governments and intergovernmental organizations, from the private sector and civil society organizations, as well as from academia and research institutions.

This technical report constitutes the first step of the roadmap. It builds upon the scientific literature, FAO and FTA experience, and the consultation of 425 stakeholders, including regional experts, decision-makers, and youth involved in activities related to the forest sector in the Asia-Pacific region.[1] It examines the potential and barriers for disseminating and deploying innovative technologies for sustainable forest management (SFM) in the region and provides recommendations and options for decision-makers. It delineates and informs the process by which decision makers and actors can identify: the potential of innovative technologies to advance SFM; their potential impacts; the constraints to technology uptake and scaling up and how to overcome these constraints and facilitate adoption. The chapters of this study are organized along these steps. The roadmap is enriched by the results of the technologies workshop (Pingault et al. 2021a) and by contributions from students and young people involved with innovative technologies in the forest sector of the region (Pingault et al. 2021b).

1. Framing: concepts and definitions

Forests have multiple and diverse definitions, reflecting both the diversity of forest ecosystems and the diversity of human perceptions and uses of forests. This study uses the widely recognized FAO definition of a forest, defined as a piece of *"land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ"* (FAO 2018a). FAO further distinguishes two categories of forests: naturally regenerating forests (including primary forests) and planted forests. This study also considers trees outside forests, present in a variety of systems, including agricultural tree crops, agroforestry systems, or urban trees. In line with APFSOS III, this study uses the terms "forestry" and "forest sector" interchangeably to encompass all economic activities that mostly depend on the production of goods and ecosystem services from forests.

Human population and income growth exert strong pressure to convert forests to other land uses to satisfy growing demand for land, food and tree products, leading to a gradual decrease in global forest area

1 In this roadmap, the Asia-Pacific region covers the 49 countries and territories listed here: https://www.foreststreesagroforestry.org/wp-content/uploads/2020/10/FAO-FTA_Roadmap-Note-on-geographical-scope_DEF.pdf

over the past decades. This intensifies the pressure on remaining forests, jeopardizing biodiversity, carbon stocks, and the various other ecosystem services forests provide. In contrast to this global trend, Asia and the Pacific have experienced an increase in forest area in recent decades as a result of strong afforestation and reforestation policies in some countries such as China, India or Viet Nam. However, total forest area continues to decrease in other countries of the region. Additionally, primary forests are still decreasing at the regional level: according to FAO (2019), based on data from FAO Global Forest Resources Assessment (FRA) 2015, they now cover only 140 million ha, i.e. 19% of the region's total forest area, much lower than the global average (32%). Nonetheless, there are positive trends. The area of forests under legal protection or long-term management plans is continuously increasing in the region, showing a strong commitment to advance SDG 15.[2] Protected areas now cover 25% of Asia's total forest area and 16% of the Pacific's (compared to an average of 18% at the global level). The percentage of forest areas under long-term management is 64% and 31% respectively, compared to an average of 54% at the global level. The areas of certified forests in Asia and the Pacific are limited (25 million ha and 12 million ha respectively) but have increased since 2000.

Forests and trees make important contributions to most of the 17 SDGs. Whereas the forest sector is often considered conservative, innovative technologies are revolutionizing forest management and forestry value chains. The deployment of innovative technologies in the forest sector has the potential to provide new products and services, improve productivity and reduce costs, reduce waste and improve the efficiency of resource and energy use, thus generating further income and employment opportunities, conserving natural resources and limiting negative social, economic and environmental impacts. As highlighted by APFSOS III, the effective utilization of innovative technologies in the forest sector has the potential to further enhance sustainable forest management and advance many SDGs, provided that progress is made in the following priority areas of work: forest science and research; forest monitoring; forest productivity and wood resource use efficiency; forest governance and tenure, including stakeholder participation and community empowerment; and forest finance and investment.

This study considers **innovative technologies** in light of these domains and how they can contribute to improve SFM. For the purpose of this study, the term 'innovative technologies' embraces both: (i) new technologies in the generation, proof-of-concept, or pilot phases that could become mainstreamed or mature before 2030; and (ii) recent technologies emerging for new purposes or in new contexts. It is recognized that innovation is contextual and that innovative technologies may emerge directly in the forest sector or be adapted from other sectors.

2. Innovative technologies in the forest sector

This study identifies four main categories of innovative technologies as having the most promising potential to support sustainable development in the forest sector in Asia and the Pacific: (i) digital technologies; (ii) biological technologies; (iii) technical innovations in processes and products; and (iv) social innovations and innovative finance. Each category is presented in detail in **Chapter 2** and illustrated with tangible examples.

Digital technologies can considerably facilitate accurate cost-effective and real-time monitoring of forest resources and forest value chains. They can facilitate information sharing and capacity development, thus improving transparency and participation and empowering local stakeholders and communities. They can also enable breakthrough innovations in the three other categories: for instance, blockchain

2 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss."

technology, securing electronic transactions, opened a new world for innovative finance mechanisms. This category gathers a variety of information and communication technologies (ICT) and geospatial technologies such as drones, satellite-based observations and other remote sensing technologies, laser imaging detection and ranging (LIDAR), radar, acoustic and camera sensor networks, early warning systems, global positioning systems (GPS) and geographic information systems (GIS), online collaborative platforms, artificial intelligence (AI), machine learning, mobile phone and crowdsourcing applications, social media and video conferencing.

Biological technologies can facilitate the collection, domestication, selection, breeding, propagation, and dissemination of high-quality germplasm and genetic material at a reasonable price. Genetic resources (germplasm) are the most important input in any tree production system as the genetic and physical quality of the germplasm determines the upper limit of the system's potential yield, as well as the productivity of other inputs (e.g. labor or agrochemicals). Genetic research and development should prioritize species' disease resistance, drought resistance, growth, and adaptation to climate change, or adapt wood composition to the different possible uses.[3] Innovative tree domestication efforts should expand to include native timber species, non-wood forest species, and other underutilized forest species for local utilization. In the case of these less-domesticated species, the basic selection and use of quality genetic material to improve productivity and income generation is an innovation that requires not only appropriate techniques but also social innovation to effectively deploy improved material to communities and smallholders. DNA profiling can help identify and document the natural and geographic origin of biological samples, thus increasing transparency and traceability along forest value chains and helping track and combat illegal activities and illegal trade.

Process innovations can directly improve productivity and cost efficiency, reduce waste and improve resource use efficiency at all stages of forest value chains. This category includes: improved silviculture management, including refined site preparation, planting and post-planting practices; precision forestry based on the use of digital technologies; reduced impact logging (RIL) and winch-assisted harvesting; computer numerical control (CNC) machining to optimize product design or wood processing; portable sawmills; spindle-less lathe technology to reduce waste and use small diameter logs; drying technologies that reduce energy use and costs; and microwave plasma technologies to enhance wood properties (e.g. improve appearance, durability and water resistance). Process innovations can also create new uses for previously underutilized and hence undervalued wood species, such as fast-growing small-diameter species. The main drawbacks are that process innovations can be expensive and usually require important upfront investments and strong personal skills.

Product innovations have created a new generation of wood-based materials that can substitute non-renewable or more energy- or resource-intensive products (e.g. steel or concrete, plastics from fossil fuel) in multiple domains. These products can create new uses for low-value underutilized species, wood scraps from processing mills and other wood waste; greatly increasing wood recovery and recycling rates, thus generating additional economic and environmental benefits. These innovative products include: engineered wood such as cross-laminated timber (CLT), mass timber, medium density fiberboard (MDF), particleboard, oriented strand board (OSB), veneer and plywood; engineered bamboo products; experimental bioplastics; transparent wood to be used as an alternative to glass; bio-based composites and cellulose nanomaterials, with possible applications for paper and packaging, food, health, construction, biosensors and electronics; bioenergy that can reduce

3 e.g. low-lignin wood for improved pulp production or high-lignin wood to produce cellulosic derived sugars for bioplastics, biofuels, and other products.

greenhouse gases (GHG) emissions and dependence on fossil fuels; and biochar that increases soil carbon storage and enhance soil fertility.

Social innovations are new forms of organization. They often aim to enhance the provision of services and opportunities to society, seeking to provide equitable access to disadvantaged or marginalized groups. They are often multi-sectoral and multi-organizational. Prevalent social innovations in Asia and the Pacific are the concept of community forestry (CF, also called social forestry and community-based forest management), forest and farm producers associating as a diverse group of land managers, and public-private partnerships (PPP). While established for decades, CF is now more widely used, integrated and recognized. Many governments promote CF as an effective national strategy to empower local communities, enhance gender equity and empower women and girls, reduce poverty, improve food security and livelihoods, and contribute to biodiversity conservation and climate action. Concurrently, CF has evolved as a mechanism for agrarian transformations, the creation of forest- and farm-based enterprises, the commercialization of locally-produced commodities, and integration with private sector investment and PPP. Forest and farm producers, collectively and individually, own or manage 65% of the world's land, including locally controlled forests and associated forest- and farm-enterprises. PPP are social innovations that combine private finance and public resources to implement projects for public benefit.

Innovative finance. The long-term horizon of forestry operations makes them less attractive to investors as it leads to high biological, climatic, social, market and political risks. Innovative finance mechanisms have emerged over the last two decades that can address these issues. These include: blended finance associating public and private investors with complementary risk and return appetites; impact investment; green, social, climate or sustainability bonds; crowdfunding platforms that open new avenues for small investors and strengthen the link between borrower and lender; payments for ecosystem services (PES); ICT-enabled mobile banking, and financial and e-commerce services that facilitate transactions and access to value chains, credit and markets. These technologies support the development of a viable digital economy where small-scale producers, communities or organizations can directly market products or services to consumers. Such arrangements promote efficient value chains avoiding commissions to middlemen, which can reduce transaction costs, increase margins received by the producer (individual, community or organization), and enable lower prices for the consumer.

Sustainable forest management involves a variety of **functions** that can be grouped in broad categories including: monitoring and forest management, harvesting, processing, distribution and trade, final utilization in different sectors, information sharing and capacity development, community participation and governance. The use of innovative technologies throughout forest value chains affects these functions and the extent to which they contribute to sustainable development in the forest sector. Innovative technologies can not only perform existing functions better than currently utilized technologies but may also provide completely new functions, products and services. The way one technology performs a given function, as well as its positive or negative impacts on people and the planet, may vary significantly across contexts and may be perceived differently by different stakeholder groups even in the same context. In addition, the social, economic and technical contexts are also evolving. Assessing the strengths and weaknesses of each innovative technology in performing these different functions will ground an analysis of their advantages and disadvantages in different contexts. The assessment conducted in this study offers a framework to compare very different innovative technologies and helps identify and categorize the most promising innovative technologies for the forest sector in the coming decade.

3. Innovative technologies: opportunities and challenges

The adoption, dissemination and scaling up of innovative technologies in the forest sector come with important opportunities and challenges.

The growth in human populations and innovative technologies will likely generate major **shifts in wood demand and forest value chains**. Despite overall economic growth, per capita consumption of wood is decreasing as a result of technology improving resource-use efficiency and substitute non-wood lignocellulosic materials, reducing the pressure on remaining forests. Concurrently, the increasing use of previously under-utilized species and wood processing residues or co-product, as well as improved productivity and waste reduction along forest value chains, are improving wood recovery rates and reducing pressure on overharvested species. By opening new uses for wood products and improving wood processing, innovative technologies can enable the development of a circular bioeconomy that contribute to and address the challenges of climate change and sustainable development.

The accurate, cost-effective and real-time **monitoring** of forest and other land resources are among the most important and consequential achievements of innovative technologies. Enhanced monitoring and early warning systems based on a variety of digital technologies can facilitate forest management, prevent risks and limit environmental damage. Many of these monitoring technologies are user-friendly and use open-source tools, applications, and platforms, making data and information more easily available for all stakeholders, particularly NGOs and local communities, and facilitating their participation in decision-making processes. Enhanced access to accurate data can also strengthen local land tenure and access rights, help track and prevent illegal activities, and mitigate land conflicts. However, innovative technologies can also be misused to facilitate access to resources and their unsustainable exploitation, thus accelerating deforestation and forest degradation and threatening biodiversity. Access to the data generated by monitoring tools, applications and platforms may be restricted by the institution that generated the data or holds the legal rights to the technologies. The use of efficient monitoring technologies could also result in job losses, particularly for low-skill labor and seasonally employed rural residents. The new job opportunities created are likely to require skillsets that favor people with technical training over local residents.

The large volumes of data and information generated by remote sensing and other innovative technologies can be used to enhance **forest planning and management**. This includes identifying threats and implementing mitigation strategies.
The concepts of improved silviculture management and precision forestry promote the use of data and information from various sources to refine site preparation, planting and operations to improve SFM. RIL and winch assisted-harvesting can increase productivity, log recovery and profitability, while reducing waste and collateral environmental damage. However, innovative technologies can also have negative impacts on forest management, such as by promoting the unsustainable exploitation of natural resources or resulting in the loss of low-skilled jobs.

Many innovative technologies can contribute to reduced waste and **improved resource use efficiency**, thus increasing the profitability of the forest sector and contributing to the sustainable management of natural forest resources. Innovative technologies can also limit pollution and collateral damage to ecosystems. Combining digital technologies and process innovations, such as through CNC, can further improve resource processing, improving productivity, recovery rates and profitability.

The success of any planting operation heavily depends on the **genetic and physical quality of the planting material** and on the correct matching of the genetic material selected with the local site conditions. This matching can build upon the wealth of existing intra- and interspecific genetic variation. Genetic improvement programs, however, require time, capital and technical expertise. As a result, genetic improvement activities have often been restricted to a limited number of species, focusing on those of commercial value. Species of local importance have seldom been prioritized. Similarly, improved germplasm is often in limited supply and expensive, which could restrain access by farmers and communities. Participatory multiple-species improvement and delivery programs, conducted with local stakeholders, are important innovations to address those barriers. Additionally, access to genetic material developed by private companies or individuals could be restricted by intellectual property rights (IPRs).

Innovative technologies have the potential to generate further **income and employment** opportunities through the development of new products and services and of innovative, safer and greener skilled jobs, making the forest sector more productive, sustainable and attractive, in particular for youth, who will be the forest managers of tomorrow. However, the uptake and scaling up of innovative technologies is likely to lead to the loss of some existing low-skilled jobs. This could negatively impact people involved in traditional labor-intensive management systems, who may have limited human or financial capacity to adapt.

4. Enabling the uptake and scaling up of innovative technologies

The Asia-Pacific region shows very high potential for innovation. However, this innovation potential does not necessarily translate to the forest sector and is mainly concentrated in a few countries, with large divides in innovative capacity across countries within the region. Three broad categories of countries and territories can be identified in the region:

- the '**innovation tigers**', which show the highest potential, including: Australia, China, Hong Kong (China), Japan, the Republic of Korea, New Zealand and Singapore;
- the '**emerging innovators**', mainly upper-middle-income to low-income developing economies, which show encouraging performances on some indicators and promising potential for innovation uptake and scaling up in the coming decades, including: Brunei Darussalam, Cambodia, India, Indonesia, the Islamic Republic of Iran, Malaysia, Maldives, Mongolia, Nepal, the Philippines, Thailand, and Viet Nam;
- a third group consisting of countries where particular efforts are needed to build upon the assets they have and develop their own innovation potential that could benefit from regional and international cooperation.

Two main **barriers to innovative technologies uptake and scaling up** were identified during the development of the roadmap: (i) a lack of capacity (in terms of human, natural, physical, financial and social capitals); (ii) unaligned policies and regulations.

Technology adoption is highly context-specific and very uneven across the region. Upfront costs and investments may be too high for many stakeholders. Local communities may need external support to build capacities and physical infrastructure and access the financial resources needed to harness the opportunities offered by innovative technologies. The challenge is to '**adapt innovative technologies to smaller scales and to local needs, priorities and circumstances** so that they can also benefit smallholders and local communities, even those with limited human and financial resources and limited capacities to embrace innovation.

Demonstration is key to the successful dissemination and uptake of innovative technologies. Full engagement with intended adopters is important to achieve buy-in. Government agencies, conservation organizations, universities and research institutions, the private sector, and communities should also be involved in promoting and demonstrating technologies. Organization and leadership will be essential.

The adoption of innovative technologies also requires new operational standards, investment in new equipment, and capacity building in the effective use of the new equipment and implementation of the operational standards. This is a significant investment in capital and time that affects short-term productivity and profitability. Financial and institutional inertia can block or delay the adoption of innovative technologies, requiring consequential investment and capacity building.

Public investment, procurement and support for research and development are powerful tools to support the uptake and scaling up of innovative technologies. Private sector partners will be crucial for technology transfer and dissemination. It is important that adequate incentives are offered to attract private sector participation. Establishing trust and clear communication regarding the use, advantages and disadvantages of innovative technologies can enhance their dissemination and adoption. Ownership and IPRs can be a barrier to the development and dissemination of innovative technologies.

In many countries, there is neither a clear strategy to support the **uptake and scaling up of innovative technologies** in the forest sector nor long-term forestry research for a development perspective, while other countries proactively support the adoption and utilization of innovative technologies. The following factors should be considered to facilitate the adoption of innovative technologies: (i) the technology and its characteristics; (ii) the adopters, either individuals or organizations (private sector, government agencies, civil society, communities); (iii) the larger economic, social and environmental context; (iv) the demonstrated worth of the technology; and (v) communication and dissemination channels that promote the technology.

Capacity building, education and training are required for professionals and local residents who will adopt and use the new technology. Meanwhile, the most vulnerable, whose employment is threatened or eliminated by the adoption of innovative technologies, must be accommodated with some form of re-training to avoid being left behind. Priority targets are: (i) indigenous peoples and local communities, women and marginalized groups who often have a unique knowledge of local ecosystem management; and (ii) youth of either gender, rural and professional, to attract them to forestry as a career. Training in the safe operation of the technologies will also be essential, particularly with process and product innovations that can be dangerous to the inexperienced. Training and capacity building will be required in a wide range of areas: institutional management, leadership, language proficiency, integration of Indigenous and technical knowledge, value chains, marketing, and small business operations. Attention should also be given to identifying complementarity and synergies between innovative scientific technologies, traditional technologies and Indigenous knowledge.

Besides capacity building, the successful deployment of innovative technologies will require **improved access to credit and markets**, as well as adequate infrastructure, equipment and financial resources. Blended finance is particularly useful to facilitate investments in community development, including in infrastructure that supports the adoption of innovative technologies. Payment for ecosystem services (PES) mechanisms and programs can be designed to improve financial or economic returns for non-marketable service provision and to include support for infrastructure, equipment and community development. ICT-enabled mobile banking and financial and e-commerce service technologies can all support the development of viable local economies where small-scale producers, communities or organizations can directly market products or services to consumers. These arrangements increase returns to producers (whether individual, community or organizational) by reducing transaction costs, minimizing the role of middlemen, increasing margins, and enabling lower prices for the consumer. Innovative finance mechanisms can provide new ways to match big funds with small projects and finance local community small-and medium-sized enterprises (SMEs) that provide greater employment.

Many innovative technologies facilitate the collection and sharing of accurate real-time data and analysis, strengthening community participation, transparency and accountability in **forest governance**. Mobile phones, apps, GPS, GIS, drones, online platforms, social media and video-conferencing facilitate direct community involvement in forest monitoring and citizen science, information sharing with other stakeholders, and participation in decision-making. Such technologies can be used to support participatory governance and empower local communities, including by supporting their land tenure and use rights. The full benefits and scaling up of the technologies thus both depend upon and influence governance of the sector. CF schemes seeks institutional change, shifting the control of forest resources away from sole dominance by government agencies toward the active involvement of local communities.

Supportive policies and regulations are needed to facilitate the adoption of innovative technologies and appropriate safeguards to limit their negative impacts on the economic, social and environmental dimensions of sustainable development. Policies and regulations should support agile governance, improved communication, research and development, technology development and transfer, education and capacity-building and promote multi-stakeholder strategic partnerships with all actors, private or not, involved in innovation. Policies and regulations often lag behind quickly evolving technologies and often target the macro-environment and major actors. A flexible and reactive legal framework that can follow breakthrough transformations and address the specific needs of small-scale actors and local communities is needed to foster innovation uptake and scaling up. Cooperation, collaboration and coordination across countries, sectors and actors at different scales, considering various sustainable development objectives, will be critical to align and harmonize policies, strategies, investment plans and plans of action.

5. Innovative technologies for sustainable forestry: overarching recommendations

The following main areas of interest emerged from this study: monitoring of forest resources; improved productivity and resource use efficiency; research and development; extension and capacity building; infrastructure and finance; access to innovative technologies and safeguards against their negative impacts; international and regional cooperation; governance and policy coordination; network building and stakeholder engagement; and attention to youth, small and vulnerable actors and local communities. These areas were used to structure the roadmap recommendations around the two following questions: (i) Why do we need to harness the potential of innovative technologies? (ii) How can we overcome current constraints and support the uptake and scaling up of innovative technologies in the forest sector?

The results, developed in **Chapter 5**, provide a framework to facilitate the uptake of innovative technologies and enhance SFM in the Asia-Pacific region. Given the diversity of situations across the region, it is obviously impossible to craft a short set of actionable recommendations that are adapted to all national or local circumstances (context, priorities and needs) at the same time. To be useful for policy- and decision-makers on the ground, recommendations need to be actionable and adapted to the local context. Additionally, the recommendations must go beyond general principles and consensual objectives and suggest clear targets, impact-assessment mechanisms and concrete means of implementation.

This is why, to facilitate the implementation of these recommendations and associated options at different scales, FAO and FTA propose two complementary tools to help governments and other actors build upon this common framework and develop their own roadmaps adapted to their specific circumstances (context, priorities and needs):

- A four-step guideline for practical roadmap implementation (**Section 5.3**); and
- A detailed matrix linking each recommendation and options to the evidence and case studies (**Table 7**).

Introduction

Background and purpose of the study

The Third Asia-Pacific Forest Sector Outlook Study (APFSOS III: FAO 2019), launched in June 2019 at the Asia-Pacific Forestry Week in Republic of Korea, highlighted that the use of **innovative technologies**, including information and communications technologies (ICT) and new wood-based products, creates huge opportunities and challenges for SFM in the Asia-Pacific region. Nearly 300 forestry students and young professionals from more than 30 countries were consulted for this Outlook Study. They suggested that the uptake of new technologies in the forest sector has been too slow and called for improved opportunities for young people to learn and apply these new technologies. They also highlighted the need for greater participation and transparency in forest governance in the Asia-Pacific region (FAO 2019).

The extraordinary technological innovations of the Fourth Industrial Revolution[4] (e.g. geospatial technology, AI, machine learning, ICT advancements) is merging the physical, digital and biological worlds in ways that create both huge opportunities and challenges. The uptake and scaling up of innovative technologies assist in addressing key challenges facing the regional forest sector. Forest areas are declining but face growing demand for forest products and services. SFM will remain and gain importance as a crucial landscape management approach. Innovative technologies facilitate SFM through effective planning and implementation, enhanced productivity, improved resource use efficiency, and cost savings. Innovative technologies also generate employment and income opportunities for rural populations, youth, women and marginalized groups. SFM and innovative technologies will retain these vital roles as temperature shifts, droughts, floods, fires and other climate-related stresses continue to threaten our environment.

Following up on the outlook study, FAO and CIFOR, the lead center of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA), collaborated to develop a roadmap on innovative forest technologies in support of SFM in the Asia-Pacific region. This roadmap has been developed through an inclusive and participative process involving key regional stakeholders and technical experts from governments and intergovernmental organizations, from the private sector and civil society organizations, as well as from academia and research institutions. The whole process, described in detail in **Annex 1**, paid special attention to the contribution of students and young professionals from the forest sector in the Asia-Pacific region.

This technical report constitutes the first step of the roadmap. It builds upon the scientific literature, FAO and FTA experience, and the consultation of 425 stakeholders, including regional experts, decision-makers, and youth involved in activities related to the forest sector in the Asia-Pacific region. It examines the potential and barriers for disseminating and deploying innovative technologies for SFM in the region and provides overarching recommendations and specific options for decision-makers. It delineates and informs the process by which decision-makers and actors can identify: the potential of innovative

4 See: https://www.weforum.org/focus/fourth-industrial-revolution

technologies to advance SFM; their potential impacts; constraints to technology uptake and scaling up, and how to overcome these constraints and facilitate adoption. The chapters of this study are organized along these steps. The roadmap is enriched by the results of the technologies workshop (Pingault et al. 2021a) and by contributions from students and young people involved with innovative technologies in the forest sector of the region (Pingault et al. 2021b).

Content and structure of the study

Chapter 1 frames the scope of the study. It recalls the geographic scope of the study and describes the main concepts and definitions, including SFM and innovation as a process. It further introduces the discussion on the links between innovative technologies and sustainable development.

Chapter 2, illustrated with concrete examples, highlights promising innovative technologies for SFM and organizes them around four main categories: (i) digital technologies; (ii) biological technologies; (iii) technical innovations in processes and products; and (iv) innovative finance and social innovations. In conclusion, this chapter suggests a framework to assess how innovative technologies can be used to perform different functions along the value chain.

Chapter 3 addresses opportunities and challenges in the forest sector where the use of innovative technologies can make a difference, including: shifts in wood demand and forest value chains, monitoring and reporting, forest management, improved resource use efficiency, increased need for high-quality and diverse planting material, employment and social justice. This leads to identifying the main objectives for adopting innovative technologies.

Chapter 4 discusses enabling conditions for innovative technologies uptake and scaling up. It covers: innovation in Asia and the Pacific; key barriers to technology uptake and scaling up; capacity building, education and training; sustainable value chains; governance and land tenure security and supportive policies and regulations.

Finally, based on the findings of the previous chapters, **Chapter 5** presents overarching recommendations and specific options, informed by science, to facilitate the dissemination and adoption of innovative technologies. These recommendations and options are organized around the following issues: monitoring of forest resources; improved productivity and resource use efficiency; research and development; extension and capacity building; infrastructure and finance; access to innovative technologies and safeguards against their negative impacts; international and regional cooperation; governance and policy coordination; network building and stakeholder engagement; and attention to youth, small and vulnerable actors and local communities.

1. Framing: concepts and definitions

1.1 Scope

1.1.1 Geographical scope

The geographical scope of the roadmap, referred to in this report as the 'Asia-Pacific region', covers the countries and territories of the FAO region of Asia and the Pacific.[5] It includes the Islamic Republic of Iran, which was previously included in the Near East FAO region but recently joined the Asia-Pacific FAO region. It also includes five sovereign states in free association with New Zealand or the United States of America (USA), as well as eight Australian, French and USA dependent territories situated in the region. However, it excludes France and the USA mainland, situated outside the region. Russia, although covering 29 percent of Asia, is also excluded because issues related to Russian forests are usually discussed within the FAO European Forestry Commission.[6]

5 See: http://www.fao.org/asiapacific/countries/en/

6 The 49 countries and territories included in the scope are listed here: Afghanistan, American Samoa (USA), Australia, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Cook Islands (New Zealand), Democratic People's Republic of Korea, Fiji, French Polynesia (France), Guam (USA), India, Indonesia, Islamic Republic of Iran, Japan, Kiribati, Lao People's Democratic Republic (PDR), Malaysia, Maldives, Marshall Islands (USA), Federated States of Micronesia (USA), Mongolia, Myanmar, Nauru, Nepal, New Caledonia (France), New Zealand, Niue (New Zealand), Norfolk Island (Australia), Northern Mariana Islands (USA), Pakistan, Palau (USA), Papua New Guinea (PNG), Philippines, Republic of Korea, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Tokelau (New Zealand), Tonga, Tuvalu, Vanuatu, Viet Nam, and Wallis and Futuna Islands (France). See: https://www.foreststreesagroforestry.org/wp-content/uploads/2020/10/FAO-FTA_Roadmap-Note-on-geographical-scope_DEF.pdf

1.1.2 Forest, forestry and the forest sector

A wide variety of definitions of forest and wooded areas are used around the world, reflecting both the diversity of forest ecosystems and of human perceptions and uses of forests (HLPE 2017). The FAO definition is the most widely recognized and used. In addition, as part of its Global Forest Resources Assessments (FRA), FAO has coined definitions of forested and tree-based systems that allow comparative analysis across countries at regional or global levels. This study uses these FAO definitions, as updated for the latest FRA 2020 (FAO 2018a).

Forest is defined as "land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ" (FAO 2018a). This definition excludes agricultural and urban tree stands. The FRA 2020 (FAO 2018a) further distinguishes the following two main categories of forests:

- Naturally regenerating forest: "forest predominantly composed of trees established through natural regeneration" (often also called secondary forest or natural forest); and
- Planted forest: "forest predominantly composed of trees established through planting and/or deliberate seeding".

Primary forest, considered a sub-category of natural forest, is defined as a "naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed" (FAO 2018a). Further definitions are listed in **Table 1**. As the technologies used to exploit trees outside forests are not different in nature from those used in forestry, the present study is also relevant to other systems with trees listed in **Table 1**.

In this study, in line with APFSOS III (FAO, 2019), the terms 'forestry' and 'forest sector' are used interchangeably to encompass "all economic activities that mostly depend on the production of goods and ecosystem services from forests". During its 28th session (17–21 June 2019) held in Incheon, Republic of Korea, the Asia-Pacific Forestry Commission (APFC), considering the "impacts of technological advancements on forests and forestry", also used this broad definition of forestry and the forest sector covering not only forest management but also forest industries (APFC 2019).

1.2 Sustainable forest management and its relevance to the global context

1.2.1 Global and regional context

The global human population amounted to 7.7 billion in 2019, with an annual growth rate of 1.09% in the previous five years, whereas Asia and the Pacific's population amounted to 4.6 billion (60.2% of the world population), with annual growth rates of 0.92% in Asia and 1.37% in the Pacific. While the world's human population growth rate has declined in recent years, it is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and 10.9 billion by 2100, according to the medium-variant projection of the United Nations (UNDESA 2019a; 2019b). Population growth and economic growth intensify the pressure to convert forests to agricultural, industrial, and residential uses and to satisfy growing demand for food, fuel, wood fiber and other tree products, further intensifying production pressure on surviving forest systems. Simultaneously, these forest systems are expected to provide a diverse array of environmental services.

Deforestation, which is the conversion of forests to other land uses, continues to be a global issue. During the last three decades, an estimated 420 million ha of forest were deforested across the world. The global deforestation rate has declined from 15.8 million ha yr^{-1} from 1990–2000 to 10.2 million ha yr^{-1} from 2015–2020. The deforestation rate in Asia has been nearly halved, from 4.17 million ha yr^{-1} from 1990–2000 to 2.23 million ha yr^{-1} from 2015–2020. In the Pacific, deforestation declined significantly from 655,000 ha yr^{-1} from 1990–2000 to 42,000 ha yr-1 from 2010–2020.

Worldwide, 'forest areas' have also continued to decrease, although at a slower rate during the last 30 years. In contrast to this global trend, Asia and the Pacific have experienced net gains in forest area in the recent decades, with reforestation, afforestation and natural regeneration exceeding deforestation. In Asia,[7] forest areas increased by 200,000 ha yr^{-1} from 1990–2000; 2.4 million ha yr^{-1} between 2000–2010; and 1.2 million ha yr^{-1} during 2010–2020. In the Pacific, although forest areas declined by 200,000 ha yr^{-1} over 1990–2010, it increased by 400,000 ha yr during 2010–2020, reaching an overall net balance (FAO 2020a). Despite the overall positive trend, regional forests remain under pressure from: population growth, migrations and conflicts, globalization and economic growth, urbanization and infrastructure development, agriculture expansion, and disease outbreaks; with many of these stresses exacerbated by climate change (Laumonier et al. 2021; Oldekop et al. 2020).

This regional picture, however, does not reflect the diversity of situations encountered within the region in terms of forest extent (see Figure 1) and trends. China reports an increase of 1.94 million ha/yr between 2010 and 2020. However, over the last three decades, forest areas have decreased in South and Southeast Asia due to significant declines in some countries including Cambodia, Indonesia and Myanmar. These losses have been partially offset in terms of forest area by gains in India and Viet Nam.

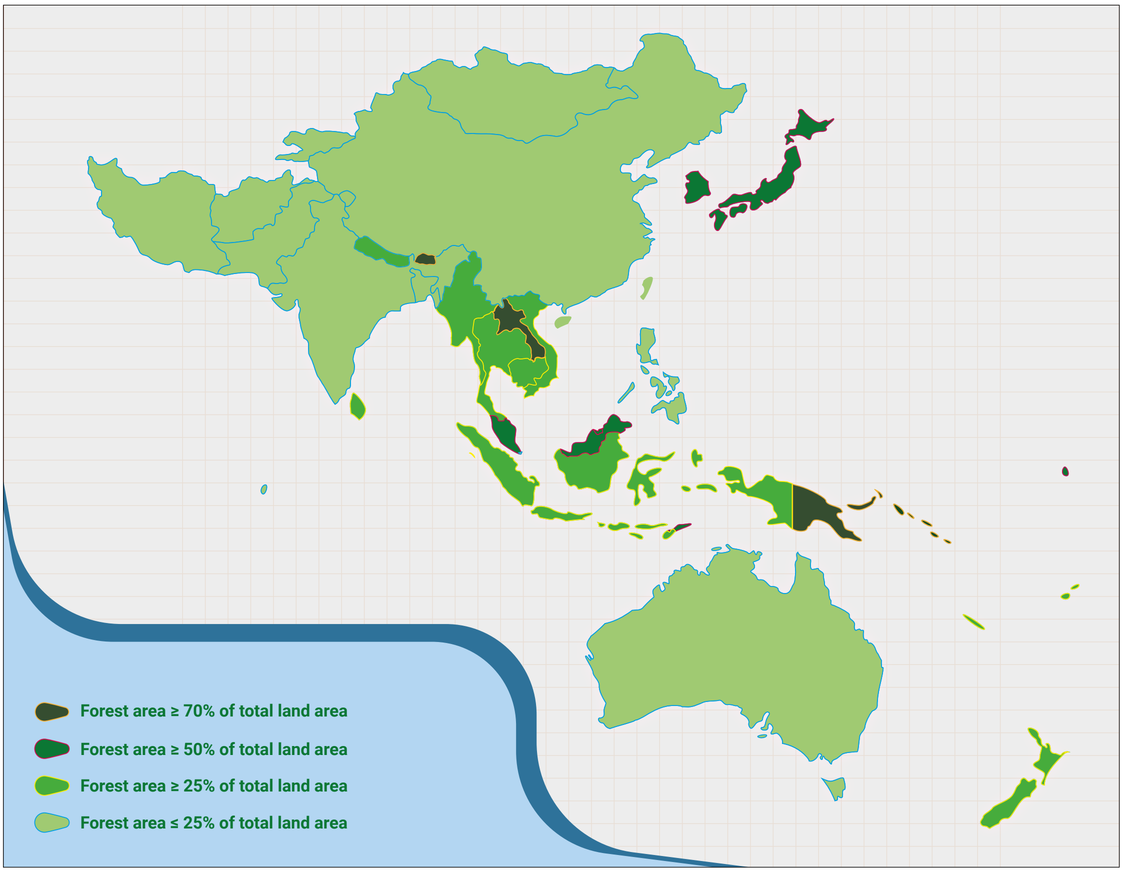
7 The FRA 2020 figures given in the following paragraphs correspond to the whole region of Asia. The geographical scope of our study is smaller. It corresponds broadly to the two FRA sub-regions of East Asia and South and Southeast Asia. It excludes the FRA sub-region of Western and Central Asia.

Table 1. Definitions of forests and other land-use systems with trees

Systems	Definitions
Primary forest	Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.
Secondary forest	Forests regenerated mainly through natural processes after significant human or natural disturbance of the original forest vegetation from a single event or over an extended period; that displaying a major difference in forest structure and/or species composition from the original forest or primary forests on similar sites (Liss et al. 2003).
Woodland	Land that has either a crown cover (or equivalent stocking level) of 5%–10% of trees able to reach a height of 5 m at maturity; or a crown cover (or equivalent stocking level) of more than 10% of trees not able to reach a height of 5 m at maturity; or with shrub or bush cover of more than 10% (FAO 2002; FAO 2018a).
Planted forest	A forest established by planting or/and seeding in the process of afforestation or reforestation. A gradient exists among plantation forests from even-aged, single-species monocultures of exotic species with a fiber production objective to mixed species, native to the site with both fiber and biodiversity objectives (FAO 2002; FAO 2018a).
Plantation forest	Sub-category of planted forest "that is intensively managed and meet ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing" (FAO 2002; FAO 2018a).
Other planted forest	Sub-category of "planted forest which is not classified as plantation forest"
Other wooded land	"Land not classified as "forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10%, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use."
Other land	"All land that is not classified as 'forest' or 'other wooded land'.
Other land with tree cover	"Land classified as "other land", spanning more than 0.5 hectares with a canopy cover of more than 10% of trees able to reach a height of 5 meters at maturity". This definition includes, for instance, agricultural tree crops, agroforestry, trees in agricultural landscapes and trees in urban settings.
Palms	Sub-category of "other land with tree cover" predominantly composed of palms for production of oil, coconuts or dates.
Tree orchards	Sub-category of "other land with tree cover" predominantly composed of trees for production of fruits, nuts, or olives.
Trees in Urban Settings	Sub-category of "other land with tree cover" such as urban parks, alleys and gardens.
Agroforestry	Land use systems in which trees and other woody perennials are deliberately integrated with agricultural crops, animals or both, in some form of spatial arrangement and temporal sequence (Huxley and van Houten 1997). A dynamic ecologically-based natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Mead 2004).

Source: FRA 2020 (FAO, 2018a) except when otherwise noted

Figure 1. Forest area in Asia and the Pacific



Source: Authors' elaboration, based on figures from FAO (2020a) and FAOSTAT.[8]

Fortunately, over the last 30 years, the rate of forest area loss in South and Southeast Asia overall has decreased by half, from 1.84 million ha yr^{-1} from 1990–2000 to 941,000 ha yr^{-1} from 2010–2020 (FAO 2020a).

Forest degradation is the change in the structure and functions of a forest that reduce its capacity to provide goods and ecosystem services (Thompson et al 2013). Globally, it is estimated that over 2.0 billion hectares of forest have been degraded (Vásquez-Grandón et al. 2018). In the Asia-Pacific region, forest degradation has resulted in a decline in the area of primary forests, which currently covers only 19% (140 million ha) of the region's total forest area (723 million ha) (FAO 2019, based on data from the FRA 2015). Consequently, a rapid decline in biodiversity has been observed. Currently, the global rate of species extinction is tens to hundreds of times higher than the average rate over the past 10 million years and accelerating. The number of forest plant and animal species has decreased sharply in the last 40 years (IPBES 2019).

Globally, the total forest carbon stock decreased from 668.4 gigatons (Gt) in 1990 to 662.1 Gt in 2020, while carbon density per hectare increased slightly over the same period, reflecting the decrease in global forest area. In Asia, total forest carbon stocks have increased by 9.9% over the last 30 years, from 77.1 to 84.7 Gt. During the same period, forest carbon stocks slightly decreased in the Pacific by 0.8%, from 33.3 to 33.1 Gt (FAO 2020a).

Eighteen percent of the world's forest area, approximately 725.8 million ha, is in legally established protected areas such as national parks, conservation areas and game reserves, corresponding to the International Union for Conservation of Nature (IUCN) categories I–

8 See: https://www.fao.org/faostat/en/#data/RL

IV (Dudley et al. 2013). Asia has 144.2 million ha of forest in designated protected areas, making up 25% of its total forest area. The Pacific has 29.1 million ha in designated protected areas, or 16% of its total forest area. Across Asia, the Pacific and the rest of the world, the area of forests in protected areas is increasing, although the rate of increase has slowed over the last 30 years.

The area of forest under long-term management plans is a strong indicator of commitment to SFM. Information on the area of forest under management plans is becoming more readily available, but many countries lack data predating 2000. According to the FRA 2020 (FAO 2020a), 54% of global forests have long-term management plans. For Asia and the Pacific, the area of forests under long-term management is 64% and 31% respectively. Trends in Asia show a steady increase, while in the Pacific, the forest area under long-term management plans has remained constant. A promising development is the independent certification of the quality of forest management. Forest certification evolved in the 1990s as a mechanism to promote SFM and trade of products originating in sustainably managed forests. At the global level, there are two main certification programs, the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). In 2019, the total area of certified forests was 426 million ha. Approximately 75% of certified forests are in Europe and North America, possibly due to constraints and costs linked to the certification programs. The areas of certified forests in Asia and the Pacific are limited (25 million ha and 12 million ha respectively) but have been increasing since 2000 (FAO 2020a).

Overall, the trends documented in the FRA 2020 are positive. Forest area and above-ground forest biomass stock are increasing in Asia and the Pacific, unlike in other parts of the world, where both indicators are in decline. The proportion of forest area located within legally established protected areas in Asia and the Pacific are 25% and 16% respectively. The proportion in Asia exceeds the global average, while the proportion in the Pacific is similar to the average. Additionally, the proportion of forest area under long-term forest management plans in Asia and the Pacific is 64% and 31% respectively. The Asian achievement surpasses the global average, but the Pacific proportion is below the global average. Certified forest management schemes are still evolving in Asia and the Pacific compared to in Europe and North America, but trends over the past two decades are positive. These extents and trends all contribute towards SDG 15 (sustainable forest management, combating desertification, and halt and reverse land degradation and biodiversity loss),[9] as well as the other nine SDGs that are pertinent to the UN Strategic Plan for Forests 2030, which are listed in the next subsection.

1.2.2 Sustainable development and sustainable forest management

Thirty years ago, the Brundtland Commission report defined sustainable development as development that “meet the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). Sustainability in this sense does not mean keeping things unchanged but rather requires the constant development of new ideas and options (innovations) to meet current needs and future challenges (van Noordwijk et al. 2008). The United Nations General Assembly recognizes “that sustainable forest management, as a dynamic and evolving concept, is intended to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations” (UNGA 2008).

Forests, trees and the sustainable management of those resources have key roles to play in achieving the 2030 Agenda for Sustainable Development of the United Nations (UN 2015). According to FAO (2018b), forests and trees make important

9 See the scoping note developed for this study: https://www.foreststreesagroforestry.org/wp-content/uploads/2020/10/Scoping_Note-Asia-Pacific-Roadmap_Innovative_Technologies_vDEF.pdf

contributions to at least 10 of the 17 SDGs (see **Box 1**):

- SDG 1. End poverty in all its forms everywhere.
- SDG 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- SDG 5. Achieve gender equality and empower all women and girls.
- SDG 6. Ensure availability and sustainable management of water and sanitation for all.
- SDG 7 Ensure access to affordable, reliable, sustainable and modern energy for all.
- SDG 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
- SDG 11. Make cities and human settlements inclusive, safe, resilient and sustainable.
- SDG 12. Ensure sustainable consumption and production patterns.
- SDG 13. Take urgent action to combat climate change and its impacts.
- SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

The FRA 2020 (FAO 2020a) reports on key indicators under SDG 15. The indicator most relevant for this roadmap is: ‘progress towards sustainable forest management’. This indicator comprises five sub-indicators: (i) annual net change in forest area; (ii) above-ground biomass stock in forests; (iii) proportion of forest area located within legally established protected areas; (iv) proportion of forest area under long-term forest management plans; and (v) forest area under independently verified forest management certification schemes. Trends and achievement in the Asia-Pacific region towards these sub-indicators are summarized in **Section 1.2.1.**

Under the general framework of the 2030 Agenda, the United Nations Strategic Plan for Forests (UNSPF) 2030 focuses more specifically on the sustainable management of all types of forests and defines six Global Forest Goals (GFGs) (UNDESA 2019c):

1. Reverse the loss of forest cover through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change.
2. Enhance forest-based economic, social and environmental benefits, including by improving the livelihoods of forest dependent people.
3. Significantly increase the area of protected forests and other areas of sustainably managed forests, as well as the proportion of forest products from sustainably managed forests.
4. Mobilize significantly increased, new and additional financial resources from all sources for the implementation of sustainable forest management and strengthen scientific and technical cooperation and partnerships.
5. Promote governance frameworks to implement sustainable forest management, including through the UN Forest Instrument, and enhance the contribution of forests to the 2030 Agenda.
6. Enhance cooperation, coordination, coherence and synergies on forest-related issues at all levels, including within the UN System and across Collaborative Partnership on Forests member organizations, as well as across sectors and relevant stakeholders

The effective utilization of innovative technologies in the forest sector should strengthen and support regional achievements towards SFM, the UN strategic plan for forests, and the SDGs to which forests and trees make important contributions.

Building upon APFSOS III (FAO 2019), several domains can be identified where progresses are critically needed to advance SFM in the Asia-Pacific region:

Forest science and research. SFM is an increasingly complex multidimensional

Box 1 Key contributions of forests and trees to the SDGs

Forests and trees address poverty alleviation (SDG 1) by supporting livelihoods and providing direct income generation through the main products and services they provision.[10] They also offer a 'safety net' to prevent local communities from sliding into or further into poverty and serve as a pathway out of poverty (Cheng et al. 2017). Forests and trees provide important support to 2.5 billion people depending on smallholder agricultural production for their livelihood (IFAD 2013). A review of meta-analyses confirms that non-wood forest products are important sources of income and improved livelihoods for rural communities (Dawson et al. 2014). Forest and trees contribute directly and indirectly to food security and nutrition (SDG 2) (HLPE 2017; Gitz et al. 2021). Forests and trees provide considerable diversity in plant- and animal-based food resources. Forest and other biodiversity are crucial for an environmentally and nutritionally sustainable food supply, including annual crops, pollinators, trees, other natural vegetation, below-ground organisms, animals, and aquatic organisms (Dawson et al. 2019a, 2019b). Forests and trees also provide wood and other fuels required for cooking. Forests and trees are more resilient to adverse weather conditions than annual cropping systems and thus contribute to household resilience by serving as essential safety nets in times of crisis and emergencies. Women and men often have different yet equally important roles in forest and tree management. Women have unique local knowledge regarding forest and tree products, unknown to men in the community (Colfer et al. 2015; Mulyoutami et al. 2015). Acknowledging these roles and enhancing access to forest and tree resources can enhance gender equality and empower women and girls (SDG 5).

Forests and trees are integral to the sustainable management of water (SDG 6) by regulating stream and groundwater flow, facilitating groundwater recharge, and reducing soil erosion and the sedimentation of water bodies. Through evapotranspiration, forests and trees also contribute to cloud generation, precipitation and the atmospheric circulation of water (Ellison et al. 2017; Sheil 2018; Creed and van Noordwijk 2018). The protection function of forest ecosystem services can make poor communities less vulnerable to natural disasters (Shyamsundar et al. 2018). As mentioned above, forests and trees are a major source of fuel for cooking as well as heating for household and industrial needs, making important contributions to affordable, reliable and sustainable energy (SGD 7). It is estimated that one-third of the world's human population rely on fuelwood as a main energy source. As such, providing access to forests for fuelwood collection is seen as an effective strategy to reduce poverty (FAO 2014a). Fuel supply is closely linked to SDG 2 and SDG 5 because of its role in food preparation and women's dominant role in fuel collection and management (FAO 2018b).

Forest products and their value chains are critically important to sustainable economic growth, productive employment, and decent work (SDG 8). Forest-based small- to medium enterprises (SMEs) foster prosperity through multiple economic, social and cultural dimensions to rural communities (Sanchez-Bardini et al. 2018). These opportunities are especially important in rural areas, where they represent the majority of off-farm employment prospects. SMEs in the forest sector are often informal, relying heavily on family and casual labor. Forest-based enterprises and employment are strongly connected to both SDG 1 and 15. The establishment and proper management of urban and peri-urban forests (UPFs[11]) make valuable contributions to making cities and human settlements inclusive, safe, resilient, and sustainable (SDG 11). This will be increasingly important as the urban populations continue to expand as a portion of the total population (Endreny 2018). Asia has the world's largest urban population (Borelli et al. 2018), and that number is projected to increase. To fulfill their prospective value for cities and other human settlements, the design, planning and management of UPFs should be fully integrated into urban planning at an early stage.

10 The OECD (2009) reports that forests and trees most effectively address poverty alleviation when pro-poor measures are developed and implemented.

11 Urban and peri-urban forests are defined as 'networks or systems of woodlots, groups of trees, and individual trees located in and around urban areas' (Salbitano et al. 2016).

Renewability, resource efficiency and responsible sourcing of forest products are at the heart of the concept of sustainable production and consumption (SDG 12). The renewable and sustainable nature of most forest and tree products (wood and non-wood forest products, NWFPs), combined with reasonable harvest and management practices, can alleviate the environmental burden of production to satisfy a growing world population. Forests and trees make major contributions to carbon sequestration in terrestrial ecosystems as a means to combat climate change and its impacts (SDG 13). Forests absorb approximately 2 billion metric tons of carbon dioxide equivalent each year (IPCC 2014). As such, deforestation and forest degradation, which decrease forests' ability to sequester carbon, is a leading cause of climate change. The most cost-effective climate mitigation options for forestry are afforestation, SFM and reducing deforestation, with differences in their relative importance across regions (IPCC 2014, 2019). Agroforestation, which is land rehabilitation through the establishment of a tree-based farming system and intensification of management, also mitigates climate change while contributing to the alleviation of poverty, enhancement of food security, and supporting sustainable economic growth (Roshetko et al. 2007). Forests and trees play a key role in protecting, restoring and promoting the sustainable use of terrestrial ecosystems, including SFM, combating desertification, and halting and reversing land degradation and biodiversity loss (SDG 15). Innovative technologies that contribute to SFM simultaneously support the attainment of the forest-tree linked SDGs. The UN 2030 Agenda for Sustainable Development (UN 2015) specifically recognizes that technological and social innovations are essential constituents of sustainable development.

Source: expanded from FAO (2020a)

concept, entailing synergies and trade-offs between competing objectives and requiring a strong scientific evidence-base. Multidisciplinary and participative approaches are increasingly needed to address complex and inter-related challenges, operating at different spatial and temporal scales, such as: climate change, conservation of natural resources (land, water and biodiversity), food security and nutrition and livelihoods of indigenous peoples and/or forest-dependent communities. According to FAO (2019), two major potential areas of interest for future scientific research in the region are bioeconomy and ecosystem resilience.

Forest monitoring. The accurate and real-time measurement and monitoring of forest ecosystems and natural resources, their status and evolution, the threats they face, as well as their contributions to the SDGs, is an indispensable prerequisite for their sustainable management. Environmental monitoring can improve our knowledge and understanding of biological processes and ecosystem resilience, particularly to climate change. Real-time monitoring can also help track and prevent illegal activities as well as fires. Accurate mapping of land resources can also improve the management of land tenure and access rights, thus preventing or limiting conflicts over natural resources (FAO 2019).

Productivity and resource use efficiency. Significant improvements in productivity and in energy and resource use efficiency along forest value chains, including through reduced impact logging, waste reduction, recycling and reuse, will be needed to meet growing demand for wood and other tree products driven by population and income growth, while limiting the volume of virgin roundwood required and alleviating the pressure on the remaining primary forests and natural ecosystems in the region. Innovative technologies can play a considerable role in improving wood processing to further enhance resource use efficiency and value addition. Such improvements could increase the profitability of the forest sector, with positive impacts on the incomes and livelihoods of forest-dependent people and communities. They could also transform the labor market, creating new skilled jobs, thus contributing to maintaining or attracting young people to the forest sector, while marginalizing traditional jobs and unskilled workers (FAO 2019).

Forest tenure and forest governance, stakeholder participation and empowerment of local communities. It is increasingly recognized that SFM cannot be achieved without clear, secure and equitable land tenure and access rights. Forest tenure is important as it determines who benefits from the forest. It is also a precondition for investments in forestry, and it influences local decisions related to forest protection and forest destruction (Siry et al. 2015). SFM requires multi-level governance, articulated and coordinated across sectors and scales (Agrawal et al. 2008; HLPE 2017). This invites a shift in forest governance from vertical, centralized, top-down models of governance to decentralized, bottom-up, participatory and multi-stakeholder decision-making processes, empowering local actors and communities and integrating different forms of knowledge (FAO 2019; HLPE 2018). Strengthening inclusiveness and participation is key to ensuring that the views and interests of all stakeholders are considered in decision-making and that costs and benefits of forest resource management, in terms of incomes, livelihoods and ecosystem services, are equitably distributed. Gender equity, including increased women's participation in decision-making, is a key area of concern in the Asia-Pacific region (FAO 2019).

Forest finance and investment. Forestry is perceived as attracting less investment than other sectors. Forests are often considered as common resources open for utilization. Production periods are long and the land areas required are large. Forestry investment horizons are long-term, between the expenditures to establish new plantations and the first monetary returns received after harvests. Similarly, investments in forest management are rewarded at the end of the rotation, while returns on improved genetic material are measured in multiple tree generations. The long time-span from investment to returns leads to high risks and uncertainties, whether biological, climatic, social, economic or political. As financial resources can be more safely invested in other sectors, forest investors require high returns and measures to reduce risks. A number of financial innovations (e.g. blended finance, green bonds, climate bonds, PES) have evolved that show potential for investment in SFM over the last few decades (Louman et al. 2020, 2021).

The following chapters will consider innovative technologies in light of these needs in order to assess how they can contribute to advance SFM.

1.3 Innovation

Innovation can be defined as "a new idea, method or device or the introduction of something new" (Merriam-Webster 2020). A more comprehensive definition is "**a new or improved product or process, or a combination thereof, that differs significantly from previous products or common processes and have been made available to potential users (product) or brought into use by an organization or sector (process)**" (OECD/Eurostat 2018). Innovation is contextual. While the forest sector is often considered traditional and conservative, it is nevertheless open to improvement and modification and readily integrates innovations that enhance its technical and business operations. In the current era of smart technology, the adoption and adaptation of innovative technologies is likely to broaden and accelerate. Innovative technologies in the forest sector include a broad range of 'smart' to more 'conventional' products, methods and processes.

For the purpose of the roadmap, the term 'innovative technologies' entails (i) new technologies in the generation, proof-of-concept, to pilot phases, that could become mainstreamed or mature before 2030; as well as (ii) recent technologies emerging for new purposes or in new contexts.[12] These technologies could be developed within the forest sector or adopted from other sectors. Innovative technologies can include products, processes, approaches, practices, and institutional or social changes (HLPE 2019).

12 See the scoping note developed for this study: https://www.foreststreesagroforestry.org/wp-content/uploads/2020/10/Scoping_Note-Asia-Pacific-Roadmap_Innovative_Technologies_vDEF.pdf

They have the potential to perform better than current technologies or even provide new activities.

The APFC Secretariat (APFC 2019) distinguishes between two types of innovative technologies impacting forestry: (i) those developed outside the forest sector, such as ICT and geospatial technologies; and (ii) those developed within the forest sector, such as production of new-generation wood-based materials such as engineered wood products, bioplastics, natural chemicals, bioenergy products, and pharmaceuticals.

Many technologies initially developed outside the forest sector can be applied to directly or indirectly influence forest use and reduce the associated negative impacts, thus supporting SFM. More efficient use of forest resources can include reducing the area harvested or damaged; facilitating the identification of protected species; improving processing and productivity; and expanding the use of small-diameter trees and fast-growing or lesser-known species that have previously been underutilized or discarded, reducing pressure on overutilized species. For example, most geospatial technologies and ICT have been developed outside the sector and adapted for use in forestry, including forestry-specific tools, databases, programs, platforms and applications. AI, machine learning and digital twin replicas that are used or show promise in geospatial, processing and product applications were all developed outside of the forest sector. All innovative finance technologies were developed outside the forest sector. The genetic improvement approaches and technologies applied to forest trees started in the agricultural sector. Even community forestry (CF) evolved from participatory methodologies that originated in the rural development sector.

When considering the adoption of innovative technologies in the forest sector, it is important to remain open-minded, flexible and 'think outside the box'. After all, transformative innovations, which can shift the entire sector to more viable futures (Loorbach et al. 2020), often originate from outside the sector where they are particularly relevant.

The deployment of innovative technologies in the forest sector has the potential to: provide new products and services; increase productivity and improve resource, energy and cost efficiency, thus generating further income and employment opportunities; and conserve natural resources and reduce negative environmental impacts (FAO 2009; FAO 2019). Innovative technologies, including new processing technologies, have the potential to reduce waste and improve resource use efficiency, thus increasing the profitability of the forest sector and contributing to the sustainable management of natural forest resources. As the human population continues to expand and forest resources are depleted, innovative technologies can also limit or avoid collateral environmental damage to ecosystems (e.g. pollution, destruction of untargeted organisms or species). Product and process innovations can help preserve natural and primary forests by opening new markets for certain wood products (e.g. small-diameter timber or fast-growing tree species) and improve resource utilization.

These innovative technologies can be used in different contexts for different purposes. In the past, technologies in the forest sector mainly focused on: (i) the assessment, monitoring and management of forest and tree resources to enhance the sustainable production of products and services; and (ii) the improvement of harvesting, transport, processing, marketing and utilization of both wood and non-wood products (FAO 2009). Technologies are now widely seen as also having important roles in social aspects of forest management and governance, including access to finance, capacity building and social integration.

Additionally, distinctions are made between incremental versus transformative innovations; product versus process innovations; and technological versus institutional innovations. These various categories of innovations, defined in **Box 2**, can be complementary, opposing or overlapping.

The next chapter describes a range of innovative technologies in the forest sector in greater depth.

Box 2 Categories of innovations

Incremental innovations are a series of small improvements or upgrades made to existing products, services, processes or methods. The changes implemented through incremental innovation are usually focused on improving the efficiency, productivity and competitive differentiation of existing products, services, processes or methods.[13] Incremental innovations are epitomized as iterative step-by-step improvements and often originate within an economic sector or organization. In the forest sector, an example of incremental innovation is reduced impact logging (RIL), which is a refinement or improvement of traditional logging methods. Traditional tree improvement programs, based on provenance[14] trials and breeding of the best performing provenances, are another incremental innovation, representing step-by-step improvement.

Transformative innovations are core concepts, ideas and activities that shift products, services, processes, methods or an entire sector into a new framework that is more viable (efficient, effective or profitable) for the future. Transformative innovations lead to novel products, entirely new value chains, value networks or new ways of doing business, creating new socio-economic trade-offs. These transformations enable and facilitate the exchange of ideas, objects and practices (Loorbach et al. 2020). While transformations can be sustaining innovations providing stability in an organization or sector by supporting their adaptation to external changes, they are more often disruptive innovations creating radical change that revolutionizes (transforms) current systems, an organization or sector. Prevailing principal products, services, methods, firms and alliance can be disrupted and displaced (Christensen et al. 2015).

Examples of transformative innovations in the forest sector are satellite-based, other remote sensing and GPS technologies. Having originated outside the forest sector, these technologies represent drastically new approaches for forest planning, management and monitoring. They can be disruptive innovations as they create new sociopolitical dynamics by providing conservation organizations and local communities with access to information that was previously restricted to government agencies, forest industry and researchers. They are also disruptive by reducing labor requirements and enabling the reallocation of staff time to other activities.

Product innovations are the development of new products, changes in design of established products, or the use of new materials or components in the manufacture of established products. Product innovations are commonly new products or products of enhanced quality and improved overall performance. Product innovations in the forest sector include cross-laminated timber (CLT) which can be manufactured from lower-value timber species or small-diameter logs. CLT are a high-value construction material that can replace concrete and steel. Bamboo- and wood-based bioplastic for packaging and as substitutes for petroleum-based plastics are other examples of product innovations.

Process innovations are the application or introduction of new technologies or methods for manufacturing products or providing services that assist an organization in retaining or gaining competitiveness and meeting market demands.

Product and process innovations can be parallel and complementary, facilitating their adoption and mutually reinforcing their effects; both can also be either incremental or transformative. Process innovations include nursery, cutting garden and tissue culture techniques adapted to mass-produce clones (rooted cuttings, micro-cuttings, etc.) of the superior genetic material developed through tree improvement programs. Such mass production techniques can be cost-effective in producing large quantities of superior

13 See: https://searchcio.techtarget.com/definition/incremental-innovation

14 A provenance refers to location of origin of a tree or its germplasm, normally within the native range of the species.

germplasm for dissemination to forest sector actors – non-government organizations (NGOs), development agencies, small scale commercial and community nurseries, and farmers. This process can also be seen as a transformative innovation by providing to various actors of the forest sector with superior-quality germplasm that was previously inaccessible to them, making it possible to expedite successful tree planting and forest restoration programs.

Technological innovations are new or improved products or processes whose technological characteristics differ considerably from previous technologies used for a similar purpose. Technological innovations can be new products (product innovations) or new processes (process innovations) that have been introduced into a sector; hence, they can include product or process innovations. They can also be either incremental or transformative innovations.

The use of satellite-based and other remote sensing technologies and GPS are an example of technological innovations. These technologies are transformative methods for managing and monitoring forest resources, providing accurate detailed information that was not previously available. They enable organizations to increase their focus on activities that are required for or are facilitated by accurate real-time forest monitoring information. For example, they can allow government agencies and conservation organizations to focus more on combating illegal logging and fostering good forest governance. Private sector firms may be able to focus more on site-specific management prescriptions and practices. Given their specificities and potential impacts, digital technologies are treated in the rest of the report as a specific category, distinct from other technological innovations. Tethered systems are another example of technological innovations. This technology uses cable-winch systems on harvesters, feller bunchers, forwarders, loaders, and skidders,[15] enabling stable and safe operation on steep slopes, which may otherwise be consider unsafe or unsustainable to harvest. Properly established and operated tethering systems can enhance log recovery; reduce damage to the residual forest; reduce soil rutting, compaction and subsequent erosion; and improve worker safety.

Institutional innovations are novel, useful and legitimate changes that disrupt the cognitive, normative or regulative operations of an institution or sector.[16] They redefine the motivation, purpose or operations of an institution, developing new internal and external relationships and networks. In the extreme, new rationales are embraced with the goal of evolving to a smarter institution that can thrive in its environment, which can be one of exponential change. The new relationships and environments should facilitate, rather than limit, new learning, adaptability, and downstream product and process innovations. Institutional innovations are operational and, by definition, often relate to process and tend to be transformative. Institutional innovations may incorporate but are separate from product, process and technological innovations.

Examples of institutional innovations are CF programs. Through these programs, government forest agencies can shift their focus from regulating forest areas and limiting local access to facilitating forest land use rights and legitimizing community forest management. These programs redefine relationships between forest agencies and communities, fostering participatory governance instead of opposition or antagonism. These developments can empower communities to enhance their livelihoods through SFM and address issues of social justice. These institutional and social innovations are also transformative as they may facilitate the exchange of ideas and practices between government agencies, other land managers, communities and development, conservation or other organizations that support CF programs.

15 Source: https://www.fs.fed.us/forestmanagement/equipment-catalog/tethered.shtml#:~:text=Tethered%20logging%20systems%20utilize%20cable,equipment%20or%20damaging%20to%20soils

16 Sources: https://www2.deloitte.com/us/en/insights/topics/innovation/institutional-innovation.html and https://www.hbs.edu/ris/Publication%20Files/Institutional%20Innovation_Raffaelli%20%20Glynn_forthcoming%20(2)_edaec7fb-875b-4efc-8c84-f446f102758e.pdf

2. Innovative technologies in the forest sector

This chapter presents four main categories of innovative technologies as identified and refined during the online inception and innovative technology workshops organized in the course of the development of this study:[17] (i) digital technologies; (ii) biological technologies; (iii) technical innovations in processes and products; and (iv) social innovations and innovative finance.

This chapter, illustrated with examples and case studies, presents in detail the four aforementioned categories of innovative technologies. Building on these presentations, the last section will then propose a framework to assess how different innovative technologies can contribute to improve SFM.

2.1 Digital technologies

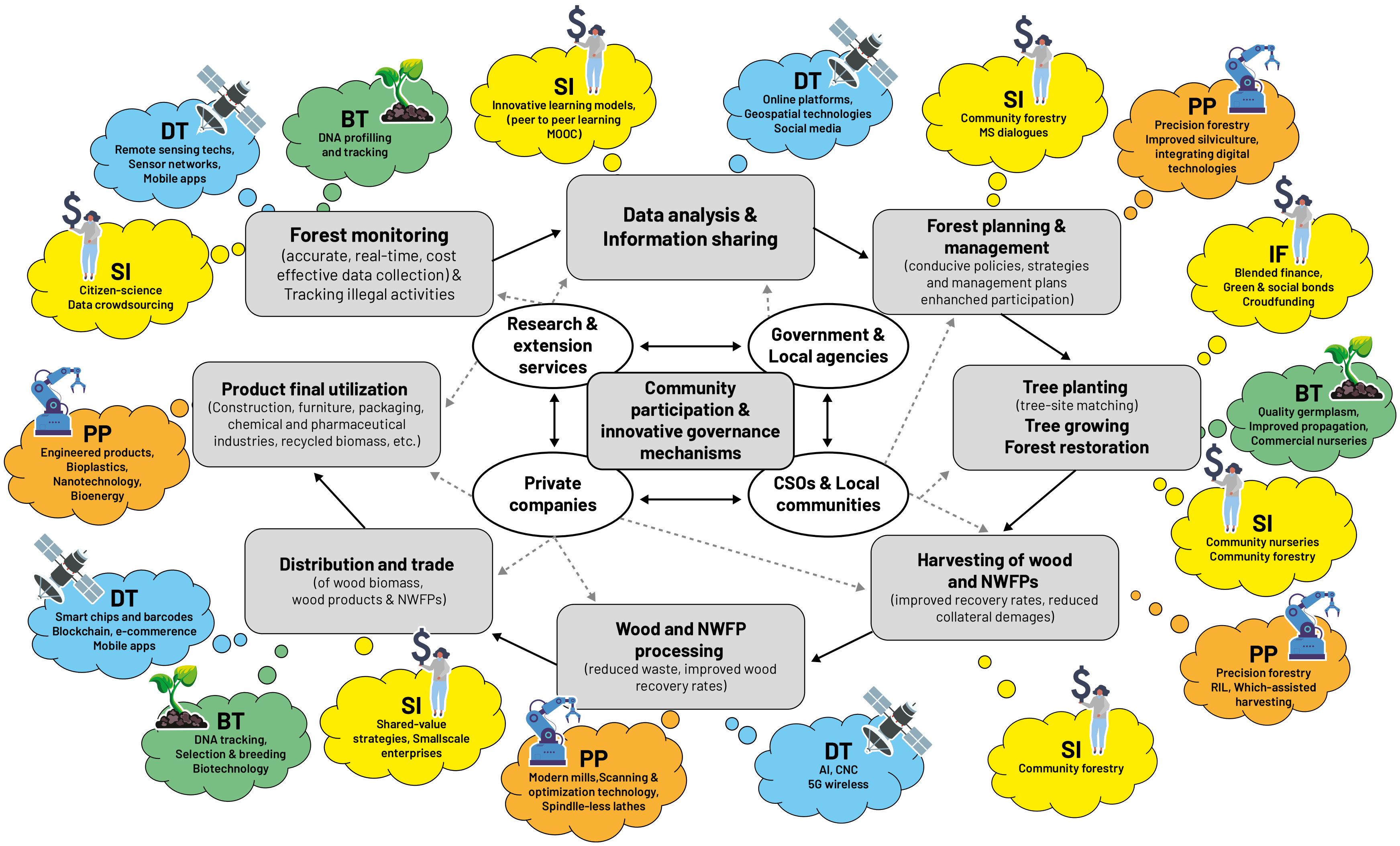
Digital technologies can considerably facilitate the efficient, accurate, cost-effective monitoring of forests and natural resources. Digital technologies can help: monitor and map forest status and trends in the region; detect early forest fires and other natural or human threats; track illegal logging and other illegal activities; and clarify forest tenure and access rights. As a group, these technologies are key tools to verify that innovations and utilization in general are not increasing forest exploitation and degradation. They thus improve transparency and accountability and advance forest conservation and sustainable management.

Remote sensing technologies (satellites, radar, laser imaging detection and ranging (LIDAR), drones, etc.), global positioning systems (GPS) and geographic information systems (GIS) technologies have had huge impacts on forest conservation and management (Oldekop et al. 2020). Digital technologies have made monitoring more efficient, accurate, affordable and accessible. They have greatly increased the accuracy of data collection and analysis, often delivering results in real time at reduced costs. They are used to improve forest demarcation and detect fire danger, pest and insect problems, and illegal logging. The analysis of soil conditions and tree health also allows more precise management prescriptions. Additionally, through these technologies, data and analysis can be made widely available – creating new sociopolitical dynamics where local communities, conservation organizations and other stakeholders have access to information which may have previously been restricted to government agencies, the private sector and researchers.

Utilizing the wealth of information that can be generated through geospatial technologies and analysis and shared through online platforms, it is possible to design management plans that integrate the multiple and competing uses of forests and trees as well as the diverging and sometimes conflicting interests, needs and rights of different stakeholders. This requires the adoption of social innovations (see **Section 2.4.2**) to establish cross-sectoral governance mechanisms articulated at different scales that: enable the full and effective participation of relevant stakeholders, particularly of forest-dependent indigenous peoples and local communities; articulate different functions of

17 See Annex 1 for a more detailed presentation of the process followed to develop this study.

Figure 2. Contributions of innovative technologies to sustainable forest management and sustainable forest value chains



Note: **DT** – digital technologies; **BT** – biological technologies; **PP** – process and product innovations; **IF** – innovative finance; **SI** – social innovations.

forests and trees, including wood and food production, biodiversity conservation and socio-cultural benefits; embrace both short- and long-term objectives; and recognize and reduce conflicts between stakeholders (HLPE 2017). This approach could also directly address the conservation of primary forests.

Online platforms, such as the Earth Observing System (EOS); the System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring (SEPAL), Global Forest Watch (**Box 3**) and others, collect and share largely real-time data that can inform more reactive and effective SFM strategies. Google Earth Engine (GEE) is a cloud-based platform that can acquire and analyze satellite imagery at a planetary scale. GEE locates imagery from various sources and in various data formats; it is a powerful tool for land use identification, mapping, planning and monitoring (Maskell et al. 2021; Sarzynski et al. 2021). Online platforms also directly support other categories of innovative technologies. The Global Tree Knowledge Platform[18] provides detailed information regarding tree species use and promoting the right tree in the right place for the right purpose to bring greater benefits to people and the global environment. The Resources for Tree Planting Platform[19] explains how to source high-quality tree planting materials that match planting objectives and environmental conditions. INBAR is developing an online tool that matches bamboo and rattan species with both site conditions and product development.[20] Norway's International Climate and Forests Initiative Imagery Programme[21] provides free access to high resolution (3–5 m) daily mosaics of forest data in tropical regions that can be used to monitor forest loss, facilitating SFM, biodiversity conservation and sustainable development in those regions.

Digital technologies can highlight and promote the ecosystem services provided by forests, including through ecotourism. They can also encourage and facilitate proactive, cost-effective and real-time participation in decision-making and facilitate innovative governance mechanisms (e.g. social media, video conferencing). The COVID-19 pandemic has limited travel and thus access to partners and forest locations, providing an incentive to better use such digital platforms and tools. These tools can enhance transparency, and promote citizens' participation, science

18 See Annex 1 for a more detailed presentation of the process followed to develop this study.

19 https://worldagroforestry.org/output/resources-tree-planting-platform

20 https://speciestool.inbar.int/

21 https://www.planet.com/nicfi/

Box 3 Global Forest Watch

Global Forest Watch (GFW) was created by the World Resource Institute (WRI) in 1997 as a network of NGOs. It is an open-access and dynamic online forest monitoring and alert system, creating unprecedented transparency about what is happening in forests worldwide.

The aim of GFW is to provide access to timely and reliable information about forests by using mapping applications that unite satellite technology, open data, and crowdsourcing.

Why is GFW needed? Smarter decisions need to be supported by better information. GFW empowers people and organizations everywhere to better manage and protect forests for current and future generations. With greater transparency, GFW helps the public hold governments and companies accountable for how their decisions impact forests.

How does it work? GFW enables anyone to create custom maps, analyze forest trends, subscribe to alerts, or download data for their local area or the entire world. Anyone can also contribute to GFW by sharing data and stories from the ground via GFW's crowdsourcing tools.

Weblinks: https://www.globalforestwatch.org/
https://wri-indonesia.org/en/our-work/projects/global-forest-watch

and control. They can be very powerful, but they should be properly managed to ensure the quality of information. Online trading, e-commerce and banking platforms can support financial and social innovations. A transdisciplinary approach involving all stakeholders (technologists, scientists, government agencies, the private sector, and communities) to deliver technology transfer and capacity building is needed to realize the potential of digital technologies.

There are two broad sub-categories of digital technologies that contribute to SFM: **ICT** and **geospatial technologies**. Relevant ICT include: 'big data' analysis and storage, cloud computing, shared user platforms and analysis sharing. Emerging technologies such as AI, machine learning and digital-twin replica[22] have the potential to: analyze large amounts of spatial data; generate detailed information at the local to global scales in close to real time; enhance and accelerate decision support systems; and assume routine tasks previously conducted by people. Strategic investments and technological breakthroughs are required to facilitate broad adoption in the region, particularly in developing and less-developed economies.

Geospatial data and technologies, including remote sensing, GIS and GPS, have broad applicability to the forest sector. Geospatial data are geographic specific data linked to latitude-longitude coordinates, geopolitical locations (cities, towns, districts, etc.), postal codes or specific addresses. Geospatial data at a large scale is usually generated from satellite-based observation (including low earth orbit micro-satellites) and other remote sensing technologies. LIDAR, both terrestrial and airborne, is a technology that is becoming increasingly used in the region to analyse terrain, forest structure, height and density of the stand and the habitats within the forest (see **Box 4**). LIDAR pulses are affected by weather conditions such as dense fogs, smoke, or rain. Radar technology, unlike LIDAR, is not affected by such adverse weather conditions and has therefore been extensively used in remote sensing to assess forest cover in the humid tropics, where cloud cover is a recurrent challenge for optical remote sensing. Although the resolution of images returned by radar may be of lower quality compared to that of LIDAR, it is often used in conjunction with optical remote sensing, especially in studying forest degradation (Mitchell et al. 2017; Crowson et al. 2018).

Geospatial data, technology, and analysis are revolutionizing forest management and environmental monitoring in the Asia-Pacific region. These technologies have greatly increased the accuracy and transparency of information available for forest agencies to plan, map and model their forest resources and develop responsive and responsible policies to monitor their impacts. Specifically, these technologies facilitate the monitoring of land use changes, the documentation of illegal activities, tracking the sources of timber and forest products, and information sharing with multiple stakeholders from government officials to local communities. Bhutan and Singapore provide good examples of how spatial information, analysis and online databases are being used to enhance SFM (see **Boxes 5** and **6**).

Land use planning (LUP) tools provide a framework for government and multiple stakeholders to use geospatial data to develop sustainable land use plans that balance economic, conservation and local livelihood objectives. Trade-offs between these priorities may make policymakers reluctant to protect the environment, as doing so may postpone short-term economic development. Such decisions are short-sighted as environmental health and sustainability are vital to long-term economy stability and growth. The concept of green growth presents a new approach to economic growth that puts human well-being at the center of development, ensuring that sustainable management of natural assets continues to provide products and services

22 A digital twin is a digital model of a physical object. The concept of digital twin, anticipated by Gelernter (1991), made possible by the incredible advance in digital technologies and big data analysis, now has many applications in urban planning or in building, manufacturing, automobile or healthcare industries (Grieves 2019).

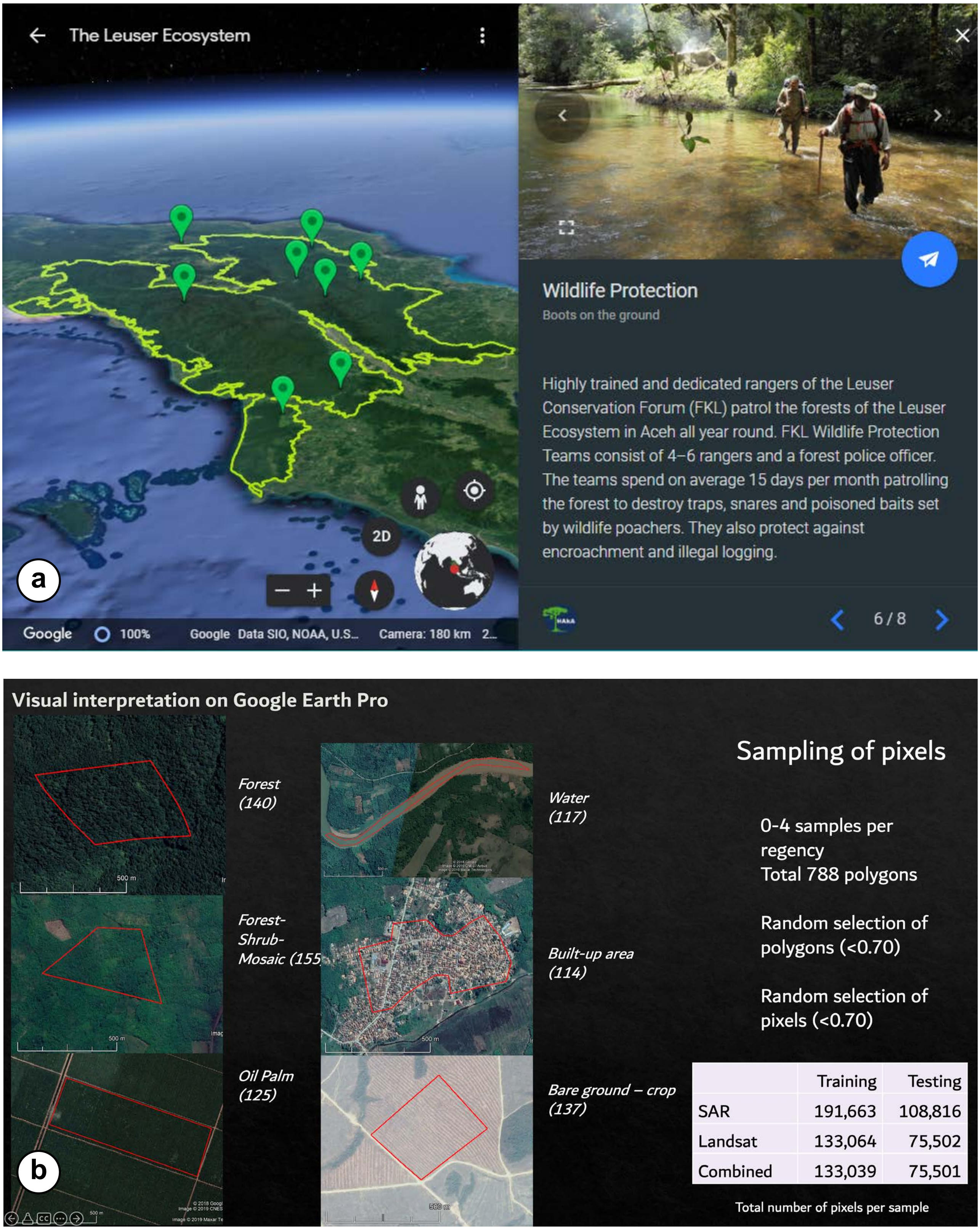


Photo 1. a) Global Forest Watch (GFW) is an open access platform that provides timely access to reliable information about forests that combine satellite technology, open-access data and crowdsourcing (Credit: Google Earth Voyager). b) Google Earth Engine (GEE) is a web-based application developed to help land planners acquire and analyze open-access satellite imagery at a planetary scale. GFW and GEE facilitate the engagement of civil society and communities in forest monitoring (© Thuan Sarzynski).

Box 4 LIDAR (*Laser Imaging Detection and Ranging)*

LIDAR technology

LIDAR (*Laser imaging detection and ranging' or 'light detection and ranging')* is a remote sensing technology that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses, combined with other data recorded by the airborne system, generate precise, three-dimensional information about the shape of the Earth and its surface characteristics. A LIDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. There are two types of LIDAR: (i) topographic LIDAR typically uses a near-infrared laser to map the land; (ii) bathymetric LIDAR uses water-penetrating green light to also measure seafloor and riverbed elevations. LIDAR systems allow governments, land managers, scientists, and other professionals to examine both natural and manmade environments with accuracy, precision, and flexibility to support land use planning and management.

Source: NOAA (2021)

LIDAR for monitoring invasive plant species

Biological invasions can affect ecosystems across a wide spectrum of bioclimatic conditions. Therefore, it is often important to systematically monitor the spread of species over a broad region. Remote sensing has been an important tool for large-scale ecological studies in the past three decades, but it was not commonly used to study alien invasive plants until the mid-1990s. The authors synthesized previous research efforts on remote sensing of invasive plants from spatial, temporal and spectral perspectives. They also present a recently developed state-of-the-art image fusion technique that integrates passive and active sensing of energies concurrently collected by an imaging spectrometer and a scanning-waveform LIDAR system respectively. This approach provides a means to detect the structure and functional properties of invasive plants of different canopy levels. Finally, they summarize regional studies of biological invasions using remote sensing, discuss the limitations of remote sensing approaches, and highlight current research needs and future directions.

Source: Huang and Asner (2009)

LIDAR for mangrove inventory estimation

The Geoscience Laser Altimeter System (GLAS) on the NASA Ice, Cloud and land Elevation Satellite (ICESat) provides a three-dimensional view of the Earth with unprecedented accuracy. GLAS LIDAR altimetry data collected from 2003 to 2009, together with the Digital Elevation Model from the Shuttle Radar Topography Mission (SRTM), were used to generate canopy height maps for mangrove forests worldwide. LIDAR pulse, containing its energy between the ground and the top of the tree, is correlated with elevation data from SRTM to derive the canopy height of trees. The canopy height data is subsequently used to estimate mangrove aboveground biomass (AGB).[23] Canopy height and AGB derived from spaceborne LIDAR and in situ measurements are valuable data for assessing variation in mangrove forest structure and carbon cycle dynamic at the global level.

Source: Schutz et al. (2005)

23 https://daac.ornl.gov/CMS/guides/CMS_Global_Map_Mangrove_Canopy.html

Photo 2. The Singapore National Park Board's Remote Tree Management System (RTMS) uses a combination of LIDAR, drones, digital twins and geospatial mapping to remotely assess the health of and management options for all 6 million trees under the Board's manage (© National Park Board).

that support economic development (OECD 2013). Notable LUP software packages include LUMENS (Land-Use Planning for Multiple Environmental Services), ARIES (Artificial Intelligence for Environment and Sustainability), inVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) and TESSA (Toolkit for Ecosystem Service at Site-based Assessment) (see **Boxes 7** and **8**).

Geospatial data and analysis can also be used to develop data on forest reference levels (FRLs) and forest reference emission levels (FRELs) that countries report to the United Nations Framework Convention on Climate Change (UNFCCC) and to support the implementation of climate change mitigation measures (**Box 9**). Additionally, geospatial technologies, data and analysis have huge potential to support environmental conservation (see **Box 19** and **Box 20**).

Drones and unmanned aerial vehicles (UAVs),[24] hereafter referred collectively as drones, are very versatile tools that are used to perform a variety of functions. Drones facilitate real-time and rapid forest monitoring, even in remote, crises or conflict areas. They can be used to track illegal activities, evaluate forest health, assess fire risk, recognize forest types and species, monitor collateral environmental damage linked to infrastructure development, conduct forest inventory, monitor forest boundaries and property lines, and evaluate ecosystem services and forest genetics. Drones can provide 3D pictures of forest stands at different levels from both above and inside the canopy. Drones can also enhance local governance by empowering communities and NGOs to engage in independent forest and land use monitoring. Drones have been used to deliver tree seedlings and other inputs to planting sites, as well as food and water for field teams (Herries 2018). They can also be used to catch insects (Kamran et al. 2021), evaluate and document forest degradation (Lee 2021), measure tree and forest volume (Saputra et al. 2021), and sow (blast) seeds (Fortes 2017).

Sensor networks are another very promising innovative technology that has emerged in recent years. Sensor networks are groups of spatially dispersed and dedicated sensors for monitoring and recording the physical environment conditions and reporting the

24 Drones are unmanned aircraft, ships or land-rovers guided remotely or autonomously. UAVs are aircraft that can fly without a pilot onboard. UAVs are a type of drone.

Box 5 Spatial information and online database enhance SFM in Bhutan

Bhutan has taken positive steps to sustainably manage its national forest resources. The use of innovative technologies, in conjunction with sustainable management principles, ensures the effective achievement of long-term sustainable management goals. This is especially relevant with the increase in local governance and participation, the threat of climate change, and the international agreements to which Bhutan is a member. Key application of innovative technologies applied to the forest sector in Bhutan include the following.

Forest information and database

Information systems are one area of technology that has a big impact on forest management. SFM relies on timely and accurate information for informed decision making and for national forest monitoring purposes. The databases currently employed in Bhutan include the following:

- The Forest Information Reporting and Management System (FIRMS) is an online database system designed to streamline the information management system of the Department of Forests and Parks Services by capturing all information and data pertaining to forest resources and services. This database aims at facilitating planning, monitoring and evaluation of programs and sub-programs within the Department.
- The Spatial Monitoring and Reporting Tool (SMART) is an interactive interface where management decisions made during SMART patrol planning can be physically implemented by the SMART patrol team at various levels.
- The Spatial Decision Support System (SDSS) is another interactive interface designed to support a user or group of users in improving the effectiveness of decision making while solving semi-structured or unstructured spatial decision problems which are characterized by many actors, many possibilities, and high uncertainty. This system integrates database management systems with analytical models and expert knowledge, to provide analyses and results that can be viewed through graphical display.

All these databases contribute to the central database maintained at the departmental headquarters, which is also the central data repository.

Forest and wildlife resources assessment

The National Forest Inventory (NFI) and the National Wildlife Survey (NWS) involve collecting data and information on forests and wildlife resources for compilation, assessment and analysis to enable appropriate policy and management decisions. The Department has already carried out a first round of NFI and NWS, which provided the quantitative baseline required for sound forest management in the country. The NFI was carried out by drawing national survey grids (2,424 sampling plots) aided by the use of innovative technologies, like the Open Foris collection tool or Trimble GPS, with in-built survey designs using mobile apps for data collection, and subsequent data analysis using the CoCac (R-statistical) Package.[25] The NWS involved the use of radio telemetry and camera traps laid at predesigned grids. Generally, the NFI and the NWS were carried out by field crews and enumerators with minimal use of GIS and remote sensing technologies. However, immense opportunities are foreseen in employing remote sensing and GIS technologies in future assessments and surveys.

Source: Dorji (2021)

25 https://cocalc.com/features/r-statistical-software

Box 6 Urban tree management system in Singapore

Singapore's National Parks Board manages over 6 million trees. The Urban Tree Management System enhances tree management by leveraging smart technologies and tools through the Remote Tree Management System (RTMS). The RTMS uses LIDAR scans to create a point-cloud model of all managed trees. A machine-learning algorithm is used to map the geospatial location and create digital twins of individual trees. The digital twins are remotely-assessed for tree health using multi-spectral and hyperspectral analyses to identify trees that are chlorotic or low in leaf area index. The tree structures are analyzed using the tree structural model (TSM+) and panoramic photographs obtained during the LIDAR scans. TSM+ considers the load-bearing capacity of tree components, properties of the wood, and the wind load acting on the tree. Sensor networks are also deployed across the parks to monitor tree tilting and movement to evaluate risk of uprooting and collateral damage. The networks are linked to GIS platforms that record historical movement of each tree. Should a tree be flagged for attention, inspectors simulate the effects of pruning or other management measures on tree stability to evaluate mitigation options. Once the remote analyses are complete, the inspectors compile a list of trees and mitigation options for field inspections. The field inspections may involve the use of traditional tools, resistographs, and/or tree inspection drones (TID). In addition, citizen science programs encourage the public to take an active role in their parks by crowdsourcing information and observation. The crowdsourced data is shared on an online platform that is publicly accessible. This high-tech approach to urban forest health is an effective means to identify individual trees which require attention and keep park environments safe.

Source: www.nparks.gov.sg

Box 7 LUMENS (Land Use Planning for Multiple Environmental Services)

LUMENS was developed by World Agroforestry (ICRAF) and tailored to support the concept and context of green growth. LUMENS is a spatially explicit modeling platform of land use science that projects ecological and economics outcomes of land uses and land use changes. The platform can simulate various development scenarios, projecting ex-ante impacts of various management options to provide balanced input for negotiations among policymakers and other stakeholders.

LUMENS runs effectively with minimum data inputs, matching conditions in many developing countries where detailed data can be lacking. The types of datasets required by LUMENS include: (i) time-series maps of land use and land cover change; (ii) carbon stock data of representative land use and land cover types; (iii) plot level biodiversity; (iv) annual rainfall; (v) river debit; (vi) soil types; (vii) peat distribution and depth, including emissions and decomposition from drained peat lands; (viii) fire occurrence and hotspots; (ix) land allocation; and (x) economic and statistical data, such as the profitability of dominant land use systems, regional economies, location quotient[26] (LQ), shift share and labor.

Three regulating ecosystem services are regularly modeled by LUMENS for each land use change scenario: (i) habitat quality and configuration for biodiversity maintenance; (ii) carbon emissions and sequestration as part of climate regulation; and (iii) watershed services. Habitat quality and configuration within a landscape are measured by the DIFA (degree of integration of focal areas) index. The lower the DIFA, the more segregated[27] the ecosystem. Carbon emissions from land use changes and peat management are presented showing the locations and land-based sectors contributing to the emissions. Watershed regulation functions are indicated by sedimentation yield and surface runoff within sub-watersheds.

LUMENS supports green growth planning and strategies by providing: (i) well-founded accurate information on development options; (ii) integration of those options into existing development and conservation plans; and (iii) inclusive multi-stakeholder approach in the planning process where all stakeholders can express their needs and priorities. It is essential that all relevant stakeholders understand and agree on the outcomes, scope, challenges and opportunities of green growth planning process. LUMENS planning has been used to produce provincial green growth development plans in the Indonesian provinces of South Sumatra, Jambi, Aceh, Papua and West Papua. The Indonesian government has endorsed the use of LUMENS for land-based climate change mitigation for all provinces in Indonesia. LUMENS has also been used in Lam Dong province in Viet Nam for the provincial green growth action plan and will be tested in Sri Lanka.

Sources: Dewi et al. (2014, 2015); Mulia et al. (2019).

Box 8 Aries (Artificial Intelligence for Environment and Sustainability)

ARIES is a collaborative and open-source platform for interoperable models and data, based on the Knowledge Laboratory (k.LAB) technology: an AI-powered and digital software for rapid ecosystem services assessment and valuation. It gives equal emphasis to ecosystem services supply, demand and flow in order to quantify actual service provision and use by society (as opposed to quantifying potential service benefits). It aims to provide a suite of models that support science-based decision-making where nature counts. Beyond ecosystem services, ARIES can be applied to other planning needs including natural capital accounting, agriculture and food security, and renewable energy.

Collaborative information is hosted on a network and based on simple user query. ARIES automatically integrates all of the actors involved in the nature and societal interactions, connects them into a flow network and creates the best models for each actor and connection. The system to be analyzed is defined by selecting a spatial context (i.e. bounding box, political jurisdiction, watershed and more) on the map and setting the spatial and temporal resolution. This allows for a detailed and dynamic assessment of how nature provides benefits to people. ARIES has global models for carbon storage, sediment regulation, pollination, crop production, nature-based tourism, outdoor recreation, and the monetary valuation of forest ecosystem services through spatially explicit meta-analysis; with models of riverine flood regulation and water supply in advanced prototype and regional models.

ARIES is an operational example of semantically integrated, distributed, collaborative modeling. The ARIES system grows as an international network of scientific collaborators contribute data and models, and each new assessment automatically adopts the best data and models available. In the near future, users will be able to not only develop, but also run models directly from the world wide web, enabling a simple, two-step modeling workflow suitable for non-technical users, such as decision makers and their staff. ARIES has been adopted by the Statistics Division of the UN Department of Economic and Social Affairs (UNDESA) and the UN Environment Programme (UNEP) as the SEEA Explorer platform.

Sources: https://ecosystemsknowledge.net/aries and https://aries.integratedmodelling.org

26 Location quotient is an analytical statistic that measures an area's economic specialization relative to a larger geographic unit, usually the nation.

27 Segregated landscapes or ecosystems are those where land use is more specialized or monocultural. The end of the spectrum is integrated 'multi-functional' landscapes or ecosystems.

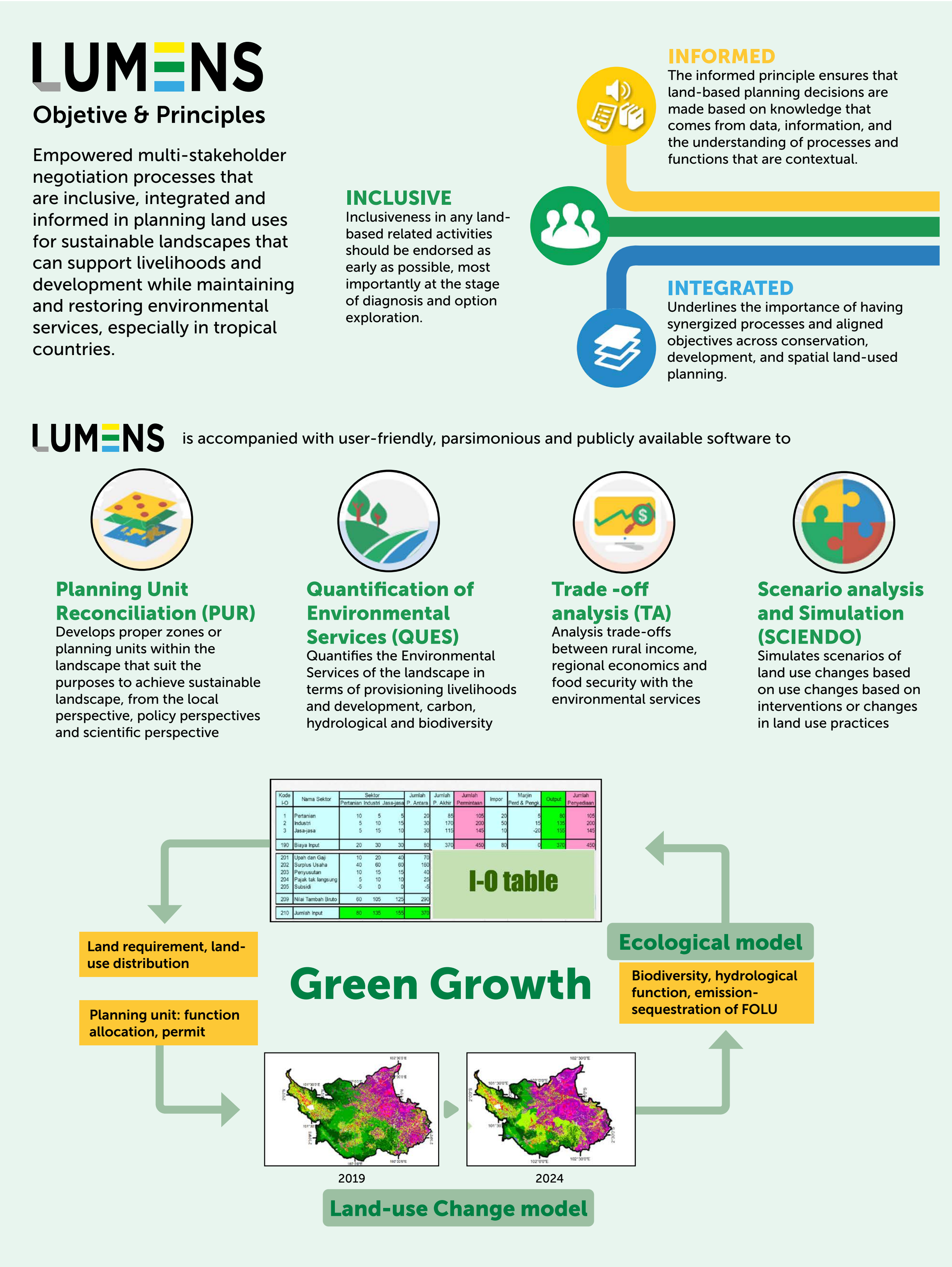


Photo 3. LUMENS empowers multi-stakeholder negotiation processes that are inclusive, integrated and informed to plan land uses for sustainable landscapes that support livelihoods and development while maintaining and restoring environmental services (© ICRAF).

Box 9 Forest reference levels (FRLs) and forest reference emission levels (FRELs)

Establishing forest reference levels (FRLs) and forest reference emission levels (FRELs) are an important initial step that countries need to take to benefit from REDD+ (according to paragraph 71 of decision 1/CP.16[28]). As key components of national forest monitoring systems, FRLs and FRELs provide a baseline against which emission reductions can be measured and subsequent results-based payments can be made. The UNFCCC does not explicitly differentiate between a FRL and a FREL, but a common understanding is:

- **The forest reference level (FRL)** is a benchmark for emissions from deforestation and forest degradation and removals from the sustainable management of forests and enhancement of forest carbon stocks (all REDD+ activities).
- **The forest reference emission level (FREL)** is a benchmark for emissions exclusively from deforestation and forest degradation (REDD only).

Reference levels are expressed as tons of CO_2 equivalent per year for a reference period against which the emissions and removals from a results period will be compared. Thus, reference levels serve as benchmarks for assessing each country's performance in implementing REDD+ activities. Reference levels must be kept consistent with the country's greenhouse gas inventory estimates.

Reference levels should be transparent, taking into account historic data, and be flexible to accommodate differences in national circumstances and capabilities, while pursuing environmental integrity and avoiding perverse incentives. Developing country Parties implementing REDD+ can use a stepwise approach to construct reference levels, incorporating better data, improved methodologies and, where appropriate, additional pools. They should also update their reference levels periodically, taking into account new knowledge, new trends and any modification of scope and methodologies.

Developing countries aiming to implement REDD+ activities are invited to submit a reference level to the UNFCCC secretariat, on a voluntary basis and when deemed appropriate. The information contained in the submission should be transparent, complete, accurate and consistent with guidance agreed by the Conference of the Parties (COP). The information provided should be guided by the most recent guidance and guidelines of the Intergovernmental Panel on Climate Change (IPCC), as adopted or encouraged by the COP.

Each submission of a proposed reference level, in the context of results-based payments, shall be subject to a technical assessment, in accordance with the procedures and timeframes established by the COP. The technical assessment process is conducted once a year and is coordinated by the Secretariat. The full guidelines and procedures for the technical assessment of submissions from Parties on proposed reference levels are contained in decision 13/CP.19[29] and its annex.

Having an assessed national reference level or, as an interim measure, subnational reference levels in place is one of the requirements to be eligible for results-based payments in accordance with decision 9/CP.19. A link to the final technical assessment report should also be provided in the Lima REDD+ Information Hub.

Source: https://redd.unfccc.int/fact-sheets/forest-reference-emission-levels.html

28 https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=12

29 https://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=34

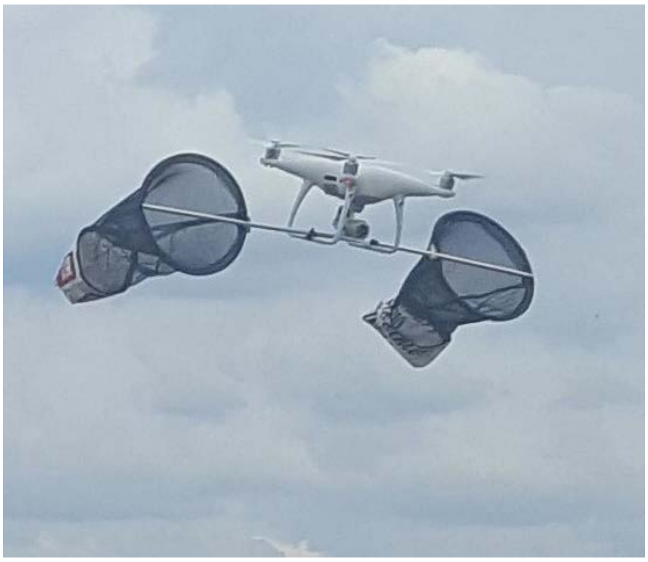
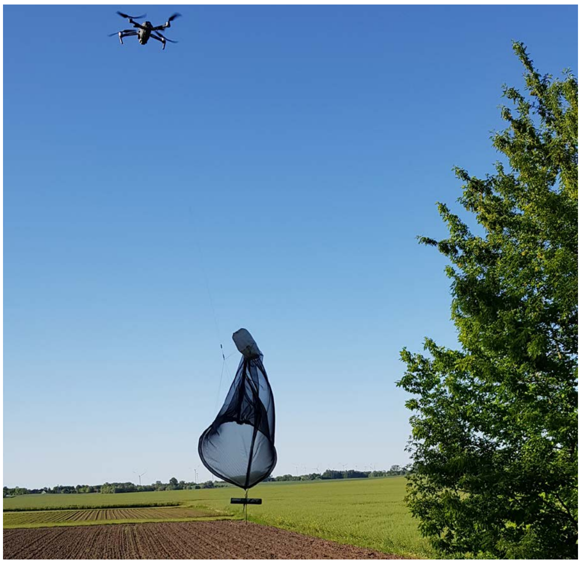



Photo 4. Drones can be used to collect insects to diagnosis environmental health issues and assist in developing management options (© Shahrukh Kamran).

collected data at a central location. Such networks can provide real-time data on many topics including soils, climate, flora, fauna, sound and pollution levels. These data flows can feed integrated models using the internet of things, big data analysis, AI and machine learning. Acoustic (Burivalova et al. 2019; Game 2021), optical (Barmpoutis et al. 2020) and camera (Steenweg et al. 2017) monitoring are innovative technologies that can operate independently or as part of a broader sensor network. Conservation surveillance technologies (CSTs – drones, sensor networks, and related technologies) are valuable tools that can have both positive (e.g. effective monitoring of natural habitat and populations) and negative (e.g. unauthorized human surveillance) impacts on people, raising ethical questions over privacy. A set of provisional principles for the socially responsible use of CST and data have been proposed by conservation professionals to address this important issue (Sandbrook et al. 2020).

Mobile phone and crowdsourcing applications can help empower communities and other local stakeholders by facilitating capacity building, information sharing and networking and allowing them to contribute actively to forest monitoring, management and governance. For example, mobile apps have been used to map forests, designate specific locations of interest, collect inventory data (for subsequent analysis by specialists), improve record keeping and reporting (making field data collection and patrolling more effective), monitor the success of reforestation activities, document land use and land cover changes, and report suspicious activities. In the Philippines, an app called Snitch is being developed to empower communities to monitor forest and water resources. The mobile phone application allows users to consolidate data and run simulations. Community members can share information and collaborate with other stakeholders to advocate for sustainable environmental management (de Jesus 2021). The use of mobile phones and apps can increase local participation, transparency and accountability. Mobile apps can also strengthen market integration and commerce, such as by estimating timber volumes, quality and market values and linking small-scale timber producers (smallholders, cooperatives, communities, etc.) to companies in the timber processing sector.

INBAR's mobile app is a tool for monitoring natural or planted bamboo areas. It can monitor a single clump of bamboo, a large plantation or a forest. The data is automatically submitted and synchronized in a central web-based database. Users can extract information from the database remotely. The database provides essential information for business feasibility studies including the condition of bamboo forests, volume of bamboo per species, quality of bamboo, location, ownership, and transportation conditions. Furthermore, the app can also be used to assess an area's suitability for bamboo establishment and commercial production (Wu 2021a; Trinh Thang Long, personal communication, 2020[30]).

2.2 Biological technologies[31]

Experts consulted for this study emphasized two priority categories of biological technologies: (i) innovations around genetic resources and germplasm (including exploration and collection, evaluation and selection, seed source management, breeding, propagation options, multiplication, dissemination and marketing); and (ii) DNA identification and tracking.

2.2.1 Genetic resources and germplasm

Genetic resources (germplasm) can be the single most important input in any tree production system, whether forest, plantation, agroforestry or any other systems with trees. Independently of other inputs, the germplasm quality makes significant contributions to productivity (Simons et al. 1994). The genetic and physical quality of germplasm defines the upper limit of the system's potential yield, as well as the productivity of other inputs (agricultural chemicals, labor, management, etc.). After planting, due to issues of governance, access, size and remoteness, there is often little to no management or investment (in fertilizers, labor, etc.) in many tree production systems. This makes germplasm genetic and physical quality paramount. There is significant intra-specific genetic variation regarding site adaptability, growth characteristics, wood properties, fruit production and many performance parameters of many tree species used for commercial or subsistence purposes. The genetic superiority in these traits can be captured through proper selection and/or formal breeding of the right populations and genotypes to improve niche complementarity,[32] productivity, quality and profitability when matched to specific planting sites and user requirements (Dawson et al. 2014).

Selection and breeding of plant species are not new: plant domestication to meet the needs of human populations is an ancient process (Harlan 1971; Sauer 1952). However, systematic work to improve tropical tree species is far more recent (Page 2021). In a review of tropical tree research, Simons and Leakey (2004) report that only about 40 taxa have benefited from improvement programs. Efforts to select and improve tree genetic material for local needs are even newer (Leakey et al. 2012; Roshetko and Evans 1999; Page 2021). They generally involve collaboration with communities of farmers and the integration of their livelihood objectives (**Box 10**). Working on genetic material and germplasm are not only product innovations but also process innovations, as well as social innovations that will go through cycles of modification as the technologies and methods of tree improvement are refined and transformed for a different set of parameters, species, and uses.

Experts consulted for this study identified the following priorities for **genetic material and germplasm** (tree domestication) research and development: enhancing species disease resistance, drought resistance, growth, and adaptation to climate change, or to yield wood with high lignin (to produce cellulosic

30 Trinh Thang Long, Program Coordinator, INBAR, 23 November 2020.

31 Article 2 of the Convention on Biological Diversity (CBD: UN, 1992) defines biotechnology as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use". Biotechnology incorporates traditional, low-tech approaches, such as microbial fermentation, as well as more advanced technology-driven approaches such as bionics, AI and machine learning (Gomez San Juan and Bogdanski 2021). This study adopts this definition and uses interchangeably the terms "biotechnology" and "biological technologies".

32 Niche complementarity designates situations where coexisting species use different forms of a resource,

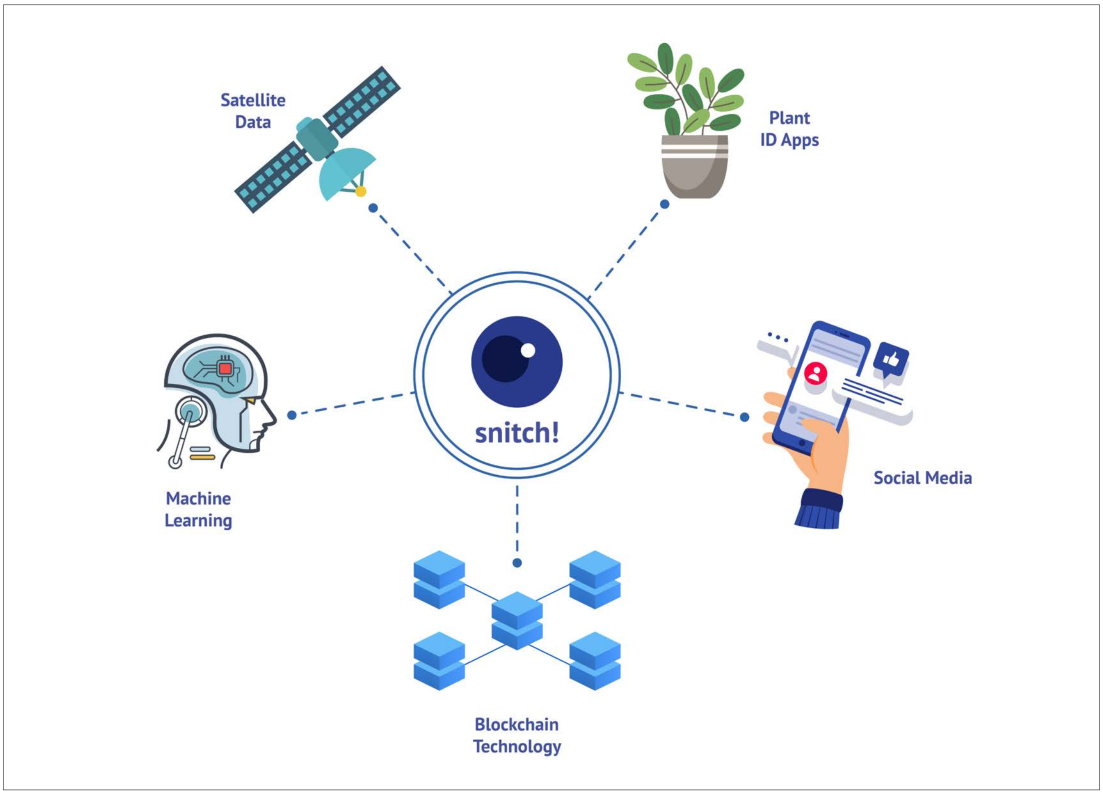


Photo 5. Multiple innovative technologies can be combined in the Snitch platform (© Creative Commons – CCO).

derived sugars for bioplastics, biofuels, etc.) or low lignin (for improved pulp). These efforts should continue with species of recognized industrial and high commercial value such as acacias, eucalyptus, rosewoods (*Dalbergia* spp.), teak (*Tectona grandis*), and poplars (*Populus* spp.). Superior genetic material — provenances, varieties, landraces and clones — have been identified for these species. This material should be accessed and multiplied in state-of-the-art research and commercial nurseries to produce high-quality planting material to optimize growth and meet product needs. This is possible as reliable efficient nursery, cutting garden and tissue culture techniques have been developed for the mass production of clones of industrial tree species (Monteuuis and Goh 2017; Harwood and Nambiar 2014; Nambiar and Harwood 2014). It may be appropriate to develop genetic material for more production goals. In Malaysia, the forest industry has developed rubber (*Hevea brasiliensis*) clones both to increase latex yield and to increase timber production (Harun 2021).

Simultaneously, it is important that a participatory breeding approach be undertaken with a broad group of local stakeholders (farmer groups, communities, civil society, indigenous communities) targeting locally prioritized tree species, including indigenous species. Low-input and 'tree diversity breeding'[33] encompasses multiple species, with varied improvement objectives for different environments (Urzedo et al. 2022; Graudal et al. 2021; Lillesø et al. 2021; Lillesø et al. 2018). These approaches can focus on timber, fruit, vegetables or other prioritized tree products and services.

Within the Asia-Pacific region, **biotechnology** has been used to develop genetically modified material of species of high economic importance for improved growth, wood characteristics, and pests and disease resistance. China and India are reported to be developing genetically modified trees of *Eucalyptus* spp., *Populus* spp. and *Tectona*

33 'Tree diversity breeding', emphasizes maximining novel, creative linkages between existing tree breeding methods that are responsive to different global trends, thereby aligning breeding with multiple values to support broad development progress (Graudal et al. 2021).

Box 10 Genetic selection and improvement for local needs

Research efforts on agroforestry tree domestication were initiated in the mid-1990s to multiply germplasm and develop propagation techniques for fruit and nut species prioritized by farmers. In the first decade, efforts were led by scientists working in humid West Africa. Subsequently work expanded to the rest of Africa, Latin America, Asia (primarily Southeast Asia) and Oceania. While the assessment of species potential and the development and dissemination of techniques for improved germplasm production were the principal activities in the first decade, the second decade was characterized by a growing research agenda that included characterization of genetic variation using morphological and molecular techniques, product commercialization, farmer adoption and protection of farmers' rights. In parallel with this expanding research agenda, there was increasing use of laboratory innovations to quantify genetic variation of the chemical and physical composition of marketable products (e.g. essential oils, food-thickening agents, pharmaceutical and nutraceutical compounds, fuelwood). Leakey et al. (2012) predicted that the next decade of applied research in agroforestry tree domestication would focus on rural development agendas to enhance the livelihoods of poor smallholder farmers, including: continuing advancements in genetic and germplasm improvement; post-harvest processing, storage and packaging of agroforestry products; scaling domestication to focus on marketing, income generation and nutrition; the development of producer-trader linkages and greater involvement of the private sector; and the formulation of intellectual property rights (IPRs) to protect the innovations and indigenous rights of farmers and local communities. Their prediction was largely correct as most of these topics have been research priorities over the past decade.

Source: Leakey et al. (2012).

grandis towards the eventual development of large-scale industrial plantations (FAO 2019). The Viet Nam Academy of Forest Sciences (VAFS) has recently started to develop genetically modified *Eucalyptus* spp., with the objectives of shortening rotation lengths, improving field performance and enhancing wood characteristics (Phuong 2021; Vo Dai Hai, personal communication, 2020[34]). This technology holds potential for application to additional tree crops. As occurred with the commercialization of genetically modified agricultural crops in some parts of the world, deploying genetically modified trees may be politically and socially controversial. It is recommended that progress be deliberate and public concerns be investigated. The potential costs and benefits of the technology and the views of protest groups should be carefully considered. The objective is to avoid fostering the development of a potentially polarizing protest movement against genetically modified forest crops (Hall 2007). A group of science-based environmental NGOs has recently proposed a responsible governance model for the deployment of biotechnology crops in agriculture and the environment to contribute toward sustainable management, food security, and an enhanced future. The model includes six principles that together address avoidance of human and environmental risks, societal engagement and benefits, science-based regulation and oversight transparency on genetically modified products, and inclusive access to technology and products (Gordon et al. 2021). This model offers a method of addressing agricultural and forestry production demands, SFM and societal concerns (May et al. 2022). Countries that lack adequate institutional and policy frameworks or technical capacity for the sustainable development and use of forest genetic resources should first address these issues before considering genetically modified forest crops (FAO 2019).

Innovative tree domestication efforts should expand to include native timber species, non-wood forest species, and other underutilized forest species for local utilization. Research in small-scale forestry has prioritized the development of such species to enhance local livelihoods, commerce and sustainable forest resource management (Narendra et al.

34 Vo Dai Hai, Director General, Viet Nam Academy of Forest Sciences, October 2020.

2013; Leakey et al. 2012; Nichols and Vanclay 2012). In the case of these undomesticated species, one innovation is the basic selection and use of quality genetic material to improve productivity and income generation, requiring not only appropriate techniques but also social innovation to effectively deploy improved material to communities and smallholders (Page 2021). This work needs to start with the exploration and collection of natural populations and landraces to evaluate and select the best genetic material for the performance parameters of interest. Geotagging superior mother trees can bolster tree domestication programs of priority native species by identifying seed source for management and collection of superior germplasm for multiplication in commercial nurseries (Almoite and Togado 2021). It is essential that the domestication process start with the exploration and evaluation of existing genetic resources, as many reforestation, landscape restoration and tree planting activities are constrained by inadequate attention to matching the available genetic material of the species being planted with site conditions or expected use of the product (Jalonen et al. 2018; Roshetko et al. 2018).

As quality germplasm is often in limited supply and not readily available, what steps can be taken to broaden access to quality germplasm at a reasonable cost? What approaches can be used to multiply larger quantities of quality germplasm to facilitate dissemination to users? This is particularly important for farmers, communities and local organizations who often have the least access to quality genetic material and formal germplasm sector and often rely on germplasm of unknown or inferior quality (Pachas et al. 2019; Roshetko et al. 2018; Harwood et al. 1999). Government, research and development agencies that support communities and local organizations with reforestation and tree planting activities can facilitate the dissemination of the highest-quality genetic material that match local conditions. Local organizations and farmers can be trained in germplasm production, collection and management to multiply quality germplasm and sustain local supplies of superior material into the future. Farmers have a proven ability to successfully operate germplasm production and supply pathways. However, in most situations this will not develop spontaneously. Leadership and support from technical and development agencies will be required, including capacity building for local communities and organization and facilitation with germplasm business plans and marketing (Lillesø et al. 2018; Lua et al. 2015; Nyoka et al. 2015; Catacutan et al. 2008). Assistance should include the development of simple seed-based propagation methods that fit local conditions (Bertomeu and Sungkit 1999), as well as farmer and community-based systems for the mass production of clonal material of priority species for the support of the commercial forest sector (Page 2021).

2.2.2 DNA technologies

DNA technologies have emerged as indispensable innovations that use cutting-edge genetic testing to identify and document the geographic origin of a biological sample. DNA identification, also called DNA tracking, profiling or fingerprinting, enables the accurate traceability of forest products and improves the governance of their value chains, contributing to the prevention and prosecution of illicit trade. DNA profiling technology is frequently used in the trade of premium tropical timbers, and can be applied to either natural forest or plantation-grown timber. However, in clonal plantations, it needs to be combined with or replaced by chemical testing linking the timber to the soil where it was grown. During harvest, logs are commonly stamped or documented to identify their geographic origin. However, overharvesting and mixing logs from different origins are common problems. DNA fingerprinting at the forest origin and DNA testing along the value chains can help verify documentation that accompanies timber consignments in the Asia-Pacific region and globally (Lowe et al. 2021). The establishment of origin-specific genetic datasets can support this process. Fingerprinting helps timber suppliers, traders and buyers confirm the integrity of the value chains and satisfy the import regulations of the European Union (EU), North America, and Australia.

Photo 6. Community cutting nurseries (gardens) and plantations of improved genetic material established with assistance from forest sector partners, support farmers in contributing to landscape restoration, the supply of timber resources, and enhancement of their livelihoods (© Tony Page).

DNA tracking is used with a wide range of species for which illegal logging is a problem because they have a high market value, are heavily traded or are threatened. Genetic maps exist for species of interest, and the Global Timber Tracking Network promotes innovative tools to facilitate species identification for 250 species (**Box 11**). Species for which DNA tracking has been used include teak (Dunker et al. 2020; Dormontt et al. 2019), *Intsia palembanica* (Lowe et al. 2010), *Cinnamomum* species (Hung et al. 2017), *Swietenia macrophylla* (Degen et al. 2013), and rosewoods (Yu et al. 2017). DNA tracking has been used to confront illegal logging of *Acer macrophyllum* (**Box 12**) and to document the legality of teak supply chains (**Box 13**).

Besides timber, DNA profiling is also used to track invasive insects (Lees et al. 2011), wildlife movement (Evens et al. 2020), forest reproductive material (Degen et al. 2010) and bushmeat imports (Kamran 2018). Genetic tracing combined with geolocalization can match specific genetic material to specific local climatic conditions. This facilitates the identification of genetic material that should perform well at sites that are experiencing climate change and have or will have climates similar to the native climate of the genetic material.

Wood microscopy is also used to identify tree species and track illegal logging and illegal trade of forest products (Gupta et al. 2021).

2.3 Technical innovations in processes and products

Several types of process and product technologies were identified that have significant potential to contribute to SFM in the Asia-Pacific region. These various technologies can be categorized under the following broad categories:

- process innovations that address forest management, harvesting, processing and manufacturing; and,
- product innovations that include engineered wood, bamboo products and nanotechnologies.

A principle uniting these technologies is the importance of making more efficient use of forest resources, improving recovery rates and reducing waste and forest collateral damage during harvest. This includes an emphasis on underutilized species that have been largely overlooked but hold huge potential that remains largely untapped. These efforts should build on strong research collaborations and include a focus on moving wood products up the value chain. These technologies, combined with improved varieties or clones of priority and underutilized species, have the potential to

Box 11 Global Timber Tracking Network

The Global Timber Tracking Network (GTTN) promotes the use of innovative tools for species identification and to determine the geographic origin of wood to verify timber trade claims. The network and tracking tools are used to curb illegal logging and the illegal timber trade. The GTTN consists of standard protocols and guidelines, a reference database, an expert database, and communication, policy and advocacy activities.

The GTTN:

- Was formed through the joint vision of all stakeholders involved in global action against illegal logging and associated timber trade, with the network's activities financed through an open multi-donor approach.
- Supports researchers who develop the tools, forest and timber industries that exercise due diligence, and law enforcement agencies in the fight against illegal logging and trade around the world.
- Includes working groups that elaborate and implement a joint roadmap to reach shared aims, linked to GTTN core activities.

Weblink: https://globaltimbertrackingnetwork.org/organisation/about/

Box 12 Battling illegal logging of bigleaf maple

A common target of illegal logging in the Pacific Northwest of North America is bigleaf maple, *Acer macrophyllum* Pursch. Its timber is highly valued for its grain and translucent pattern and widely used in string instruments such as guitars. The illegal removal of old growth maple trees from national parks along the west coast of North America is a significant and increasing problem. Motivated by the discovery of a cluster of illegally felled bigleaf maple trees in Washington state, the US Forest Service worked with the University of Adelaide to develop a DNA profiling tool to identify the timber in supply chains back to felled stumps.

One hundred and twenty-eight single nucleotid polymorphic (SNP) loci were designed to capture inter-individual variation in bigleaf maple (Jardine et al. 2015). Using these markers, a DNA reference database was developed consisting of 394 individuals from 43 sites across the range of the bigleaf maple. The assay was subject to a strict forensic validation procedure based on the Scientific Working Group on DNA Analysis Methods validation guidelines to ensure reliability for forensic purposes. A range of sample types (leaf, cambium, timber) were analyzed to represent the variety of case samples that may be encountered, and mother trees and seedlings compared to confirm the Mendelian inheritance of the markers. The assay was demonstrated to work effectively at low DNA concentrations (<1 ng/μL) and to have high species specificity. Based on the reference data, the FST[35]-corrected probability of identity (P_{ID}) was 1.785×10^{-25}, meaning that the chance of the assay returning a match between samples that did not originate from the same tree (or clone) was miniscule. The resulting publication was the first to apply forensic validation criteria to an assay developed for individualization of timber (Dormontt et al. 2020). Using the developed assay, several pieces of wood seized from a sawmill were compared with samples from illegally felled stumps in the Gifford Pinchot National Forest and a match was detected. In a subsequent legal case in 2016, four defendants pleaded guilty to violations of the Lacey Act 2008, the first domestic prosecution under this legislation.

Source: Lowe et al. (2021).

35 The FST (fixation index) is a measure of population differentiation due to genetic structure.

Box 13 Document legality in teak supply chains

In addition to being used to identify illegally logged timber, DNA fingerprinting and genetic profiling can support claims of legality in timber supply chains. A critical timber supply chain in this respect is teak. Teak timbers are sought after the world over and are prized for their durability and water resistance, making it ideal for the construction of super yachts, high quality furniture, veneer, carvings and turnings. The high demand for naturally grown timber, due to its perceived structural superiority over that grown in plantations, has led to a black market in 'conflict teak', where illegally harvested timbers are laundered into legitimate supply chains. These illegal activities are strongly associated with environmental and human rights violations.

In Myanmar, forestry systems have management and paper documentation practices introduced by UK and Germany regulators to authenticate the source of teak, but the global movement of illegal timber has made further assurance necessary. One of the primary ways that illegal timber enters the market is by being mixed into legitimate supply chains, accompanied by fraudulent documents. Teak logs confiscated from illegal logging groups are resold into the market rather than destroyed, and the practice has become controversial for customers in the EU, which requires illegal timber to be excluded from supply chains completely. Whilst mixing of legal and confiscated timber can be controlled in certified supply chains, the EU has raised doubts as to the reliability of paper verification.

Lowe et al. (2021) sought to determine the potential for using genetic profiling to support legal verification in teak supply chains in two ways: (i) through assignment of samples back to their population of origin; and (ii) through individualization of matched samples from the same tree along supply chains. These tests were applied to the supply of teak from natural populations in Myanmar and plantation populations in Indonesia.

To achieve these aims, a set of 132 neutral SNP loci (Dunker et al. 2020) were applied to over 1,000 tree samples taken from across the natural range of teak in Myanmar, Thailand and Lao PDR, and samples from naturalized populations and plantations in Indonesia, Lao PDR and PNG (Dormontt et al. 2019). Population genetic structure across the natural range of teak in Myanmar produced self-assignments that were 69% accurate to the fine-scale collection site level. Assigning the five most likely reference collection sites within a 100 km radius buffer allowed the correct origin of samples to be identified in over 95% of cases. This approach was effectively used in blind samples (not collected from the same specific sites used in the reference data) to verify the claimed origin and support demonstration of due diligence. DNA fingerprinting methods were also used to match blind samples of sawn timber from the log yard to cut tree stumps and accurately traced each piece of timber to its individual tree stump in the forest or plantation.

In Indonesia, DNA was used to trace teak timber along a large plantation supply chain from the Perhutani Forest Management Unit at Cepu. The assignment of plantation material back to its population of origin was successful in verifying supply chain integrity.

Overall, across the Myanmar and Indonesia case studies, the individualization of matched samples provides the highest level of certainty with respect to the verification of intact supply chains, which is also the most logistically challenging. As such, it should only be used for the most tightly controlled supply chains.

Source: Lowe et al. (2021) and Lowe et al. (2016)

reduce pressure on natural forests. Finally, there is a need for integration given links and potential synergies with innovations from the other categories (digital technologies, biological technologies, financial innovations and social innovations).

2.3.1 Process innovations

Process innovations are relevant to forest management, forest harvesting, wood processing and wood product manufacturing. Improved silviculture management, including refined site preparation, planting and post-planting practices can directly

Photo 7. DNA fingerprinting and tracking along the value chain is used to prosecute illegal harvesting and trade of Acer macrophyllum (© Elly Dormontt & Andy Lowe).

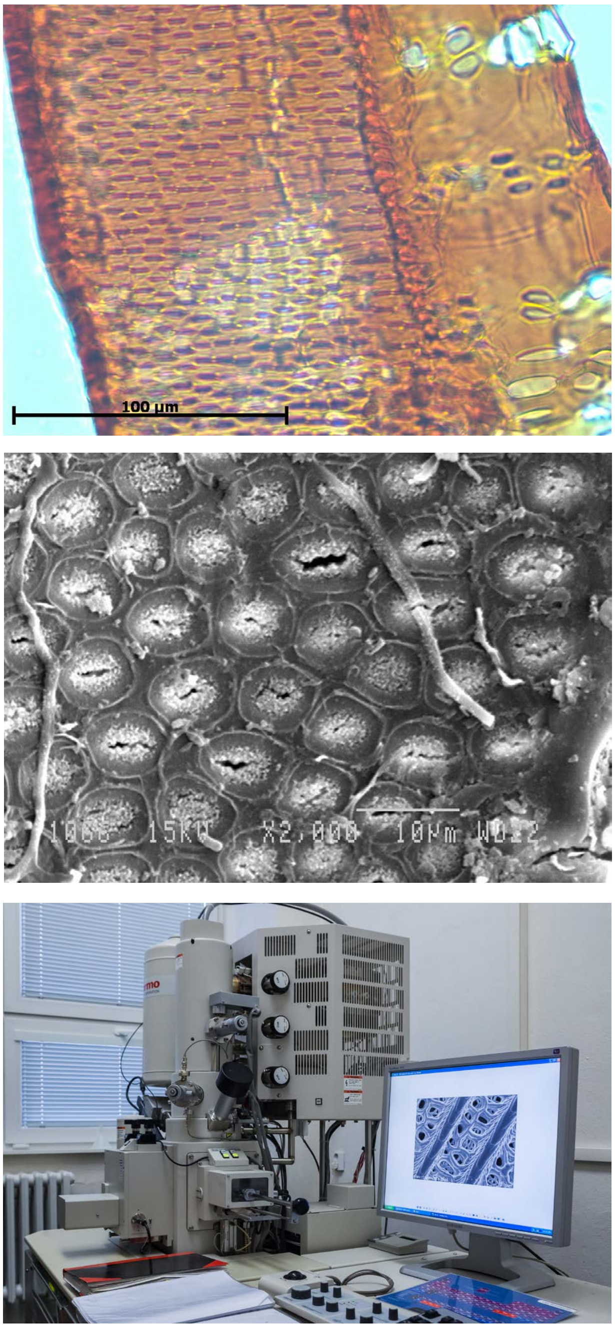


Photo 8. Different microscopy techniques are used to analyze wood anatomy to identify tree species and track illegal logging and illegal trade of forest products. Images taken with light microscopy (above and above left) and scanning electron microscopy (lower left and middle left). (© Dr. V. Vishnuprasad & Creative Commons License & Prachi Gupta).

improve SFM and productivity. There are synergies between the digital and biological technologies mentioned above and the process of improving silvicultural management. Geospatial data and analysis is improving decision making and forest management to increase yields, reduce waste and costs, and maintain ecosystem services. Geospatial analysis can be used to automate the targeting of weed and pest control in forests and plantations (Tim Payne, personal communication, 2020[36]). Additionally, the use of quality genetic material and appropriate matching between site, species and germplasm can enhance the productivity of improved silviculture management and its inputs.

Precision forestry is an emerging management approach that utilizes geospatial technology, data and tools to access and analyze large amounts of data and information. The objective of precision forestry is improving decision making and forest management to increase yields, reduce waste and costs, and maintain ecosystem services. It is seen as an effective way to effectively achieve forest management goals that integrate economic, environmental, sociocultural and sustainability objectives. Precision forestry commonly uses remote sensing, navigation systems, and GIS. It can integrate the use of all the digital technologies mentioned in **Section 2.1**. The use of geospatial technology and analysis enables iterative measurements, actions and processes to plan forest management and harvest. Simultaneously, information linkages can be established between actors in production and in the wood supply chain, including resource managers and environmental community (Kovácsová and Antalová 2010; Fardusi et al. 2017). Precision forestry can generate more accurate information than traditional forest management approaches. It can also incorporate species identification, genetic selection and site matching, and nursery operations. Despite its wide potential application domain, precision forestry is neither extensively known nor adopted in the Asia-Pacific region. It has been adopted in Australia and New Zealand, where labor costs are high and strong personnel and financial capacity exists to use and integrate geospatial and digital technologies. However, precision forestry has not yet been widely adopted in developing and less-developed economies of the region, where labor costs are low and technology costs high (FAO 2019).

Aerial seeding (or **aerial sowing**) is an innovative forest regeneration technology that is receiving renewed attention. The concept is not new, having been trialed as early as the 1930s in Hawaii to restore inaccessible forests after fires (Horton 2008). Modifications to the technology have been made over time. Seed can now be sown untreated, pre-treated to hasten uniform germination, or encapsulated – also called seed balls, where seed is mixed with soil, clay, compost, humus, microbial inoculants and agricultural chemicals to improve growth and survival. The technology can be efficient and cost-effective under the right conditions. However, the costs of operating the aircraft, sowing and related equipment, and training are to be considered. Additionally, seed preparation (including capsule characteristics) and sowing conditions (including drop height) must match the site conditions to achieve successful regeneration (Novikov and Ersson 2019; Vovchenko et al. 2020). Suitable seedbed and soil conditions at site are considered critical criteria for success (Forestry Tasmania, 2010; Vovchenko et al. 2020). Seed predation by wildlife can limit seedling establishment. The technology seems best suited for remote inaccessible areas and to assist natural regeneration (Forestry Tasmania 2010; Xiao et al. 2015; Novikov and Ersson 2019; Vovchenko et al. 2020). Aerial seeding with drones can be more cost-effective than manned aerial vehicles (MAV) on some remote and degraded sites (Novikov and Ersson 2019).

Residual damage from careless harvesting and overharvesting has led to the degradation and decline of growing stocks in Asia-Pacific forests. There is a broad need to improve harvesting practices, associated with

36 Tim Payne, Professor of Sustainable Forestry, SCION, October 2020.

improved control and monitoring, to reduce this damage. Innovations in harvesting and transportation are key for improving SFM in the region. **Reduced-impact logging (RIL)** is the careful planning and control of timber harvesting operations to minimize collateral environmental damages. It includes the following practices and guidelines:

- detailed pre-harvest inventory, identification of trees to be harvested, and planning of roads, skid trails and landings;
- construction of roads, trials and lands to reduce environmental damage;
- when appropriate, cutting vines before harvest and directional felling to avoid damage to the residual forest;
- cutting stumps low and bucking logs to commercial lengths to avoid waste;
- winching logs along pre-planned road and trials, using light-weight winch ropes (ITTO 2021).

The concept of RIL originated in the 1990s. The application of RIL in Asia and the Pacific has been limited due to weak institutional capacity, low political commitment, inertia to change, a lack of incentives, and high perceived upfront investments. Although efficiency gains and reduced damage provide net financial benefits, both immediately and in the future (FAO and USAID 2012). Besides reducing damage to the residual forests (including soils, tree regeneration and biodiversity), RIL also increases wood recovery, improves worker safety, and improves local livelihoods. Due to these multiple benefits, RIL and its components deserve wider application and adoption in the region. A notable exception is Bhutan, where timber extraction strictly abides by low-impact logging principles, using a number of technologies and types of machinery that reduce the environmental impact of logging, skidding and transport (see **Box 14**).

An innovative technology related to RIL is **winch assisted-harvesting**. These relatively new systems consist of winch-assist machines (WAM; also referred to as tethered, cable-assist and traction-assist machines) at the top of the slope and steep slope machines (SSM) to maneuver down slopes. The SSM is secured and supported by the WAM, enabling it to conduct mechanized harvesting and skid the logs to the landing area. The logs can be removed either by wheeled transport or fully suspended. These systems are appropriate for harvesting on steep slopes and are proven to reduce damage to the residual forests, soil rutting, soil compaction and subsequent erosion, as well as improve worker safety. Drawbacks are that the systems are expensive and, like precision forestry, require strong technical and financial capacity (Holzfeind et al. 2020; Leslie 2019). They are currently used in developed countries but hold potential for the industrial forest sector in Asia and the Pacific. Integrated Planning for Timberland Management (IPTIM)[37] is a forest industry management software package developed in Finland that enables

Box 14 Low-impact logging in Bhutan

Bhutan maintains a forest cover of 71% of its total land area. SFM practices are prioritized to protect and conserve the nation's forest and biodiversity resources ensuring social, economic and environmental well-being and happiness of present and future generations. Timber extraction in Bhutan strictly abides by low-impact logging principles to minimize adverse impacts on the environment. Pre-harvest inventory and mapping of forest to be harvested are conducted. Cable-crane systems are used that can extract timber within a range of 500 m to 1,500 m with minimal skidding on the forest floor, particularly on steep slopes that are susceptible to soil erosion and landslides. The construction of roads and the implementation of trials are carefully planned to further minimize environmental damage. Timber extraction is conducted using Telly loggers, swing yarders, tractor mounted mini-cable cranes, Penz log loader and trucks. The use of innovative technologies and SFM practices is essential for the country to protect its rugged and fragile mountain ecosystem while simultaneously satisfying its timber demands and earning foreign capital.

Source: Dorji (2021).

Photo 9. The use of geospatial technology to improve forest planning and management can increase yields, decrease waste and costs, and support SFM (© Raffaelle Spinelli).

managers to develop and implement full-cycle timberland management solutions that consider short- and long-term objectives. The package has been used in Central and South America and is likely too elaborate for most Asia-Pacific conditions but sets an example for future innovations that can be developed for local conditions. The region's technical capacity in the application of timber harvesting innovations must be increased to enable financially viable and sustainable operations that are in line with productive and sustainable forest management.

Within the region, **sawmills and wood processing technologies** need modernization to achieve resource use efficiency and reduce waste, increasing profitability of operations and contributing to sustainable management of natural forest resources. For example, the wood industry sector in Viet Nam comprises about 4,500 wood processing facilities, but with limited application of innovative technologies. Some early adopter companies are applying or developing innovative solutions, including computer numerical control (CNC) machines to optimize product design or wood processing. The industry still relies predominantly on hydropower for wood drying, but this is changing. Innovative drying technologies include renewable energy sources such as solar power, which can offer long-term financial savings and reduces demand on the national power grid and sector. Thermal technologies such as microwave plasma are used to change wood properties for specific purposes, such as improving its appearance, durability and water resistance. Some processing facilities integrate AI for wood species identification and to monitor the legality of wood supply, both domestic and imported (Phuong, 2021). In processing mills across the region, there is a need for investment in scanning[38] and optimization technologies to increase

37 See: http://www.iptim.com.s3-website-us-east-1.amazonaws.com

Photo 10. Plantation thinnings and other small-diameter wood can be used by process technologies to enhance resource utilization and economic benefits (© Shengfu Wu).

recovery rates, productivity and grade yield. Similarly, **spindle-less lathe technology** for veneer peeling holds potential for reducing waste and allowing utilization of small diameter logs. These examples hold potential for transfer and adoption in other countries across the region.

Portable sawmills are a technology of particular relevance to small-scale forestry as smallholder timber production and CF schemes have become widespread and well-established in the last 20 years (**Box 29**). While not strictly a 'new technology', portable sawmills are linked to institutional and social innovations and an example of technologies that have become available or relevant to new groups of stakeholders. Small enough to be easily moved, portable sawmills can be easily transported to and set up in rural areas. This makes it possible to economically harvest or thin secondary forests, small-scale plantations and smallholder plantings, as well as to harvest small-diameter trees, which are common in all three systems. The technology is particularly important for mature smallholder timber plantings, which are often located in less accessible areas as smallholder timber production was often promoted as an effective land use for underutilized sites. While portable sawmills hold potential, precautions are also warranted: portable sawmills will be a new and potentially dangerous technology in most places and require thorough training with an emphasis on safety. The stress on technical capacity cannot be overstated as improper use can easily result in high-quality logs turning into moderate- to low-value lumber. In some cases, it may be best to sell high-quality logs of premium timber species to the local forest industry, using the portable sawmills for the conversion of fast-growing species, lower-value species and small-diameter logs. Portable sawmills could be owned by village-level enterprises, communities or individuals. Regardless, a financial and economic analysis must be carried out before making the investment to ensure it is a viable commercial option.

2.3.2 Product innovations

Within the region, there is a great opportunity to engage the forest manufacturing industry in the development of the new generation of wood-based materials. **Engineered wood products** are a group of wood products manufactured from wood boards, veneers, strands, particles or fibers with adhesives or other fixers to form composite material (Milner and Woodard 2016). Engineered woods are

38 scanning wood and suggesting how to cut/process the wood to maximize value and recovery rates

Photo 11. Wood scraps from processing mills and other wood waste can be used to manufacture MDF, OSB and particleboards to increase wood recycling and utilization, generating economic and environmental benefits (© Shengfu Wu).

also called composite wood, man-made wood and manufactured board. Specific engineered wood products include cross-laminated timber (CLT), mass timber, glulam (glue laminated timbers), medium-density fiberboard (MDF), particleboard, oriented strand board (OSB), veneer and plywood. While these are not strictly 'new' products, contextually expanding their manufacture and quality represents an innovation in many countries in the region. CLTs, engineered to meet precise specifications, are used in home construction and commercial buildings. Mass timber products are strong building materials that have the potential to replace steel and concrete. The manufacture of MDF and particleboards can use low-value, previously under-utilized species, wood scraps from processing mills, and other wood waste. The manufacture of OSB can also utilizes small-diameter under-utilized species. This is greatly increasing wood recycling and recovery rates while generating additional economic and environmental benefits. All engineered wood products represent carbon sinks with positive climate mitigation impacts. They often increase the lifespan and thus carbon storage of wood scraps and small soft woods that would have otherwise been used for energy production at best.

The technology required to produce engineered wood products is compatible with regional wood processing industries. In Malaysia, rubberwood and other species are used to manufacture MDF, particleboard, OSB, veneer and plywood. Research is currently underway to produce CLT and glulam from rubberwood and other species (Harun 2021). Malaysia's rubberwood industry is an excellent example of a viable forest industry developed to utilize a formerly undervalued and under-appreciated timber asset (**Box 15**). Binderless particleboards are environment-friendly and sustainable alternatives to conventional wood-based particleboards. They can be manufactured from short rotation species, scrap and

Photo 12. Engineered bamboo products (cross-laminated bamboo (CLB), engineered bamboo beams, engineered bamboo flooring, and engineered bamboo veneer) provide decorative and structurally sound alternatives to traditional timber (© Shengfu Wu).

recycled wood, or other alternative non-wood biomass, including kenaf (*Hibiscus cannabinus* L), oil palm (*Elaeis guineensis*), or bamboo. Heat and pressure are applied to lignocellulosic raw materials, inducing physical bonds and chemical reactions, making the use of synthetic adhesive unnecessary. This product innovation preserves the working environment and worker health, reduces atmospheric pollution and GHG emissions, improve use efficiency, and reduces costs, thus increasing profits (Ramatia et al. 2021).

Engineered bamboo products are another high-quality alternative to traditional timber. Products include bamboo panels, cross-laminated bamboo (CLB), bamboo scrimber,[39] engineered bamboo beams, engineered bamboo flooring, and engineered bamboo veneer (Wu 2021b). While still relatively new commodities, engineered bamboo products are finding a place in the global market. As is the case with engineered wood products, bamboo processing technology holds huge economic potential for the region's forest industry. Expanding the sustainable exploitation of bamboo would reduce pressure on timber resources and remaining natural forests.

Bioplastics engineered from wood and bamboo are viable substitutes for packaging and petroleum-based plastics and hold promises as part of the development of the bioeconomy (see **Chapter 3**). They are renewable, biodegradable and have low carbon footprints compared to conventional plastics. Bamboo bioplastics are used to manufacture a broad range of products, including single-use products such as plates, cups, cutlery, containers, bags, straws, paper and packaging, toothbrushes, and cotton buds, as well as durable products such as phone cases, laptop cases, watches, glasses, kitchen items, helmets, bikes, skateboards, and furniture (Li 2020). Wood-based bioplastics have a similar breadth of application. Scientists have also experimented with the production of **transparent wood**, which retains its mechanical properties and can provide a viable alternative to glass from a sustainable and renewable source (Eichhorn 2021). Previous methods of producing this material were highly energy-intensive and used harmful chemicals, but a recent study shows a new method to make wood transparent with far lower energy consumption (Xia et al. 2021).

Similarly, there is considerable potential for the production of **biochemicals and**

39 A bamboo fiber-based composite made from crushed bamboo fiber.

Box 15 The development of the Malaysian rubber wood industry

Rubber (*Hevea brasiliensis*) is an important crop not only to Malaysia but to large parts of Africa, Latin America and the rest of Asia, with 10 million hectares cultivated globally each year. It is predominantly a smallholders' crop for latex production, and 70% of the latex produced is used to manufacture tires. Globally, rubber cultivation supports approximately 40 million families. Upon replanting, rubberwood production can provide smallholders with additional income from harvested rubber trees, which can help improve their livelihoods. Harvested rubber trees can be sold to saw millers, veneer and plywood mills as well as to bio-composite mills for the production of medium-density fiberboard, particleboard and oriented strand board.

After 25 years, the economic yield of latex normally decreases and rubber plantations are traditionally replanted. In Malaysia, the logs of rubber trees were initially used for energy or simply removed to clear the site. Intensive research and development (R&D) efforts in the 1980s and 1990s focused on fundamental rubberwood properties (anatomical, physical, mechanical and chemical) as well as its workability in product manufacturing. These concerted R&D efforts enabled innovative uses of rubberwood in furniture manufacturing that are now recognized as suitable due to the high quality and abundant availability of rubberwood. The rubberwood furniture industry has developed rapidly since it took off in the 1990s, catapulting Malaysia into the world's top 10 furniture exporters. Rubberwood furniture constitutes 80% of Malaysia's total annual furniture export, amounting to a value of MYR[40] 9.1 billion in 2019. This figure has consistently ranged from MYR 7–10 billion over the past five years. Domestic furniture consumption has an estimated annual value of MYR 5–7 billion over the same period. Major export markets for Malaysian rubberwood furniture include the USA, Japan, the EU, the Middle East, China and Australia. The main components of wooden furniture are currently manufactured based on 'original equipment manufacturing'[41] (OEM) or reproductions. More furniture companies are moving towards ODM (own design manufacturing) and eventually OBM (own brand manufacturing). Both ODM and OBM typically command higher selling prices than OEM furniture.

Besides furniture manufacturing, rubberwood and other forest timber species can be converted into building components or builder, joinery and carpentry (BJC) such as floors, moldings, window and door frames. Current trends are gearing towards the use of timber as a load-bearing structure in multi-story buildings. Rubberwood with a density between 500–640 kg m^{-3} with a light color and high workability can be effectively used for building components and multi-story load-bearing structures in building constructions. R&D efforts are now being carried out on the use of rubberwood in load-bearing construction and using industrialized building system (IBS) technology. In Malaysia, exports of BJC and wood moldings amounted to MYR 1.9 billion in 2019.

Bio-composite products such as medium-density fiberboard (MDF), particleboard, oriented strand board (OSB) veneer and plywood have been effectively manufactured from rubberwood trees. Malaysia exported MYR 1.4 billion of MDF and particleboard in 2019. These bio-composite products are made of almost 90% rubberwood. As such, rubber tree utilization in Malaysia has reached almost zero waste: sawn timber, veneer plywood and bio-composite materials are converted into high-value-added furniture and building components and other products.

Source: Harun (2021).

40 Malaysian Ringgit: MYR 1 = USD 0.25 [as of 21 December 2020].

41 An original equipment manufacturer (OEM) is traditionally defined as a company whose goods are used as components in the products of another company, which then sells the finished item to users.

pharmaceuticals from traditional medicinal plants and underutilized forest species. Scientists have also discovered pigments from fungi growing on trees whose properties may be useful in the production of solar cells and batteries, indicating potential for the production of high-tech batteries from forest bioproducts (Zalas et al. 2015; Giesbers et al. 2018). None of these opportunities have yet been fully exploited, and they all require more detailed investigation.

The potential for **bioenergy** production is often overlooked. Besides traditional fuelwood and charcoal, bioenergy can take the form of wood pellets, liquid fuels from wood and other biomass, and electricity from wood- and biomass-fired power plants (FAO 2019). These 'new' fuels represent important innovations that can shift energy reliance away from fossil fuel dependence and towards renewable sources. These bioenergy products can also increase wood and biomass recovery rates by using wood scraps from the forest industry, other wood waste, other biomass waste, and underutilized species. Bamboo is an excellent bioenergy crop, and a commercial pellet production process has been developed for bamboo in Ghana. The process is scalable, compatible with other biomass sources and appropriate for the Asia-Pacific region. Opportunities with other bioenergy crops also deserve attention, expanding the versatility of recognized bioenergy species such as oil palm (*Elaeis guineensis*), jatropha (*Jatropha curcas*), and sugar palm (*Arenga pinnata*), as well as the potential of lesser-known species like nyamplung (*Calophyllum inophyllum* L.) (van de Staaij et al. 2011; Iiyama et al. 2013; Rahman et al. 2019).

It is crucially important to develop technologies to produce these products as global demand for wood-based bioenergy is expected to nearly double from 2.6 billion m^3 in 2005 to 3.8 billion m^3 by 2030 (FAO 2009). However, the improved use of underutilized trees, soft wood and wood scraps for engineered products could compete with their use for bioenergy production. This calls for improved management of competing demands as well as for the cascading use of wood, agricultural commodity bi-products and other biomass resources. Cascading use prioritizes higher-value uses that allow the reuse and recycling of products and raw materials, promoting the use of new raw material for energy only when the supply of or access to other options are insufficient (Erajaa 2020). There are also important synergies for the development of innovative ways to produce bioenergy to benefit local populations in off-grid areas (see **Boxes 23** and **24**).

Biochar is used as a soil amendment to increase soil carbon storage, enhance soil fertility, reclaim degrades sites, and address issues of salt and heavy metal contamination. Its soil regeneration ability gives biochar high mitigation and adaptation potential to address the negative impacts of climate change on agriculture management and production. Biochar can be produced at an industrial or small scale. Production at scale generates concerns regarding competition for arable land with agriculture and the conversion of natural ecosystems. This can be addressed by relegating biochar production to existing underutilized lands, including degraded lands (IPCC 2019). Biochar can be produced from industrial scrap wood, other wood waste, other biomass waste, pruned branches, and thinned trees, further reducing production pressure on land.

Nanotechnology is the study and engineering of matter at the scale of 1 to 100 nanometers, where physical, chemical, or biological properties are fundamentally different from those of the bulk material. These properties make it possible to create uniquely designed materials, structures or systems. In the forest sector, nanotechnology is enabling the production of new generation nano-based manufacturing processes and wood-based materials such as bioplastics, natural chemicals, and pharmaceuticals (Moon et al. 2006; FAO 2010). Specifically, nanotechnology can produce bio-based composites and nanomaterials to improve the performance-to-weight ratios of paper and packaging products. Beyond paper and packaging, cellulose nanomaterials have potential applications in food, health, construction, sensors and electronics. Biosensors made of cellulose nanocrystals can detect high-moisture-content zones in wood vulnerable to decay, thus helping produce high-quality wood products (Bowyer 2016). Luminescent nanoparticles can be used for timber tracking (FAO 2019). Cellulose nanomaterials have also been tested in concrete and other materials to lower moisture contents, a process that makes the products sturdier and stronger. In addition, cellulose nanomaterials are used in food preservation to coat fruit, which has proved to be more effective than traditional wax coatings (Eric Hansen, personal communication, 2020[42]). In Viet Nam, nanotechnology is being studied as a tool for species identification, particularly for rare and endangered species (Phuong 2021). Nano-delivery systems are moving from the medical sector to agriculture. Nano-carriers hold promise for delivering precise amounts and controlled release of agricultural chemicals (fertilizers, micronutrients, pesticides, and herbicides) to increase crop production while reducing environmental impacts and producing safer food. Further synergies are foreseen in combination with plant breeding (Vega-Vasquez et al. 2020). These innovations would have similar applications to forest production. Nanotechnologies hold huge potential in the forest sector. However, its rate of growth has been slow as the research required is broad, complex, expensive and long-term (Moon et al. 2006; FAO 2019).

2.4 Innovative finance and social innovations

2.4.1 Innovative finance[43]

Investments in the forest sector stand out from financial opportunities in other sectors due to the nature of forestry activities. The production of timber and other forest resources requires considerable land and long periods of time. There is a long time-span between investments in a new plantation and the first financial benefits. Similarly, if improvements need to be made, such as in genetic material or management practices, the results of such improvements may yield benefits after only one or several tree rotations. This long time-span from initial investment to maturity generates high uncertainties. What will be the future demand for forest products (and services)? How will prices evolve in the future? What will be the future impacts of climate change, extreme weather conditions, fires, pests, diseases, and land conversion? How will future policy and regulatory changes and social and environmental conflicts over natural resources affect the future use of forests and supply of forest products and services? Investors need answers to all of these questions before making decisions on investments in forestry. For investors, these perceived risks are a major obstacle, and when investing in forestry, they want to be compensated for the high risks by high returns or want these risks to be at least partly covered by insurance, guarantees or other forms of third-party involvement that reduce their risk (Louman et al. 2020).

As a result of these common conditions, forestry attracts less investment than other sectors. At the same time, there is increasing awareness of the importance of forest products and services as contributing to global climate and environmental agendas. Over the past 10 to 15 years, international initiatives have sought innovative ways to attract finance to the sector. This section highlights some innovative finance options that have become more widely used recently, although they may have been developed previously. In particular, these innovations seek to reduce risks to investor by sharing them with others and possibly in different proportions.

A broad range of financial technologies and mechanisms, including blended finance, green bonds and crowdfunding, could potentially revolutionize finance for SFM. The challenge remains how to utilize and deploy

42 Eric Hansen, Professor of Forest Products Marketing and Department Head, Oregon State University, October 2020.

43 The innovative finance options described here are summarized from Louman et al. (2020) and Louman (2021).

these options in the forest sector. The three following innovative finance mechanisms have been applied at the global level and hold potential for the forest sector:

- **Blended finance**: financing models that stimulate investment by combining commercial and other financial sources with complementary risk and return appetites (Rode et al. 2019).
- **Green, social, sustainability or climate bonds**: fixed-income instruments that represent a loan made by an investor to a corporate or governmental borrower, the proceeds of which will be exclusively applied to eligible environmental and/or social projects (ICMA 2018). Climate bonds are currently mainly related to emission reductions (carbon credits in the case of forestry).
- **Crowdfunding**: the pooling of small amounts of capital from a potentially large pool of interested funders (Short et al. 2017). Crowdfunding creates a direct link between borrowers and lenders. In some recent developments, financial institutions have become intermediaries, but in a slightly different way from their traditional roles. When funds are small, these may be donated, or lenders may expect non-monetary returns from their investments. However, with increasing amounts, lenders more often seek financial returns or a stake (equity) in the new enterprise or initiative (Lehner and Harrer 2019).

Blended finance is being promoted by large international institutions such as the UN Finance Initiative or the Organization for Economic Co-operation and Development (OECD), to use available public finance to leverage private finance to achieve international development goals such as the SDGs, the Convention on Biological Diversity and the Paris Agreement (Louman et al. 2020). Similarly, integrated finance strategies and blended finance mechanisms are promoted as viable options to implement forest and landscape restoration (FLR) activities (Gitz et al. 2020). The approach combines private funds, public funds and development cooperation to integrate efforts in addressing economic, social, and environmental objectives (FAO & Global Mechanism of the UNCCD 2015). While the details of blended finance models vary by context and program, the common primary roles of the various financing components can be summarized as in **Table 2**.

Public finance is often used to create the enabling conditions to make it more attractive for private finance to invest in actions with positive environmental and social impacts. For example, public finance can be provided to a fund manager who uses it together with private investments to lend to beneficiaries. An example of an enabling factor could be that the public finance is used for technical assistance to the beneficiaries, to embed the financed activities in the local socioeconomic and ecological environment (e.g. land use planning), to reduce the interest rates incurred by the final beneficiaries, or to cover first loss if final beneficiaries default on their loans. As such, public finance contributes to reducing the risk for private financiers when investing in risky activities. Blended finance is therefore considered useful to facilitate investments in new development projects and is widely used in the energy and infrastructure sectors, and more recently also for investments oriented at making agro-commodity value chains deforestation-free (Louman 2021). The Tropical Landscape Finance Facility (TLFF) is an innovative platform that brings long-term finance to projects and companies that stimulate green growth and improve rural livelihoods, helping Indonesia promote economic development, implement sustainable landscape management, and achieve its climate targets (**Box 16**).

The principles for **green, sustainability or climate bonds** are similar. The main difference lies in the criteria used to determine the eligibility of the initiatives to be financed. Since most bonds relate to medium- and longer-term loans, they require issuers to be stable and capable of managing funds, i.e. mature organizations, such as fund managers, banks or large corporations. They also require independent third-party certification to monitor the bond and ensure that proceeds are really used for the objectives stated at the time of issuance. Because they promise a fixed return rather than a variable profit based on the economic performance of the

Table 2. Primary roles of blended finance components

Public finance
• Leveraging private finance to achieve international development goals • Creating an enabling business environment for private investors (reducing risks, covering transaction costs, etc.) • Technical capacity building • Co-funding, co-financing and in-kind support for commercial and development activities • Dissemination, uptake and scaling up of technology (general and innovative)
Private (commercial) finance
• Soft loans (with below-market interest rates) • Preferred market access, premium price for quality commodity production • Business training and enterprise development • Targeted technical training to enhance commodity production • Development and dissemination of innovative technologies
Development cooperation (bilateral, multilateral, foundation)
• Infrastructure and human development; assistance to government • Technical and business planning, marketing and financial literacy capacity building • Supporting international development goals (SDGs and other international development and environmental goals) • Development and strengthening of SMEs (small and medium-sized enterprises) • Promotion and adoption of innovative technology
Other components (environmental, social, etc.)
• Community advocacy and agrarian transformation • Facilitate engagement with public and private sectors • Land access and land tenure • Environmental, socio-cultural and livelihood objectives • Promotion and adoption of innovative technology

beneficiaries, bonds are considered to be less risky but also provide lower returns. An advantage for the beneficiaries is that the initial investment does not have to be paid back until the bonds mature.

In 2018, the average size of these types of bonds was USD 100 million, with an average life of 10 years (CBI 2019). This makes these bonds particularly useful for large-scale homogenous forestry operations such as planting fast-growing trees, where initial costs are high and benefits accrue over a long period of time. However, bonds for the land use sector are currently constrained by the lack of high-quality, bankable and scalable projects that meet bond criteria, especially regarding benchmarking on return rate and risk assessment. There is a need for innovative and efficient mechanisms to connect large funds with small projects, and local financial institutions have a key role in identifying projects and managing relationships with clients (Louman et al. 2020). Bonds can also be useful for financing payment for ecosystem services (PES) schemes, such as payment for avoided carbon emissions or carbon sequestration (**Box 17**). One of the challenges for this type of bonds is to define what is green or sustainable, or to determine the climate contribution of the investments.

Initial forms of **crowdfunding** depended on people sharing a common set of beliefs and information on the primary movers of a given crowdfunding initiative. Such efforts were generally limited to higher-income geographic areas where residents earned sufficient income to invest in such initiatives. The digitalization of communications and financial services has allowed crowdfunding to take on new forms and dimensions, making it possible for people from all over the world to invest in

Box 16 Tropical Landscape Finance Facility (TLFF)

The TLFF combines blended finance with the issuance of bond-like notes. It is a recently set up facility that manages funds from a variety of public and private financiers and uses them to make green investments in tropical landscapes with the objective of contributing to the creation of local employment opportunities as well as the conservation of tropical forests. The TLFF involves a multi-stakeholder group (UNEP, ICRAF, investment manager ADM Capital, BNP Paribas and later WWF). Its core objectives are to provide sustainable rural jobs, rehabilitate degraded lands and provide clean electricity. The TLFF grant facility channels public funds to provide technical assistance and (co)funding for the projects at the early evolutionary stage (e.g. to provide enabling conditions for smallholder involvement). The TLFF lending platform provides long-term debt to sustainable agriculture, forest conservation and renewable energy sectors. The TLFF issues medium-term notes (BNP Paribas) for five, seven and 15 years and proposes different risk levels to attract different types of investors. The United States Agency for International Development (USAID) offers a 50% guarantee for the USD 30 million tranche of longer-term (15-year) bonds. For example, the *&Green Fund*[44] blends finance and invests in TLFF through buying notes, whose proceeds can only be used to further invest in jurisdictional projects, while part of the notes are guaranteed by USAID. The TLFF currently finances new rubber plantations (Michelin) and conservation areas in Indonesia in the context of a jurisdictional approach.[45]

Source: Louman (2021)

projects anywhere and of any type. However, providing some form of reliable knowledge on the investment initiatives and the borrowers remains a prerequisite for successful fundraising. Several digital platforms have been created to facilitate the transfer of such knowledge and directly connect borrowers with lenders. For instance, the Kiva platform[46] provide funds mainly for individuals, start-ups or small-scale enterprises through a network of local banks. This reduces the risk of fraudulent fundraisers. In addition, Kiva has started to use a digital verification system to verify the identity and credit history of the borrowers. The Impact Partners platform[47] aims to attract funds from impact investors.[48] This platform, which works more like a fund manager, can raise considerable funds and invests in businesses with a demonstrable positive social impact. Both platforms offer opportunities for investments at different rates of return and risks and ensure the monitoring of these investments.

PES are incentives (payments or rewards) offered to communities, landowners or farmers in exchange for managing their land to provide a specific ecosystem service. These payments and rewards are a transparent system for the provision of services through conditional payments to voluntary providers (Tacconi 2012). Following the Kyoto Protocol, PES emerged as innovative mechanisms to promote SFM and natural resource conservation through market mechanisms. PES programs often integrate sustainable management with carbon stocks or sequestration, biodiversity protection or enhancement, watershed protection or enhancement, landscape management for ecotourism and community development (Fripp 2014). The negotiation process for PES must be participatory, transparent and agreeable to all partners. Specifically, providers (community, landowner or farmer) must understand the services they are

44 https://www.andgreen.fund/

45 A jurisdictional approach is a type of integrated landscape management where the landscape is defined by policy-relevant boundaries and the underlying strategy is designed to achieve a high level of governmental involvement (Buchanan et al. 2019).

46 See: https://www.kiva.org/

47 See: http://impactpartners.iixglobal.com/

48 Impact investing refers to investments pursuing a beneficial, social and/or environmental impact alongside a financial return. Impact investors, whose current investments represent more than USD 500 billion, currently invest only 9% of this amount in the AFOLU sector (GIIN 2018, 2019).

Box 17 Sumatra Merang Peatland Project

The Sumatra Merang Peatland Project is a simple example where a fund manager issues carbon bonds, the proceeds of which are lent to a borrower who cedes carbon credits to the fund. The fund uses these credits to either pay back the bond from the bondholders with credits or trade the credits and make cash payments to the bondholders. In the case of this project, Mirova/Althelia (bonds issuer and fund manager fund) collaborates with PT GAL (borrower) and Forest Carbon (adviser). The project:

- Complies with the Verified Carbon Standard (VCS) and the Climate, Community and Biodiversity Standard (CCB)
- Reduces the drivers of deforestation by supporting community-selected projects and peatland protection and restoration
- Provides climate, livelihood (and gender) and biodiversity benefits
- Provides tradable carbon credits and allows bond purchasers to opt for payment in carbon credits or cash.
- Helps PT GAL to comply with environmental standards for its pulp- and paper-producing plantations

Weblink: https://ecosphere.plus/sumatra-merang-peatland/

Source: Louman (2021)

providing and agree with the benefits they are to receive. The terms of engagement should be equitable, realistic and formalized in an agreement. As this is a new territory for most communities, landowners or farmers, it is likely that there will be misunderstandings and conflicts. Thus, the agreement should be flexible and renegotiable. PES can be combined with the innovative finance options discussed above. PES is being piloted and implemented in several countries in the Asia-Pacific region, including China, Republic of Korea, Viet Nam, the Philippines and Thailand (Thuy et al. 2013; Nabangchang 2014; Leimona et al. 2015; Lượng 2018; Salzman et al. 2018).

ICT-enabled mobile banking, financial and e-commerce services facilitate transactions and access to value chains. These technologies support the development of a viable digital economy where small-scale producers, communities or organizations can directly market products or services to consumers. Such arrangements promote efficient value chains, avoiding paying commissions to middlemen and reducing transaction costs, hence increasing the price margin received by the producer (individual, community or organization) and enabling lower prices for the consumer. Although they often do not completely eliminate traders, who may provide essential market functions, product value chains are streamlined and made more efficient. These online mechanisms may also strengthen or create demand for under-recognized or underutilized rural products that are not widely known by consumers in other areas. Blockchain is an ICT that enables highly secure online transactions (payments and receivables): all transactions are documented in digital ledgers and authorized through the digital signature of the owner, authenticating and safeguarding the transaction.

Innovative finance mechanisms can facilitate investments in the forest sector, but different mechanisms are oriented at different scales and different phases of such investments. Often a combination of innovative finance options is the most viable choice, with grants important at early stages, followed by concessional loans and blending with commercial money; the latter may be raised through bonds. Crowdfunding is better suited for small-scale initiatives and start-ups and can be used to provide initial funding that may be needed to leverage grants or loans. All options require strong existing financial infrastructure to conciliate the scale and local knowledge on investment initiatives with the desired scale and risk perception of the investors (Louman 2021).

2.4.2 Social innovations

Social innovations are new forms of organization such as new rules, norms, institutions in both the public and private sectors. They can aim to enhance the provision of services and opportunities to civil society, often seeking to provide equitable access to disadvantaged or marginalized groups. They are often multi-sectoral and multi-organizational, involving governments, non-government organizations (NGOs), universities, the private sector, indigenous peoples and local communities. Common social innovations in Asia and the Pacific are community forestry, forest and farm producers, public-private partnerships and citizen science.

The most prevalent social innovation is **community forestry (CF)**, also called social forestry and community-based forest management. CF includes various mechanisms that increase the role of local communities in the governance, decision making, planning and management of local forest resources. CF aims at serving local livelihood needs and reducing poverty. It is participatory and should serve all community members equitably. Common objectives of CF include forest conservation, ecosystem service provision, household and community utilization, commercial production or a combination of those uses (Sikor et al. 2013; Sapkota 2021). Typical partners involved in CF schemes are government agencies, NGOs, development organizations, and research organizations, with possible involvement from conservation organizations and private sector entities. The comprehensive inclusion of relevant stakeholders in discussions and planning is essential in CF, as there may often be overlapping land or resource claims by communities or ethnic groups, and overlapping jurisdiction between government agencies can lead to inconsistent land use standards and regulations.

While the concept of CF became prominent about 50 years ago, recent developments and innovations have made it more applicable and dynamic. Many governments now recognize that improving access to forests and forest resources for indigenous peoples and local communities is an effective strategy to reduce poverty, improve food security and achieve SFM (Gilmour 2016; Sikor et al. 2013). CF schemes have availed many advantages to communities and individuals, but there are also some weaknesses and challenges that remain to be addressed (see **Boxes 18, 28** and **35** for illustrative case studies in Nepal and Indonesia). Besides its positive social impacts, CF can also contribute to forest conservation and SFM (Laumonier et al. 2021).

CF has evolved from its early aims of empowerment and devolution of rights advocated by global reform movements to also encompass market approaches to achieve win–win–win endeavors for SFM, climate change mitigation and robust entrepreneurial livelihoods. Asian countries have developed standard programs and policies that are often linked to broader development goals (e.g. SDGs). Unfortunately, these efforts have not always provided the intended benefits for local communities. Assistance with commodity production, enterprise development and market linkages are often lacking, as well as the meaningful involvement of private sector entities (Wong et al. 2020). As the next stage of development, CF has the opportunity to serve as a mechanism of agrarian transformations, promoting the creation of community (forest- and farm-based) enterprises and the commercialization of locally-produced commodities with private sector investment and public-private partnerships (Macqueen 2013, Moeliono et al. 2015).

As women and men often have equally important yet unique roles, skills and knowledge on forest and tree management, CF programs often integrate practices of gender equality (Colfer et al. 2015; Mulyoutami et al. 2015). This enables CF to address the issues of livelihoods, poverty reduction, SFM and empowerment of women and girls. In CF schemes that include the commercial production of wood or other


Photo 13. Community forestry mechanisms strengthen the role and capacity of local communities in the governance, planning and management of local forest resources (© Lok Mani Sapkota).

products, community forest user groups (CFUGs) or other relevant stakeholders can develop online and ICT-based marketing systems to realize the innovative finance options discussed above. The use of these innovations can strengthen supply chain transparency and enable enhanced access to consumers interested in sustainability and fair-trade issues. Transparency is likely to improve efficiency and encourage institutionalization of smallholder supply chains. CFUGs can also strengthen the negotiating position of local producers by selling larger quantities of products to traders. Shared-value business strategies could be developed through enhanced collaboration between CFUGs and traders to reduce transaction costs and facilitate product supply, enhancing economic returns for both parties (HLPE 2019; Perdana et al. 2015). Developing cooperation with government agencies and the private sector can further strengthen community-based forest enterprises (Sanchez-Bardini et al. 2018).

Forest and farm producers are a diverse group of land managers. Collectively and individually, forest and farm producers, own or manage 65% of the world's land (Verdone 2018).[49] This area includes locally controlled forests, which provide rights to smallholder families, indigenous people and local communities to make decisions regarding forest management and profit from the use of the land, forest and their components. Locally controlled forests overlap with CF. The owners and managers of locally controlled forests are increasingly recognized as important global actors and are targeted recipients of development and technical support.[50] Once empowered and assured of their rights forest and farm producers favor sustainable land and forest management to protect and enrich those assets that are a basis for generating their livelihoods. Forest and farm producers, and their communities, often operate forest- and farm-enterprises that are associated with CF systems and programs.

Public-private partnerships (PPP) are social innovations that combine private finance and public resources to implement projects for public benefit. They often take the form of contractual arrangements between the private sector (companies or individuals) and government agencies, to provide public assets or services, in which the private party bears financial risk and operational responsibility in return for payment (profits) from governments (taxpayers) or users of the assets or services provided (WBI 2012). Although commonly associated with the development and operation of infrastructure projects and systems, PPPs can also be

49 FAO IUCN Forest and Farm Facility. https://storymaps.arcgis.com/stories/724231627e694d0fa11ab707ff9b5dea

50 IIED introduction of locally control forests https://www.iied.org/introduction-locally-controlled-forestry; IUCN locally controlled forests https://www.iucn.org/theme/forests/our-work/locally-controlled-forests#:~:text=Locally%20controlled%20forests%20(LCF)%20is,markets%2C%20capital%2C%20and%20technology.accessed 26 February2022.

Box 18 Community forestry (CF) application and success in Nepal

In Nepal, CF was introduced in the 1970s. Under the program, families using a forest form a community forest user group (CFUG), register with the Forest Office and develop and implement a management plan with the support of government and civil society stakeholders. CFUGs collectively manage forests, including harvesting forest products as prescribed by the management plan, distributing these products to the members at subsidized rates, and selling the surplus to markets at competitive rates to provide financial resources to CFUGs. The following key lessons have emerged.

Achievements and strengths

- **Breaking patriarchy**: CFUGs identify both men and women as family heads with the authority to participate in CFUG decision making, including the selection of leadership. This is a significant change in Nepali society, where men are still considered family heads by default. Recognition in families and communities provides an enabling environment for women.
- **A democratically elected and inclusive community institution**: CFUG members collectively select their leaders, ensuring that at least half of the positions are filled by women. The leadership body should include representation of marginalized groups such as poor and ethnic groups.
- **Adoption of a holistic development model**: CFUGs have budgets for forest management as well as for community development. A minimum of 25% of the budget must address forest conservation, while 35% is devoted to address the needs of women and marginalized groups (the poor and ethnic minorities). The balance is for infrastructure such as schools, local roads, and drinking water systems.
- **A network of communities to safeguard their rights**: CFUGs have built a national network, popularly known as FECOFUN (Federation of Community Forest Users Nepal), to safeguard the rights of local communities and promote collaboration. Building upon this network of thousands of CFUG members, FECOFUN provides agency to local communities by helping them engage with government agencies.
- **A progressive design**: CFUGs hold commercial harvest and enterprise development rights, making them viable economic entities.
- **Strong support from key stakeholders**: The Nepali government supports the program as a major part of the forest sector. The donor community provides resources and knowledge to implement and improve the program. Civil society participation fills gaps in support from state agencies.

Weaknesses and Challenges

- **Sectoral barriers**: Despite their contribution to multiple sectors, CF policies and programs are limited to the forestry domain. This constrains the growth of CF, hampering opportunities to address challenges that span multiple sectors and emerging societal challenges.
- **Limited adaptation**: Rural conditions have changed significantly in the last 30 years. However, the CF programs have not been able to fully adapt to these changes, nor to emerging challenges and opportunities.
- **Diffusion of major structural problems in the overall state mechanisms:** Despite its good performance, CF relies on government support and is affected by the fluctuations in state planning and budgeting process. This creates obstacles for long-term SFM.
- **Weak market linkage and finance**: Many CFUGs are not effectively linked to market opportunities. This contributes to Nepal's continued reliance on timber imports, despite domestic resources being sufficient to meet domestic market demand. As a result, many CFUGs have weak financial conditions and rely on external donors, with operation support from donors becoming increasingly difficult to secure.
- **Limited technical and governance capacity**: CFUGs change leaders every five years. Leaders are expected to provide leadership in achieving multiple objectives following complex formal processes. State agencies have limited capacity and resources to support new CFUG leaders, and external support is no longer available. This has led to an erosion of CFUG capacity, contributing to suboptimal delivery of benefits to local communities.

Sources: Sapkota (2021)

utilized for natural resource development and management, including forest sector investment and CF. In these instances blended finance or other innovative finance mechanisms can be used to integrate a combination of public, private, conservation and foundation funding to address a mix of economic, social and environmental goals (see **Section 2.4.1**).

Citizen science is scientific research conducted or assisted by non-professional scientists and public stakeholders. It supports and enables public participation in scientific research, participatory monitoring and participatory action research. Citizen science advances scientific research by expanding the capacity of the scientific community and increasing the public's interest in science (Gura 2013; Steven et al. 2019). Barriers to the broader adoption of citizen science activities include: reliable connectivity and related infrastructure, access to and understanding of the technology by rural communities, the recognition and utilization by government agencies of the information generated through citizen science, and a shared vision by stakeholders (government agencies, conservation organizations, NGOs and communities) regarding the application of citizen science. Citizen science efforts often utilize ICT technologies and are utilized in CF.

2.5 Forestry functions fulfilled by different technologies: an assessment framework

SFM involves a series of functions from monitoring, managing and harvesting to the transformation and provision of forest products and services. This section examines how the use of innovative technologies affects different functions throughout forest value chains and the extent to which this contributes to SFM. Innovative technologies can not only perform existing functions better than currently utilized technologies but may also provide completely new functions, products and services.

Assessing the strengths and weaknesses of innovative technologies in performing different functions provides ground for an analysis of their advantages and disadvantages in different contexts. Such an assessment offers a framework to compare very different innovative technologies, whether originating from traditional or modern science, and help identify and categorize the most promising innovative technologies for the forest sector in the coming decade on which to focus investments and efforts. The way one technology performs one function, as well as its positive or negative impacts for people and the planet, may vary significantly across contexts in the region, which is very extensive and diverse. Impacts may even be perceived differently by different stakeholder groups within the same context. In addition, the social, economic and technical contexts also evolve quite rapidly.

An assessment framework is presented that addresses the following questions: (i) what is required to improve SFM? and (ii) what can innovative technologies contribute to SFM?

In broad terms, innovative technologies can contribute to SFM by:

- improving forest monitoring and management, including through the wider application of digital technologies;
- increasing productivity and reducing waste along forest value chains by optimizing the harvest, processing, manufacturing and final distribution of forest products;
- and enhancing local participation, transparency and accountability in forest governance.

When equitably used and widely disseminated, innovative technologies can strengthen economic returns for the forest sector, create employment and livelihood opportunities for local communities and stakeholders, and reduce poverty and inequality.

A summary of the key functions in the forest value chain and of the technologies that address those functions is provided in **Table 3**. The table is not an exhaustive list but represents the main functions and technologies identified and discussed in previous sections and with stakeholders and experts consulted over the course of the study.

Table 3. Assessment framework of innovative technologies that address different functions along the forest value chain

Functions	Innovative Technologies
Forest management / pre-harvest	
Forest monitoring	
Monitoring growth, restoration and species composition	**DT**: Remote sensing, drones, satellites, online platforms, AI
Estimating biomass and volumes and carbon stocks	**DT**: Remote sensing, drones, satellites, LIDAR, online platforms, AI
	PP: Precision forestry, improved silviculture
Inventory, mapping, modeling and reporting	**DT**: Remote sensing, drones, satellites, LIDAR, online platforms, AI, GIS
Monitoring risks (pests, diseases, fire)	**DT**: Remote sensing, drones, satellites, sensor networks
Conservation of biodiversity and environmental services	**DT**: Remote sensing, drones, satellites, GIS, mobile phones, apps, GPS, online platforms
	SI: Community involvement (with DT tools)
Tracking illegal activities (logging and poaching)	**DT**: Remote sensing, drones, satellites, GIS, mobile phones, apps, GPS, online platforms
	BT: DNA tracking
Forest management	
Forest planning	**DT**: Remote sensing, drones, satellites, LIDAR, online platforms, AI, GIS
	PP: Precision forestry, improved silviculture
Selection and provision of planting material	**BT**: Species/genetic selection and tree breeding, DNA tracking
	PP: Nanotechnology (species identification)
Planting and restoration	**BT**: Mass production of improved clones, genetically modified germplasm (biotech)
	SI: Effective germplasm dissemination, CF
	PP: Improved silviculture, precision forestry, aerial seeding, biochar, nanotechnology (species identification)
	DT: Drones (deliver of planting inputs and aerial seeding)
Tree growing and carbon storage	**BT**: Mass production of improved clones, genetically modified germplasm (biotech)
	SI: Effective germplasm dissemination, CF
	PP: Improved silviculture, precision forestry, RIL, winch-assisted harvesting: biochar, nanotechnology (species identification)
	DT: Drones (monitoring)
Ecotourism and recreational uses	**DT**: Mobile phones, apps, GPS, drones, online platforms, social media
	SI: CF
	IF: Green and social bonds, crowdfunding
Finance	**IF**: Blended finance, green climate bonds, crowdfunding, PES

Harvesting and forest industries	
Harvesting of forest products	
Logging	**PP**: RIL, winch-assisted harvesting, improved silviculture, precision forestry, portable sawmills, improved design of logging roads and trials
Harvesting NWFPs	**DT**: Mobile phones, apps, online platforms
	SI: CF, market integration, online commerce
Wood processing	
Processing	**DT**: AI, CNC, renewable energy, 5G wireless
	PP: Modern sawmills, spindle-less lathes, scanning and optimization technology, engineered materials, composite boards, bioplastics (reduced transport needs and waste management)
Distribution and trade	
Transport, storage and distribution	**DT:** Smart chips and barcodes, remote sensing, drones, satellites, online platforms, AI, GPS (monitoring product movement)
	BT: DNA tracking (select commodities)
Trade, value chains and marketing	**BT:** Genetic selection, breeding, genetically modified (ex. production of rubberwood clones facilitated the development of new value chains)
	DT: e-commerce, blockchain and mobile apps
Tracking illegal trade	**BT**: DNA tracking
	DT: Smart chips and barcodes, online legality platforms, remote sensing, drones, satellites, AI
Product final utilization	
Construction	**PP**: Engineered materials (CLT, mass timber, MDF, OSB, particleboard), nanomaterials, modern mills
Furniture	**PP**: Engineered materials, nanomaterials, bioplastics, modern mills
Pulp, paper and packaging	**PP**: Engineered materials, bioplastics, nanomaterials
	BT: Tree breeding (low-lignin for improved pulp)
Bioplastics, biochemicals, And pharmaceuticals	**PP**: Engineered materials, nanotechnology, biotechnology
	BT: Tree breeding (high-lignin to produce cellulosic derived sugars)
Recycling and reuse, waste prevention and management	**DT**: 5G wireless, AI
	PP: Engineered materials (MDF, OSB, particleboard), modern mills, bioplastics, bioenergy
Bioenergy and energy	**PP**: Wood pellets, liquid fuels, modern mills, renewable energy
	BT: Species/genetic selection and tree breeding (tree growth, high-lignin, etc.)

Community participation and governance	
Community involvement	**DT**: Mobile phones, apps, GPS, drones, online platforms, video conferencing and social media
	SI: CF
	IF: Green and social bonds, crowdfunding
Resource access and tenure	**SI**: CF
	DT: Mobile phones, apps, GPS, drones, online platforms, video conferencing
Information sharing	**DT**: Mobile phones, apps, GPS, drones, online platforms, video conferencing
Transparency and accountability	**DT:** Mobile phones, apps, online platforms, drones, blockchain
Livelihood and enterprise development	**DT:** Mobile phones, apps
	SI: CF, market integration, online commerce
	BT: Mass production of clones, effect, germplasm dissemination
	PP: Portable sawmills

Note: **DT** – digital technologies, **BT** – biological technologies, **PP** – process and product innovations, **IF** – innovative finance, **SI** – social innovations.

3. Opportunities and challenges for the forest sector: what role for innovative technologies?

There is a broad assumption that the deployment of innovations is inherently beneficial, with advantages generally outweighing the risks. However, innovative technologies could have significant negative impacts on social, economic and environmental conditions. Innovative jobs created might favor external people with higher technical skills more than local communities. Moreover, automation might lead to the loss of unskilled jobs and provide limited new employment opportunities for local residents with lower human or financial capacity. Such a downturn in employment would have a carry-over effect to the broader local economy and public sector. This would exacerbate negative social and economic conditions. Improved productivity and profitability facilitated by innovative technologies could drive an increase in demand for forest resources, resulting in unsustainable management, accelerated deforestation, habitat destruction and environmental degradation – resulting in negative environmental conditions. These potential negative impacts of innovative technologies on SFM and society (economic and social conditions) need to be anticipated and plans developed to minimize their effects.

This chapter describes the main impacts, positive and negative, associated with the application of innovative technologies. These are summarized for the four innovative technology categories and as economic, social or environmental impacts in **Table 5** in **Section 3.8**. Although not an exhaustive list, the table highlights the key advantages and disadvantages recognized during the study.

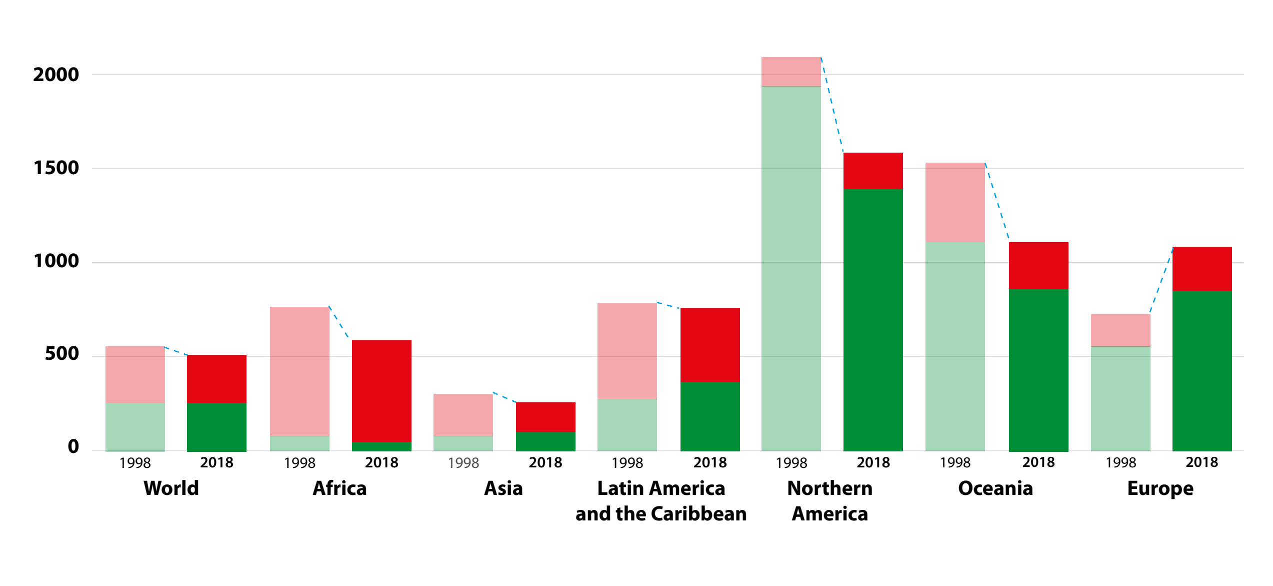
3.1 Addressing shifts in wood demand and forest value chains

Recent decades have seen huge shifts in wood demand and forest value chains. Globally, both demand for and production of industrial roundwood has grown. However, despite overall economic growth, per capita consumption of wood is decreasing as a result of population growth, technology improving resource use efficiency, substitute non-wood lignocellulosic materials, and insufficient production. In 2018, Asia had the lowest total roundwood[51] per capita consumption (265 m^3 per 1000 people against 510 m^3 per 1000 people on average at the global level), while consumption in Oceania reached 1109 m^3 per 1000 people (Gitz 2019; see also **Figure 3**).

There are clear reasons for the overall increase in consumption, particularly in the regions where it is the lowest per capita: economic development driving increased pulp, building and furniture demand driven by population growth and urbanization (Gitz 2019). The Asia-Pacific region has become a major producer and exporter of wood products (see **Figure 4** and **Table 4**). To serve this growing demand for wood products, the region imports sawnwood and industrial roundwood for processing (FAO 2019). The main Asia-Pacific wood-importing countries are China, Japan, the Republic of Korea, India and Viet Nam. Key sources of wood from outside the region are Canada and the USA. China has become the regional and global leader in forest product exports (see **Figure 5**). Wood demand has

51 Total roundwood includes industrial roundwood and woodfuel.

Figure 3. Regional consumption per capita of industrial roundwood (green) and wood fuel (red) (in m³ per 1000 people)



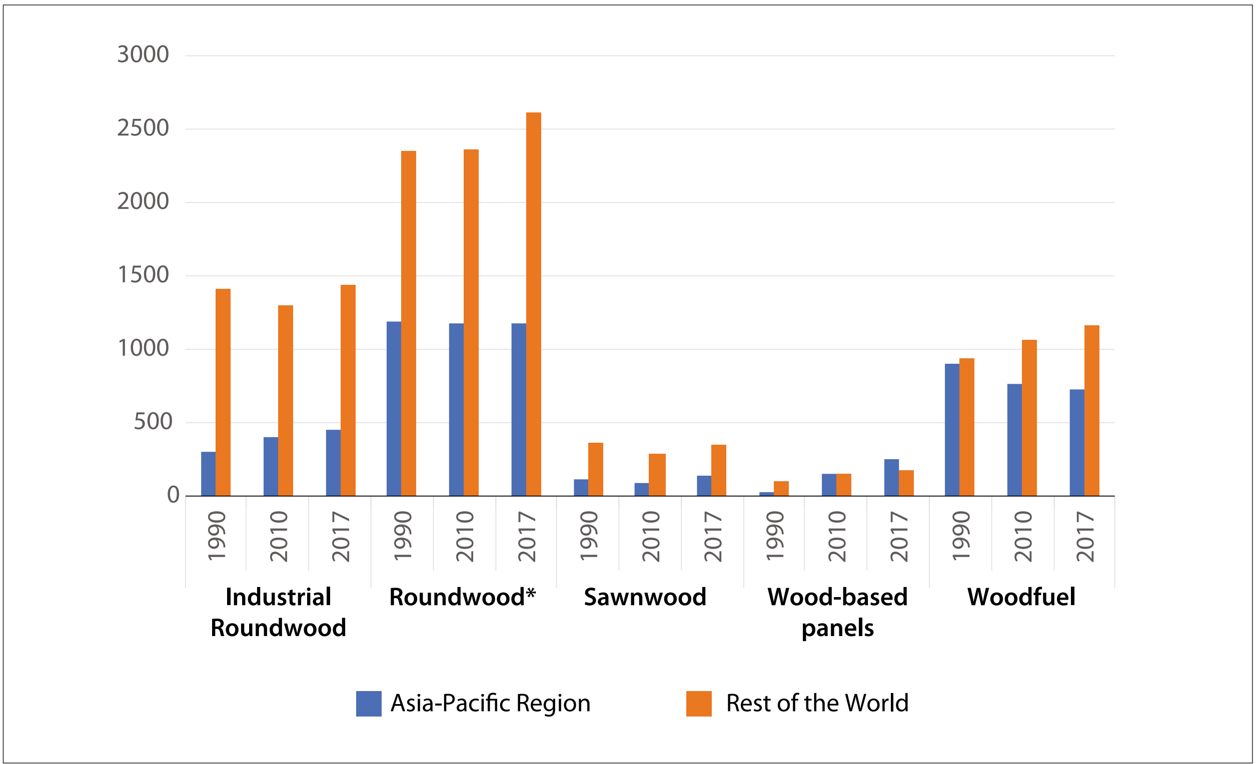
Source: Gitz (2019), based on FAOSTAT: http://www.fao.org/faostat/en/#data/FO (accessed 23/09/2019)

also grown in the region, with consumption remaining largely stable due to limited availability and innovative technologies that enhance resource use efficiency and recycling. Concurrent to these trends, global demand for fuelwood has decreased, driven by urbanization and preferences of a rising middle class for electricity and petroleum-based fuels (FAO 2019). The new wood products detailed above – engineered woods, composite boards, bioplastics, biochemicals, pharmaceuticals and bioenergy – are increasing demand for industrial roundwood, accompanied by significant changes in resource use efficiency, processing, recycling, reduction in waste, use of small-diameter logs and acceptance of underutilized species previously considered non-commercial, which can be used by new technologies and markets as part of the development of the circular bioeconomy. These developments have led to the expansion of wood value chains from local to regional and global levels.

3.2 Supporting the development of the circular bioeconomy

The circular economy and bioeconomy are separate but complementary concepts. The circular economy seeks to reduce resource consumption by improving efficiency, recycling, reusing, and reducing waste; it targets the development of closed systems and commonly has a local focus. The bioeconomy uses biotechnology and biomass to produce goods, services and energy. It seeks to produce new products and services as well as to substitute the use of fossil fuels and resource-intensive materials (steel, concrete, plastics, etc) in forestry, agriculture, and marine systems and industrial processes (Carus and Damme 2018). The products and services of the bioeconomy utilize bio-based processes conducted by micro-organisms, animal and plant cells or their components. Biological processes and tools include breeding, bioinformatics, technologies and methods for data analysis and production processes for industrial biotechnology (Gomez San Juan and Bogdanski 2021).

Figure 4. Global and Asia-Pacific production of key wood products (million m³)



*Note: Constituent components of roundwood are industrial roundwood and woodfuel.

Source: FAO (2019).

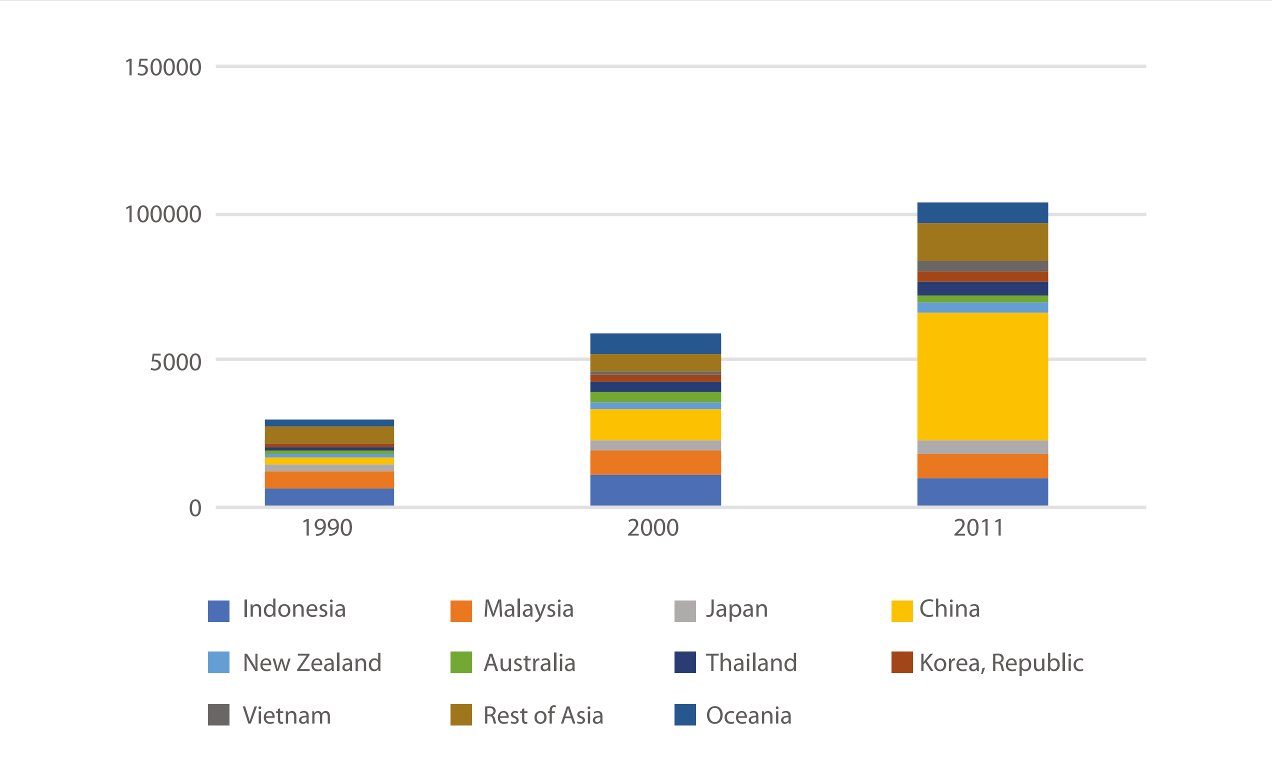
Table 4. Total export value of forest products[52] in million USD

	1990		2000		2011	
	Export Value	% Global Trade	Export Value	% Global Trade	Export Value	% Global Trade
Global	208824	-	384343	-	421160	-
Asia	27155	13.0	52577	13.7	96279	22.9
Oceania	3050	1.5	6998	1.8	7046	1.7

Source: FAO (2014b).

52 Including: forestry, wood, pulp, paper, and wooden furniture.

Figure 5. Total export value of forest products for major Asia-Pacific countries, in million USD



Source: FAO (2014b).

The development of the 'circular bioeconomy' makes significant contributions to climate change mitigation and SFM by improving the efficiency of resource use and reducing environment impacts. It is an integrated approach towards environmental sustainability and deals with the extraction of biological materials, the protection and regeneration of ecosystems and even food production in agriculture (Abad-Segura et al. 2021).

Central to this concept is how wood biomass extraction can be reconciled with environmental protection and inclusive prosperity for local communities. Modern, efficient and sustainable sources of biomaterials and bioenergy production and use can play a key role in combating climate change while providing social, economic and environmental benefits to rural communities, forestry and other sectors, but these sources are not readily available to everyone. Thus, it is essential that spatial planning agendas regarding biomass production, use and trade give ample attention to social inclusion. Topics for consideration should include sustainable production, value chains and investments, enterprise development, and green growth (Baral et al. 2021). The subsequent paragraphs revisit the innovative technologies in light of their roles in the circular bioeconomy.

Geospatial technologies and ICT facilitate the improved planning and management of forests and land resources, allowing far greater detail than is possible through traditional management, resulting in improved yields, reduced waste and SFM. Advances in ICT ease the sharing of information, contributing to the development of a paperless environment. However, contrary impacts have also occurred. The APFSOS III (FAO 2019) notes that the development of e-commerce facilitated by ICT advancements has increased demand for paper, paperboard and cartonboard for packaging.

Biological technologies develop suitable genetic material for specific field conditions. These materials grow faster, reducing rotation length and the need for chemical inputs. Breeding and biotechnology can also develop genetic material for trees with specific desired wood characteristics, improving efficiencies in wood processing, facilitating the development of new wood products and supporting the bioeconomy.

The integration of AI, machine learning, robotics and other innovations in processing industries optimizes wood utilization, reducing waste and often energy use. CLT and mass timbers can replace steel and concrete in building construction. Composite boards and bioenergy products enhance biomass utilization, recovery and recycling generating social and environmental benefits. They can be produced from short-rotation timber crops combining forest conservation, wood industry support and rural livelihood enhancement (WWF 2020).

Wood and bamboo can be used to make bioplastics. While the production of bioplastics remains technologically demanding (Brodina et al. 2017), research and development continues to advance and there is growing political support to replace single-use plastic items with renewable materials to reduce plastic pollution in support of the bioeconomy (Di Bartolo et al. 2021). These new wood and bamboo products represent carbon sinks with positive climate mitigation impacts, making contributions towards the bioeconomy.

Financial innovation and CF mutually support the bioeconomy. Blended finance, green and social bonds, impact investments and other mechanisms prioritize sustainable environmental management and economic benefits to local communities. CF supports SFM, local governance and local economies and livelihoods. This can include the development and expansion of SMEs operated by local entrepreneurs or communities adopting innovation technologies supporting the bioeconomy.

3.3 Improving monitoring and reporting

Forest monitoring at a national scale for management purposes has two major dimensions: (i) the technical and scientific dimension of producing relevant, high-quality and credible data, and (ii) the policy dimension (FAO 2017). When designing and implementing a national forest monitoring system, both dimensions must be kept in mind so that the monitoring methods are matched to deliver the objectives and are appropriate to national capacities and needs. Technology-driven approaches to comprehensive data collection should target the generation of information that can be useful for forest management, policy development and monitoring.

These cautionary comments aside, there have been rapid innovations with forest monitoring technologies that can enable the efficient, accurate and cost-effective monitoring of forest and land resources. Enhanced monitoring through remote sensing, GIS and GPS technologies generates huge data sets of comprehensive information. These data sets facilitate detailed analysis and improved forest planning, where the physical resources and staff capacity are available for analyzing and interpreting all of the data. Enhanced monitoring also holds great potential for forest and landscape protection. Real-time monitoring, measuring and reporting of conditions and changes can help better identify, delineate and assess the occurrences and risks of fire, pest and disease outbreaks, land cover change and illegal activities.

Many of these monitoring technologies are user-friendly and utilize open-source tools, applications, and platforms.[53] New coalitions of actors can be forged and new sociopolitical dynamics can be generated by making technologies and data that may have been previously restricted to government agencies and powerful private actors available to all stakeholders, particularly local communities, individuals, NGOs and marginalized groups. Access to the accurate data collected by these innovative monitoring technologies can also strengthen local land tenure and access rights, preventing or mitigating land and forest conflicts.

53 See FAO's work on National Forest Monitoring Systems online http://www.fao.org/redd/areas-of-work/national-forest-monitoring-system/en/

Box 19 Acoustic monitoring to assess wildlife conservation

Bioacoustics – specifically the recording and analysis of entire soundscapes – is an emerging innovation with great promise for the effective monitoring of wildlife biodiversity in tropical forests.

Even forests that appear intact in satellite imagery could have low biodiversity conservation value because of effects such as canopy simplification, understory fires, invasion by exotic species, or overhunting. These parameters are difficult to monitor remotely with satellite imagery, resulting in a common faulty assumption that conserving forest cover equates to conserving biodiversity. While advances in spectral imagery and LIDAR (see **Box 4**) are identifying progressively finer levels of forest change, they remain a proxy for wildlife biodiversity rather than a direct measure.

Measuring wildlife populations and the success of conservation programs used to require detailed on-the-ground surveys. However, repeated surveys are expensive, cover limited areas, and may be affected by collector bias. One possible alternative is the use of bioacoustics, which can detect wildlife species by their vocalizations. Depending on vegetation structure and the vocalizing species, acoustic recorders can detect species calls and song from several hundred meters away. The recorders also detect human activity. Autonomous sound recording devices are now available; as they are small and inconspicuous, they do not alter the areas in which they are placed. The devices can be programmed to record either continuously or at intervals, based on power source and data storage capacity. Multiyear recording studies have been completed.

Soundscapes are analyzed in many ways. Indices can be calculated that characterize individual forest types, specific locations and times. Additionally, individual species can be identified by experts, through algorithms, or through deep learning[54] (Stowell et al. 2018). Advances in bioacoustics technology, as well as the increasing robustness and affordability of sound recording devices, are making it possible to deploy sound recorder networks in forest areas to monitor legal requirements, certification, or zero-deforestation commitments. Such networks can be managed by government agencies, conservation organizations, companies, communities or individuals.

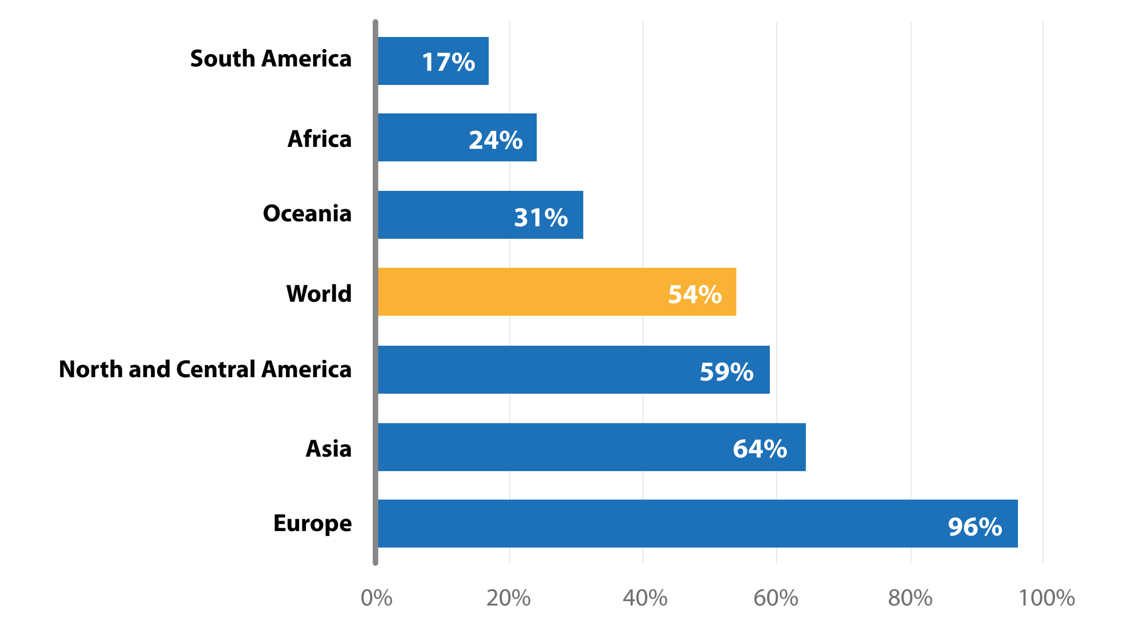
Sources: Burivalova et al (2019); Game (2021).

Optical, acoustic (**Box 19**) and camera sensor networks also monitor the physical and environmental parameters of forests (temperature, sound, movement, pressure, etc.), providing real-time data on forest conditions including climate, flora, fauna, soils, sound and pollution levels.

However, monitoring innovations may also result in negative impacts. The cost-effective and real-time collection of accurate, reliable forest inventory data may reinforce enticements for unsustainable resource use. Most monitoring technologies are user-friendly by design and compatible with open-source tools. However, a minimal level of training is nevertheless required, and inexperienced users may still struggle with monitoring technologies and accessing platforms (Bahar and Wicaksono 2021). Additionally, access to the data and tools, applications and platforms may be restricted by the institution that generated the data or the holder of the copyrights or IPRs of the technologies. The rights of parties who generate data and develop technologies should be protected, but these situations may maintain or intensify inequalities related to access and use of forest resources and related information. Limited internet connectivity and bandwidth may restrict the versatility of monitoring technologies in remote or inaccessible locations.

54 Deep learning is a type of machine learning that uses computer algorithms to improve automatically through the use of data and experience. Deep learning can be supervised, semi-supervised or unsupervised.

Figure 6. Percent of total forest area under long-term management plans



Source: FAO (2020a).

Box 20 Geospatial and Mobile Technologies for Conservation

The Center for Conservation Innovations uses geospatial and mobile technologies to enhance local forest conservation by integrating the interests, knowledge and capacity of local communities. This type of partnership enables communities to contribute to forest conservation and protect their forest-based livelihoods.

In many rural areas, particularly in remote locations, there are significant information gaps regarding forest cover, forest health and other spatial features. Information may be found in maps and old reports but is not readily available and has not been digitized. To fill these information gaps, local community members are recruited to collect forest information and trained in the use of geospatial tools like GIS, GPS, as well as mobile and web apps for mapping and image capture. Open-source technologies, such as QGIS (a desktop GIS app), Google Earth Engine, MapIT (mobile GIS app), and Landsat Explorer (a web-based app) are used to facilitate access, utilization, compatibility and cost-effective collection and analysis of forest information. Using this approach, local communities have calculated forest areas, pinpointed coordinates of specific locations, and provided imagery; confirming and documenting the location of roads, rivers and areas where forest disturbance is prevalent or of concern. This skill transfer enables local communities to contribute to the monitoring of reforestation activities, drivers of deforestation and forest degradation, biodiversity and ecosystem services. The availability of touchphones or smartphones, which are versatile gadgets with built-in GPS and cameras, and the development of software have enabled the creation of mobile apps that facilitate field data collection, the identification of species (flora and fauna – with emphasis on threatened species), and patrolling. When a wifi network is available, the data can be sent immediately to central online servers, enabling real-time reporting and analysis.

The Center for Conservation Innovations conducts this work in collaboration with local and national government agencies and local communities with input from civil society organizations, other conservation organizations and technology service providers. Activities have been implemented in the Philippines, Samoa, and Cambodia.

Source: Coroza (2021)


Photo 14. Time and motion studies conducted in the field optimize work routines, enhance productivity models and reduce risk (© Raffaelle Spinelli).

3.4 Facilitating forest management

Long-term forest management planning in Asia is ahead of the global average, while Oceania is behind (see **Figure 6**), with trends in Asia showing an improvement while those in Oceania have remained constant (FAO 2020a). Plans must be implemented to achieve the intended aims, and there remain opportunities for improvement. There are many synergies between forest monitoring and forest management. The large volumes of data and information generated by remote sensing and other innovative technologies can be used to enhance forest planning and management. This includes identifying threats such as fire, pests and diseases, drought, climate change, land conversion, and illegal harvesting and poaching, and developing and implementing mitigation strategies. The concept of precision forestry and improved silviculture management integrate the use of data and information from various sources to refine site preparation, planting and post-planting practices to improve SFM and productivity.

Similar to the IPTIM systems mentioned above, the Heureka Forestry Decision Support System (DSS) is a freely available software package developed in Sweden. Its main components are: (i) an interactive stand simulator, (ii) a tool for long-term forest planning, containing an optimization module, and (iii) a simulator for regional analyses. The system contains models for forest growth projections, silvicultural treatment simulation, and the estimation of recreation values, carbon sequestration and wildlife habitat suitability. It can be used to make projections under different climate scenarios (Wikström et al. 2011). With similar efforts and investments, regionally adapted systems could be developed for Asia and the Pacific. Geospatial technologies and analysis can also be dedicated solely for forest conservation in lieu of any production (see **Box 20**).

Operational efficiency in the forest sector is the effective utilization and economical management of forest resources. It aims to economize forest management through improved planning and execution (Silversides and Sundberg 1989). Time and motion studies, frequency studies, output studies, ergonomic and safety studies, together with cost control (in management, harvesting, and transportation), are important tools in promoting efficiency and competitiveness within the forest sector (Kosir et al. 2015; Bostrand 1992; Sessions and Sessions1992). The intent of these studies is to apply scientific methods to analyze work routines and identify means of refinement. Work studies seek to optimize work routines, develop productivity models, compare work techniques and technologies, and assess risk. Human factor studies focus on matching tools (equipment) with worker and task characteristics to maximize worker safety and efficiency. Refinements in operations are

55 Jonas Cedergren, Forestry Officer, FAO, 3 December 2021.

considered a crucial basis to future forest productivity (Allot et al. 2020). Many digital and process innovations can contribute to operational efficiency.

A recent global study of operational efficiency in the forest sector reports three main impacts. More forest biomass will enter the market, which is needed to transition towards a bioeconomy. The increased availability of forest biomass and improved cost control will have a positive price effect, making investments in the forest sector more likely to be profitable. Improvements in operational efficiency can improve log recovery, increasing harvested volumes from the same unit of forest. This last impact holds positive potential for SFM, the provisioning of ecosystem services, and climate change adaptation and mitigation (Lundmark et al. 2021). Corresponding results are reported as possible for large and small-scale forest operations in the region (Li et al. 2017; Obi and Visser 2017; Flanagan et al. 2020). In summary, more efficient forest management makes it possible to increase harvested volume of forest biomass in a sustainable manner. Enhancing operational efficiency has long been an issue in the forest sectors of developing economies (Jonas Cedergren, personal communication, 2021[55]). Partnering with research institutions can assist forest sector companies to identify the best focus for enhancing their operational efficiency (Brown et al. 2011). The subject should be given more attention by operational managers and in the training of foresters.

The forest management concepts, approaches and practices discussed in this section share a number of common positive impacts. Under standard management recommendations, all contribute to SFM and enhance the performance of the forest sector. Additionally, they improve economic and social outcomes for users of all scales and offer a range of opportunities for managerial, semi-skilled, to unskilled employment. Besides the geospatial technologies mentioned above, these forest management concepts, approaches and practices all integrate synergistically with many of the biological, financial and social innovative technologies covered in this study.

The use of innovative technologies in forest management may have negative impacts. Similar to the use of monitoring innovations, the cost savings and productivity achieved with the deployment of the technologies could promote unsustainable forest utilization, primarily timber harvesting. For example, RIL can increase productivity while reducing environmental damage (see **Box 14** and **Box 21**). However, when conducted at higher harvest intensities, RIL has been documented

Box 21 Impacts of RIL on tree species diversity and carbon storage

Commercial logging in forest concessions is a vital source of timber for the global market. However, there are concerns regarding sustainability, particularly impacts on biodiversity and carbon storage. Logging intensity greatly influences the characteristics of the residual forest. It has widely been assumed that reduced-impact logging (RIL) diminishes the negative effects of logging. To test this hypothesis, a meta-analysis of selective logging impact studies was conducted, focusing on: (i) residual forest damage; (ii) aboveground biomass; and (iii) tree species richness. The results indicate that RIL appears to reduce residual tree damage when compared to conventional methods. However, changes in aboveground biomass were negatively related to logging intensity. Any effect of RIL, independent of logging intensity, was difficult to discern since it was carried out at relatively low intensities. Tree richness appeared to increase at low intensities but decreased at higher intensities. The direct effect of RIL was difficult to detect. The results support the hypothesis that RIL reduces the negative impacts of logging on tree damage. However, without an emphasis on reducing logging intensity, they do not support suggestions that RIL reduces the loss of aboveground biomass or tree species richness. This lack of support may be a result of the relative paucity of data on the topic. An issue to consider is whether RIL is inherently a low-intensity practice; in which case RIL does reduce the negative impacts on tree species diversity and carbon storage.

Source: Martin et al. (2015).

Box 22 Spindle-less lathes improve resource utilization and economic returns

Spindle-less lathes are veneer peeling machines equipped with a pressure roller which allows logs to be peeled to a relatively small core diameter, giving the chance to process smaller diameter and lower quality plantation hardwood logs. Spindle-less lathe technology is promoted as an alternative value-adding processing strategy for small-diameter logs. In a study conducted in Australia, spindle-less lathe technology was used to process 918 billets[56] of six commercial hardwood species (*Corymbia citriodora, Eucalyptus cloeziana, Eucalyptus dunnii, Eucalyptus pellita, Eucalyptus nitens,* and *Eucalyptus globulus*). Results demonstrated that green veneer recovery rates were 68%–77% and gross veneer recovery rates were 54%–65%. These rates are two to six times higher than rates commonly reported for processing logs of similar diameter and quality with traditional solid wood processing (sawmilling) options commonly used in the study area. As expected, species, tree age, log quality and silviculture practices affected recovery rates. The study demonstrates that spindle-less lathe technology improves recovery, reduces waste, and increases economic returns. The technology holds potential for improving the value of small-diameter logs thinned from plantations, underutilized species, and logs that might otherwise be processed for lower-value products (pulpwood).

Source: McGavin et al. (2014).

to reduce tree species diversity and above-ground carbon stocks in the residual forest (Martin et al. 2015).

3.5 Improving resource use efficiency

Innovative technologies can reduce waste and improve resource and energy use efficiency along forest value chains (from harvesting to processing and distribution), thus increasing the profitability of the forest sector and contributing to the sustainable management of natural forest resources. They can also limit or avoid collateral environmental damages to ecosystems (e.g. pollution, destruction of untargeted organisms or species).

An encompassing objective of process and products technical innovations is improved efficiency in the use of forest resources through enhanced recovery rates, reduced waste, and reduced negative environmental impacts. Synergies between digital technologies and process innovations improve the planning and implementation of forest management, harvesting and resource processing.

However, some innovative technologies could be associated with challenges and possible negative impacts. RIL, portable sawmills and other harvest-related innovations can make it possible to access areas previously untouched, opening new production potential but with consequences for SFM and/or biodiversity conservation in these previously pristine areas (see **Box 21**).

In processing facilities, CNC can be employed to optimize product design and wood processing, improving recovery. 5G wireless communications, AI, machine learning and their integration can facilitate automation and optimize wood processing. Integrating scanning and optimization technologies into the operation of sawmills and other processing facilities can increase wood recovery and grade yields, reducing waste. Spindle-less lathe technology can reduce waste and allow the utilization of small-diameter logs (see **Box 22**). Engineered wood and bamboo products also greatly enhance wood use efficiency and reduce waste. Additionally, bamboo products can offset wood demand.

New forest-based bioenergy products such as wood pellets, bamboo pellets (see **Box 23**), liquid fuels from wood and other biomass, and electricity from wood- and biomass-fired power plants are all important innovations that

56 A small stick of wood, as for firewood.

Box 23 Bamboo pellet production process

The process of making bamboo pellets is similar to that of other biomass pellets and involves drying, grinding, and extruding bamboo fiber under high pressures and temperatures into pellets of a specified size. The entire bamboo plant, including the stem, branch and its rhizome, can be used to produce bamboo pellets, making it highly resource-efficient, with limited wastage. Residues produced from bamboo products or furniture manufacturing such as sawdust and shavings also serve as an important raw material source. The whole pellet production process is illustrated in **Figure 7**.

Figure 7. Bamboo pellet production process

Source: Akom et al. (2019).

can shift energy reliance away from fossil fuel dependence towards renewable resources. The use of renewable bioenergy crops – jatropha, oil palm, sugar palm, etc. – also contribute to this energy efficiency trend. The bioenergy products can utilize wood scraps from the forest industry, other wood and biomass waste, and underutilized species; increasing forest biomass recovery rates and resource utilization. Bioenergy products, renewables and bioenergy crops (see **Box 24**) all contribute to SFM by reducing utilization pressure and related negative environmental impacts.

The positive aspects of these innovative technologies to improve resource use efficiency, reduce costs and improve productivity and profitability are obvious. However, if used unwisely, these innovative technologies could accelerate forest degradation, deforestation, and habitat destruction, leading to threats to biodiversity. As discussed with innovative technologies for forest monitoring and management, productivity and profitability achieved through improved resource use efficiency may incentivize the unsustainable management of forests and other natural resources. The adoption and use of all of these technologies require careful planning and management, with emphasis on sustainability.

Furthermore, innovative technologies that enhance resource use efficiency may require the adoption of new operational standards, investment in new equipment, and capacity building. This is a significant investment in capital and time that will affect productivity and profitability in the short term. Most innovative technologies for wood processing are designed for large-scale operations. Scaling down the technologies for adoption by small-scale enterprises may be necessary and could be expensive. Financial and institutional inertia could block or delay the adoption of innovative technologies, requiring consequential investment and capacity building. Another disadvantage of some process and product innovations – particularly, RIL, WIM, portable sawmills and wood processing technologies – are the potential dangers associated with operating modern machinery. Equipment training must emphasize operational and worker safety.

3.6 Addressing the need for high-quality and diverse planting material

The number of species that have benefited from comprehensive formal tree breeding programs is largely limited to commercial species. Initiatives that plant commercial species will have an adequate diversity of

Box 24 Bioenergy potential for Indonesia

Increasing energy demand, government commitment, bioenergy crops and systems

Energy demand in Indonesia has increased significantly with population growth, urbanization, and economic development. The Indonesian government seeks to reduce dependency on fossil fuels while meeting growing energy demand. It aims to generate 23% of its energy from renewable sources by 2025. This provides an opportunity to develop bioenergy options as a crucial component of a low-carbon and energy-secure future. Bioenergy development must be guided by the selection of appropriate species for each landscape while respecting the rights and preferences of local communities. Deforested and degraded land can be ideal for the production of energy crops, as these sites are not a primary choice for agriculture and require restoration. Establishing bioenergy crops on such lands would also contribute to the government's ambitious NDC (Nationally Determined Contributions) target of restoring 14 million ha of degraded land by 2030. Studies have shown that a number of species are viable for bioenergy, including bamboo, (*Bambusa* spp.), calliandra (*Calliandra calothyrsus*) and gliricidia (*Gliricidia sepium*) as biomass crops; nyamplung (*Calophyllum inophyllum*), pongamia (*Pongamia pinnata*), and kemiri sunan (*Reutealis trisperma*) as biodiesel crops. Under the right conditions, bioenergy crops can be intercropped with food crops, creating systems that simultaneously support energy security, food security and landscape restoration. Well-designed agroecosystems could produce bioenergy crops, contributing substantially to Indonesia's targets for bioenergy while minimizing negative environmental and social effects and stimulating local economies. The potential contributions of bioenergy crops to the agricultural sector are manifold. However, questions remain regarding the economies of scale of bioenergy production at the macro level, the availability of suitable lands that are sufficiently near energy markets, and the level of operational and transaction costs. Additionally, planning needs to ensure that bioenergy crops do not compete with agriculture production, which could increase food commodity prices, hunger and food insecurity. Similarly, system designs must ensure that bioenergy production systems are sustainable and do not lead to further land and forest degradation.

Source: Baral and Lee (2016); Rahman et al. (2019); Jaung et al. (2018); Sharma et al. (2018).

Powering rural communities with reliable bamboo bioenergy

Bamboo holds huge potential as a source of bioenergy, with the added benefits of restoring degraded land and providing food and livelihoods for local communities. With a calorific value of approximately 4500 kcal kg^{-1}, bamboo is an efficient fuel and compares favorably with wood biomass. Bamboo affords superior environmental and health benefits, as it has a short production rotation and its fuel produces little smoke or odor. Bamboo can be planted on degraded public lands and underutilized farm niches. At both off-farm or on-farm locations, it also provides raw material for various household needs such as poles, construction, furniture, roofing, and fencing. The potential for powering rural communities with bamboo bioenergy has become a reality in Indonesia through dynamic collaboration between local communities, government agencies, the private sector and research institutes. Key technical partners are the research institutes, CIFOR and INBAR, and the private company Clean Power Indonesia (CPI). CPI and local governments have established bamboo-powered plants that provide 700 kWh of reliable energy to 1,200 households in off-grid remote villages of Siberut Island, West Sumatra. CIFOR and CPI are exploring opportunities to scale up this successful model across the country. These efforts include using bamboo to restore critical watersheds and provide power around Lake Batur on Bali and to provide full electrification to off-grid communities on Nias Island, North Sumatra. Further benefits from adopting bamboo cultivation for bioenergy are reducing deforestation, restoring degraded lands, and increasing local capacities to establish climate-smart enterprises to enhance livelihoods in remote and isolated, poor, vulnerable communities.

Source: CIFOR (2018); Sharma et al. (2018); Paudyal et al (2019)

Weblink: *https://www.cifor.org/knowledge/publication/7433/*

genetic material from which to choose. For other species, the selection may be limited to a few provenances or landraces that have been documented or are grown locally. For many local undomesticated species, the identification and selection of planting material should start with exploration and collection from natural populations and landraces. The availability of quality planting material is often limited, and it is therefore important to multiply larger quantities of quality germplasm to facilitate dissemination to users. This is particularly important for farmers, communities and local organizations who have the weakest access to quality genetic material. These local stakeholders are also generally interested in multiple species beyond commercial species. Thus, it is important to develop participatory low-input breeding programs that can deliver improved germplasm of multiple species and technical skills to a broader array of these local stakeholders (Lillesø et al. 2011; Graudal 2021). Low-cost greenhouses, propagation chambers and drip irrigation systems enable farmers to grow agricultural crops in dry landscapes (FAO 2020b). Likewise, these innovations can be deployed to operate tree nurseries and plantations and enhance water use efficiency. Smallholder tree production systems are increasingly recognized as reliable sources of timber and other tree products for local to international markets (Midgley et al. 2017). The primary motivation for smallholder tree cultivation is to generate financial returns. Tree domestication is an important innovation to produce quality tree germplasm for smallholders, optimize returns and reduce risks (Page 2021; Leakey 2014; Roshetko et al. 2007; see also **Box 25**). Quality tree germplasm is of particular importance for smallholder systems producing commercial products, to assure those products meet market quality specifications (Lillesø et al. 2018). Effective models of germplasm dissemination are required for tree domestication to improve smallholder income generation (Page 2021). The widespread smallholder adoption of quality germplasm can be achieved through their participation in germplasm supply chains (Roshetko et al. 2007) and domestication activities that develop and exchange improved germplasm among farmers (Cornelius et al. 2010; Leakey et al. 2012; Tchoundjeu et al. 2010). Government, research organizations and development agencies all have vital roles in facilitating smallholder tree domestication programs.

PNG provides a dynamic case study of successful collaboration and integration between farmers, communities, research organizations, community development organizations and government agencies to simultaneously support local livelihoods and the commercial forest sector by cultivating teak of superior genetic quality (see **Box 26**). The program demonstrates that engaging farmers and communities in the process of domestication permits greater stakeholder ownership (Ceccarelli and Grando 2007), providing stronger potential for long-term

Photo 15. Innovative technologies adapted to the conditions of local small-scale nursery operators enables farmers and communities to participate in the production of improved quality germplasm for local use and sale to other stakeholders (© June Mandawali).

Box 25 The domestication of the son tra apple (*Docynia indica*)

Son tra, or the H'mong apple (*Docynia indica*), is a fruit indigenous to South and Southeast Asia. In Viet Nam, it is valued for multiple uses including as a dessert, wine, vinegar and tea. ICRAF, the Vietnamese Academy of Forest Sciences and the Australian Centre for International Agricultural Research (ACIAR), teamed in 2005 to start son tra domestication in the North West region of Viet Nam. The project included tree selection and domestication for yield and quality, a market analysis and the development of value chains for fresh fruits and transformed products.

Over 2,400 trees were screened in 13 locations. Screening involved a sequence of selection processes, first identifying 600 trees with superior fruit yield, then selecting 150 trees with superior fruit appearance, followed by taste trials to identify 10 'candidate plus'[57] trees with high yields, superior morphology, peeling characteristics and taste qualities for fresh fruit consumption; and 20 'candidate plus' trees with high yield, superior fruit morphology and suitable taste for wine production. Son tra propagation trials confirmed a grafting technique success rate of 90% and potential to double current fruit yields. Grafts of selected genotypes have been established in clonal field tests to evaluate performance and adaptability to local growing conditions. Domestication has therefore helped identify genotypes that could be propagated as clones to improve son tra market potential. In parallel, a value chain and market analysis was conducted that revealed the potential for market expansion.

The improvement of genetic material, as well as the development of market opportunities helped support the adoption of son tra as part of agroforestry systems that contribute to the reduction of soil erosion from steep areas and improve incomes and livelihoods of smallholders in the Northern region of Viet Nam. A study over a period of seven years comparing agroforestry systems with son tra or longan (*Dimocarpus longan*) to monocultures confirmed that agroforestry systems generate higher average annual income while enhancing ecosystem services, water and soil conservation, soil fertility, and resilience to extreme weather events.

Sources: Tiep et al. (2018), Do et al. (2020).

sustainability in the absence of institutional funding for tree breeding (Page 2021).

Planting material must also be adapted to the intended production objectives of the tree planting enterprise. For timber production, these objectives could include: tree (log) height and diameter; straightness and wood density; chemical composition (e.g. low lignin for improved pulp production, high lignin for bioplastics production); or other specific characteristics such as high latex production for rubber. For commercial species, genetic material may have already been identified or bred for these specific objectives. For example, different lines of rubber clones have been developed for latex yield and timber production (see **Box 27**). The genetic diversity and superiority of specific production or product traits in existing populations can be further captured through selection and formal breeding. Additionally, biotechnology can be utilized to develop genetically modified genetic material matching specific objectives. China, India and Viet Nam are all developing genetically modified material for priority commercial species to support the forest industry sector, strengthen SFM and reduce GHG emissions. Genetic exploration and collection, tree breeding and biotechnology programs require time commitments, technical capacity and financial resources. Collaboration between individuals, organizations and within the region is a strategic option to generate the greatest genetic and financial gains from the combined resources available. The emerging strategy of 'tree diversity breeding' combines existing plant breeding methods in response to different priorities, providing a systems approach that addresses a broad set of

57 'Candidate plus' trees are those that will be used for future tree improvement programs based on their clonal and progeny performance.

Box 26 Development and deployment of teak germplasm in PNG

A teak improvement program in PNG involved the participation of the Forest Research Institute (FRI), the University of Natural Resources and Environment (UNRE), the Organisation for Industrial, Spiritual and Cultural Advancement (OISCA, a local NGO), research organizations and local communities. This approach promoted scientific rigor and maximized the potential of technology adoption. Teak improvement in PNG was based on provenance introductions,[58] phenotypic selection and vegetative propagation. Activities included: (a) the establishment of provenance trials (UNRE, FRI) and provenance plots (OISCA and farmers); (b) the clonal capture of candidate plus trees (29 selections); (c) the identification and clonal capture of phenotypic selections in three mature stands (18 selections); and (d) the early selection and clonal capture of candidate individuals from within provenance trials (21 selections). Two clonal archives comprising clonal hedges were established to preserve and replicate the selected individuals. From these archives, a new clonal seed orchard was established on secure government land, and two clonal test trials were established (UNRE and OISCA) to assess the performance of the 21 phenotype selections. The clonal propagation of selected trees was based on the potential to capture non-additive genetic variation[59] as well as to avoid the limitations of teak's slow reproductive maturity and low seed production and viability (Kjaer et al. 2000). The mean annual stem growth of selected trees is 12.5% greater than that of unselected stock.

Farmer growers were provided with seed and seedlings of known provenance, as well as training in woodlot management and identification of the attributes of a good timber/seed tree. This enabled the deployment of seed to growers at the same time as the more formal improvement activities described above. This was important to satisfy household demands for seed, develop capacity to manage nurseries and woodlots and establish local distribution networks for improved seed/clones. Lead farmers were engaged with a view to building their skills in assessing woodlot quality (Page et al. 2016a, 2016b).

Farmer teak woodlots of known provenances were established through low cost bare-root seedling production on family land. The technology was adopted widely, with 38 community nurseries distributing seedlings within their communities. Through this process, 280 farmers planted 22,000 seedlings with the source provenance recorded, while an additional 8,000 seedlings were planted by outside groups. While the rate of adoption may be considered modest, the independence of the growers in establishing these woodlots without cash or other incentives offers a sustainable model for scaling out when local germplasm supply increases.

When woodlots were five to six years old, some trees were 20 cm diameter at breast height (DBH). Tree owners were approached by village-based portable sawmill owners to cut the trees for sale. Demand for teak thinnings was significant, with posts sold down to an over-bark small end diameter (SED) of 9.0 cm (mean SED of 15 cm). The posts were sold on a linear meter basis for USD1.42/ linear m which equated to USD 123 to PGK[60] 493 m^{-3} (Jenkin 2019a). This shows the very high demand for timber in the region and demonstrates an avenue for commercial thinning. For final harvest, most landholders are willing to wait until the trees attain a commercial size of around 40 cm (~12–15 years). A community teak estate of 174 ha will satisfy timber demand for local house construction in 20 years (Jenkin 2019b). This will reduce pressure on remaining local forests. The commercialization of smallholder teak timber will however, require reforms to existing legislation and policy to enable smallholders to legally market timber derived from their woodlots (Jenkin 2019c).

Tree improvement and the equitable distribution of quality germplasm is an important innovation. In PNG, a base population of genetically diverse teak has been established with institutions and smallholder growers. This forms the foundation for the selection and improvement of teak germplasm, with local networks in place for germplasm distribution to smallholder growers. Smallholder teak plantings are already producing durable posts for the construction of local outbuildings. The timber produced at final harvest will enable the construction of permanent structures. This will improve livelihood outcomes for families that currently have limited access to timber. The wider adoption of teak planting can also reduce regional dependence on timber extracted from natural forests and create opportunities for sustainable domestic commercial timber supply.

Source: Page (2021)

Box 27 Clones for latex or for wood: tree breeding in the Malaysian rubber sector

Rubber *(Hevea brasiliensis)* is among the five most important tree commodities in the world. Although native to Brazil, rubber has been cultivated in Malaysia for over 130 years. The national rubber estate is approximately 1.2 million hectares, predominantly owned by smallholder farmers with less than 2.5 ha per family. The Malaysian rubber industry originally focused on latex production. Originally, old trees were cut, burned in the field or utilized as wood fuel when their economic productivity declined. To expand economic opportunities for rubberwood, the Rubber Research Institute of Malaysia (RRIM) initiated research on rubberwood properties and potential in the 1980s. Research success led to the development of the Malaysia rubberwood furniture industry in the 1990s. The RRIM conducted extensive breeding research to develop rubber clones yielding greater amount and better-quality latex. High-yield clones including the RRIM 600 and RRIM 900 series not only benefitted Malaysia but were also disseminated to Thailand and countries in Africa and Latin America. Thailand is the largest producer of rubber in the world: RRIM 600 clones are cultivated over 60% of its rubber estate. As the lucrative rubberwood industry and markets expanded, demand evolved for high-yielding genetic material. The RRIM, since restructured as the Malaysian Rubber Board (MRB), diversified its breeding program to develop clones for wood production. The new clones yield high-quantity latex, while simultaneously producing larger-diameter and more spherical stems. The best performing latex timber clones (LTCs) are the RRIM 2000 and RRIM 3000 series. LTC are widely planted by farmers and plantations who want to diversify production and market risks.

Source: Harun (2021).

global challenges, including participatory governance and management, environmental restoration, biodiversity conservation, harnessing biotechnology, demand for tree and forest products, livelihood enhancement, and private sector engagement (Graudal et al. 2021).

While germplasm production and dissemination innovations provide broad positive environmental, social and economic impacts to society, there are some potential disadvantages. Genetic improvement programs require time, capital and technical expertise. As a result, genetic improvement activities may be restricted to a limited number of species, with a majority of the selected species being those of commercial value. Species of local importance may not be prioritized. This can lead to limitations in the number of species that are effectively used. There are also risks of a reduction in genetic intraspecific variability, which should be addressed with appropriate conservation plans for genetic diversity. Given the costs of genetic improvement, its benefits could be reserved to actors that have sufficient financial and human capitals unless there are mechanisms in place to facilitate broader use. Improved-quality germplasm is often of limited supply and expensive, which could restrain access by farmers and communities. Additionally, access to genetic material developed by private companies or individuals could be restricted by IPRs.

3.7 Creating employment and livelihood opportunities

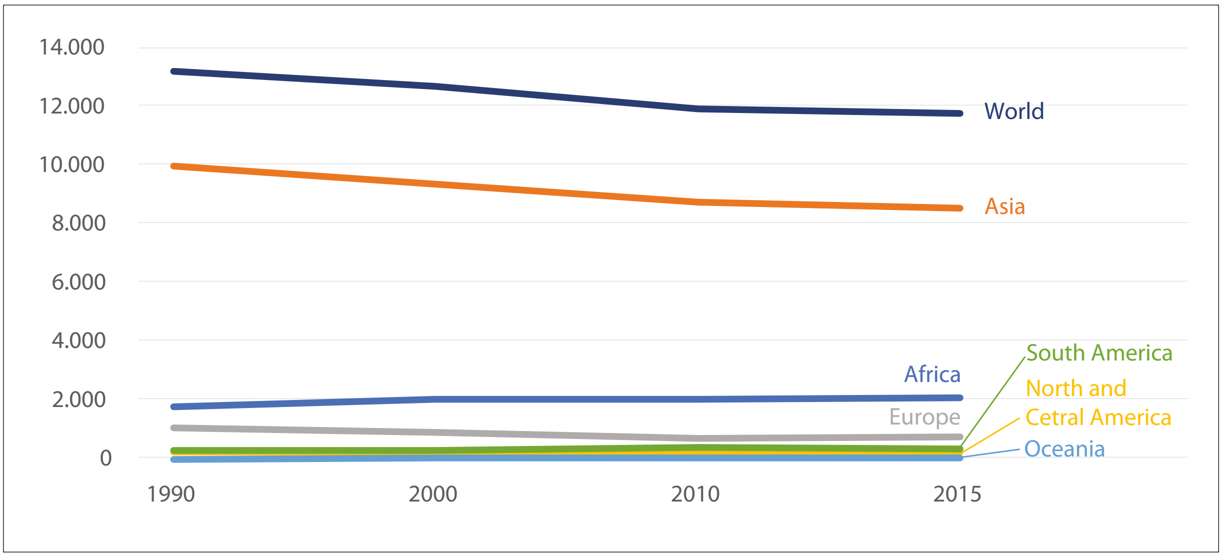
Employment in the forest sector has been on a global decline since the 1990s. Asia has followed the global trend, while the forest sector in Oceania has experienced a large employment gain during this period (see **Figure 8**). The trend in Asia was precipitated by a decline in China, where employment in the forest sector has more than halved between 1990 and 2015 (FAO 2020a). Innovative technologies can provide new products and services, improve productivity and reduce costs, thus generating new employment opportunities

58 The introduction of genetic material from specific provenances

59 Non-additive genetic variation results from interactions between genes.

60 Papua New Guinea Kina (currency)

Figure 8. Number of people employed in forestry and logging (x1000 Full Time Equivalent - FTE)



Source: FAO (2020a).

and the development of new 'skilled jobs' such as drone operators, ICT operators and adaptors, data collectors and analysts, value chain and e-commerce entrepreneurs. Many of the innovative technologies also improve working conditions and worker safety. This is particularly relevant in the forest management, harvesting and wood processing sectors, where working conditions can be particularly dangerous. There is also considerable potential for green technologies that enhance employment and livelihoods. Innovative, safer and greener jobs can help make the forest sector more productive, ecological and attractive, particularly for youth, who are the forest managers of tomorrow.

However, automation and efficiencies associated with digital technologies, improved forest monitoring and management, wood harvesting and processing and product manufacturing can lead to the loss of existing semi-skilled and unskilled jobs (FAO 2019). This might marginalize traditional practices and negatively impact people involved in traditional labor-intensive management systems, who have limited human or financial capacity to adapt. The innovative jobs generated by technologies might benefit external people with advanced skillsets rather than local communities, exacerbating social inequalities. The choice of technologies to be deployed must therefore be adapted to local conditions (specifically, labor market, level of education, skills and capacities), and the potential social impacts of technology adoption must not be overlooked. This trade-off – technology improving productivity and efficiency but potentially reducing employment for local labor – requires the consideration of all economic, social, and environmental implications. To reinforce community ties and retain forestry as an attractive career path, the forest sector and individual employers should foster capacity building and encourage recruitment in local areas. This could include raising awareness of opportunities and providing subsidized or free training in rural areas.

Emphasis also should be placed on generating jobs in local and equitable economies. In areas of fast-paced technological advancement, the adoption and uptake of innovative technologies should be commensurate with capacity building efforts at all levels, most notably in local communities. This is important as technologies may expand quickly while capacity often lags behind. Local infrastructure and financial resources may also be limited, requiring external support and funding to enable communities to access opportunities related to innovative technologies. Besides technical capacity building, other types of capacity may be necessary. Communities and individuals will be required to engage with the new economies in ways previously uncommon. Organizational and leadership capacity will be essential. The translation of technology operation guidelines and manuals to national and local languages is essential to facilitate uptake. Additionally, with geospatial and ICT technologies, training in the use of technologies will need to be matched with investment in compatible hardware and software packages.

A principle of some forms of innovative finance is to maintain or create employment for local communities with targeted investment. This is specifically true for blended finance, green and social bonds, and impact investment. With these funding innovations, budget allocations can be earmarked to enhance community capacity. Consistent with this concept is a preference for developing small- and medium-sized enterprises (SMEs) over large-scale facilities, as SMEs support more employment, while large-scale operations trend towards automation. Attention should also be given to identifying complementarity and synergies between innovative scientific technologies and indigenous knowledge and technologies (Urzedo et al. 2022; HLPE 2019); the latter is often efficient and less costly under local conditions.

Of the new operational and data interpretation jobs to be created, not all will require a high level of formal education, practical technical training may be enough. Rural residents who are familiar with local forest conditions and accustomed to handphone-level technology may offer an attractive combination of appropriate skills to assume field-based jobs associated with innovative technologies. In most cases, the technology skills gained in these jobs will be transferable to other sectors, thus creating a capable cadre of trained residents. The transformative change associated with innovative technologies can bring disruption to the employment market, but not all disruption may be negative. New economies are likely to contain multiple new value chains for diverse forest products and services. Policy and capacity building investment in diversifying production and marketing systems will strengthen local livelihoods and the provision of ecosystem services (HLPE 2019). The net result on employment could be positive. Local entrepreneurs opting to engage in these new value chains could be rewarded with lucrative self-employment. Individuals and communities selling wood or NWFPs, can develop new and innovative e-commerce value chains. Such links can create business opportunities, enhance knowledge of markets and customers, reduce commissions and transaction costs, and improve margins on product sales. In these cases, training and capacity building in value chains, marketing, and small business operations will be beneficial.

The new jobs and opportunities elucidated above should be particularly attractive to young professionals and rural youth. Young people in general are familiar with and proficient in the use of technology (Dutta et al. 2020), and many are interested in conservation and improved environmental management. They are the most suitable people to build and service ‘innovative rural economies’ that offer safe, green, modern employment opportunities, superior to minimum wage labor or service employment in urban and peri-urban economies where the cost of living is high. Emphasis should be placed on inspiring and attracting young people to the new jobs generated by innovative technologies. Additionally, consideration should be given to women, ethnic minorities and marginalized groups to assure equity of opportunities. This inclusivity will benefit the new economies and sustainable management, as these groups often have unique knowledge and experience with resource use and the management of natural resources. In Nepal, the livelihood opportunities and other social impacts generated by CF are specifically intended to benefit marginalized groups (see **Box 28**).

3.8 Considering all potential impacts of innovative technologies

As shown above innovative technologies have benefits that most often generate more positive than negative impacts, justifying their adoption. However, it is important to consider all potential consequences in various domains and on all categories of stakeholders. Such evaluation and precautions will limit negative impacts. It will also help to facilitate adoption and scaling up by mitigating potential opposition from stakeholders who can be exposed to negative impacts from the adoption of innovative technologies.

When considering the adoption of innovations, it is essential to consider not only the main objectives for their adoption but also all of their potential impacts, potential synergies and trade-offs with other objectives. This can lead to the broader adoption and scaling up of environmental and social safeguards or, as appropriate, to design compensatory or accompanying measures, such as training plans for laid-off workers or support to enable small enterprises to adopt the technique and avoid being left behind big companies.

The key expected positive and potential negative impacts of innovative technologies by technology categories presented in **Chapter 2** are summarized in **Table 5**, along the three dimensions of sustainable development (economic, social and environmental).

Box 28 Social impacts of community forestry (CF) in Nepal

In Nepal, there has been broad adoption of CF since it was introduced in the 1970s. Over 30,000 CF users' groups (CFUGs) currently exist. Membership and interest in CF are high, with nearly half the country's population – approximately 14 million people – involved in CFUGs. These groups are responsible for managing 43.1% of the national forest area, or approximately 2.57 million ha. Sustainable management by CFUGs is one factor credited with expanding the country's forest area by almost 3.0% between 1986 and 2015, an increase of over 435,000 ha.

In the early 1970s, it was predicted that community management would result in degradation and a decline in the supply and growing stock of forest products. Successful piloting shifted this thinking. By the 1980s, CF was seen as a means of halting forest degradation. Studies have documented that CF enhanced the sustainable flows of forest products due to improved management and condition of forest resources. Additionally, the legal reform in forest management, such as through the 1993 Forest Act, have improved community entitlements and their ability and willingness to adopt SFM.

CFUGs have created new social forums that facilitate community-level development planning, strengthen social structures and social cohesion. This has evolved into networks and institutions that enable collective actions from community to national levels. The benefits of social cohesion vary by households and individuals but, in general, community members enhance their knowledge on forest use rights, which leads to more opportunities for securing livelihoods. Involvement in CFUG planning and management improves the human capacity and confidence of community members, further strengthening their ability to secure livelihoods.

Revenue generated from forests, based on the management plans prepared by the CFUGs, is primarily used to improve forest management and enhance community infrastructure or services. Common priorities for these investments include forest protection, forest restoration (nurseries, plantations), drinking water systems, the construction and maintenance of rural roads, school facility maintenance and development, teacher salaries, the construction of community halls or temples, and community electrification. Generally, these investments reach all community economic classes equally. However, a greater flow of benefits may reach community elites. Concerns that poorer and marginalized households may not benefit from CF are common but unfounded in most cases, as CFUGs generally comply with requirements that 35% of financial resources be focused on uplifting poor and marginalized groups (e.g. women and Dalits). Some community forests generate larger amounts of income based on marketable forest products and a nearby market. Timber and non-timber forest products such as pine resin are common commercial products. In some cases, these funds are used to develop micro-credit schemes to provide financial access at affordable interest rates to CFUG members for income generating activities.

Household livelihood opportunities are a key measure of social impacts enabled through CF. Studies have documented a number of direct household income-generating activities established through the community forest management plan, often prioritized for the poorer households. These commonly include the collection and sale of firewood and medicinal herbs, beekeeping, goat rearing, and employment as forest guards, fire watchers and caretakers of tree nurseries. Additionally, CFUGs support household income generation by: (i) supporting the identification and development of SFM activities that support livelihoods (either products for household use or market sales); (ii) capacity building and training in response to livelihood opportunities; (iii) coordinating the livelihood support activities of government agencies or other stakeholders; (iv) creating forest product- and service-based enterprises and marketing opportunities; and (v) developing micro-credit schemes to operationalize forest-based enterprises and marketing opportunities.

These opportunities and successful case studies do exist, but their potential is not being fully explored in most communities. This has been a perennial shortcoming of CF in Nepal, which is linked to the weaknesses and challenges summarized in **Box 18.**

Sources: Sapkota (2021), Dev et al. (2003)

Table 5. Key positive and negative economic, social and environmental impacts of innovative technologies by technology cluster

Technology cluster	Economic impacts	Social impacts	Environmental impacts
Digital technologies	**(+)** Enable efficient, accurate, cost-effective, real-time monitoring of forests, ecosystem services, and the threats they face **(+)** Facilitate precision management of forests and value chains. **(+)** Improve productivity and profitability	**(+)** Facilitate data collection and analysis as well as information sharing, empowering all stakeholders, particularly local communities and marginalized groups **(+)** Enable citizen science initiatives **(+)** Enhance transparency and participation in monitoring and reporting **(+)** Generate new skilled job opportunities, making the forest sector more attractive **(-)** Can lead to the destruction of local unskilled jobs	**(+)** Allow more reactive, flexible and efficient conservation strategies **(+)** Support forest landscape restoration (via monitoring and information sharing) **(+)** Track illegal activities **(-)** Can increase the risk of overexploitation and degradation of natural ecosystems
Biological technologies	**(+)** Improve productivity and profitability **(+)** Provide high-quality genetic material for multiple uses **(+)** Contribute to the development of a circular bioeconomy	**(+)** Increase traceability and transparency along forest product value chains **(-)** Can maintain or increase inequalities, further marginalize the most vulnerable groups and limit their access to natural resources and improved material **(-)** High costs may limit access by smallholders further increasing social inequalities	**(+)** Track illegal activities that threaten protected species **(+)** Contribute to the development of a circular bioeconomy **(-)** High costs may limit application to a small number of commercial species, reducing diversity **(-)** Genetic improvement may reduce intraspecific diversity **(-)** Access to improved genetic material and biotech products can be restricted by inappropriate IPR legal and regulatory frameworks **(-)** Can lead to unexpected collateral damage to natural ecosystems and biodiversity
Technical innovations (processes and products)	**(+)** Reduce operational costs **(+)** Reduce waste and increase resource use efficiency **(+)** Improve productivity and profitability **(+)** Provide new products and services or develop new uses for forest products **(+)** Contribute to the development of a circular bioeconomy (-) Direct and indirect costs of adoption (equipment, loss of productivity, training, etc.)	**(+)** Generate new skilled job and new income opportunities, making the forest sector more attractive **(-)** Can lead to the destruction of local unskilled jobs **(-)** Can maintain or increase inequalities, further marginalize the most vulnerable groups and limit their access to natural resources	**(+)** Increase wood recovery rate, thus reducing pressure on natural forests **(+)** Contribute to the development of a circular bioeconomy **(-)** Can increase the risk of overexploitation and degradation of natural ecosystems

Innovative finance and social innovations	**(+)** Improve smallholder access to credit and market **(+)** Facilitate resource mobilization and investments in the forest sector **(+)** Support livelihoods and enterprise development	**(+)** Support the livelihoods and resilience of local communities **(+)** Enhance traceability and transparency **(+)** Support capacity building and awareness raising **(+)** Foster participation in decision making, empowering local communities, farmers and marginalized groups **(+)** Enable innovative and inclusive governance and investment models **(-)** Can be captured by local or external elites and perpetuate inequalities	**(+)** Contribute to SFM (e.g. community-forest management) **(+)** Support forest landscape restoration (through local empowerment and access to financial resources)

Note:(+) denotes positive impacts, (-) denotes negative impacts

Source: elaboration of the evidence provided in Chapter 2 and Chapter 3

4. Enabling the uptake and scaling up of innovative technologies for sustainable forestry

The aim of this chapter is to identify, understand and address the technical, economic and social barriers preventing the uptake and scaling up of innovative technologies in the forest sector in the Asia-Pacific region. This chapter also considers the institutional changes needed in forest sector governance (land planning, land tenure and other relevant development policies) to overcome these barriers and support the uptake and scaling up of innovative technologies in the region and to ensure that these technologies can effectively contribute to SFM. Regional cooperation, investment, infrastructure development, education and capacity building are key to supporting technology transfer and dissemination and accompany the populations at risk of being marginalized by these technological advances. This chapter provides insight and discussion towards such collaboration.

4.1 Innovation in Asia and the Pacific

All sectors combined, the Asia-Pacific region holds an important and rapidly increasing potential for innovation. However, while Asia-Pacific is catching up and quickly becoming a leading region for innovation, huge discrepancies remain across countries and territories within the region. These are illustrated below.

Innovation is often associated with economic growth and urbanization that facilitate the birth of strong science and technology (S&T) clusters. Over the past decades, Asia has been quickly urbanizing, and this trend is expected to continue. The urban population ratio has increased from 17.5% percent in 1950 to 49.9% in 2018 and is expected to reach 66.2% by 2050 (UNDESA 2019d). According to the World Bank World Development Indicators (WDI) database,[61] between the 2008–2009 financial crisis and the COVID-19 pandemic, the average gross domestic product (GDP) annual growth rates in East Asia and the Pacific (4.6%) and South Asia (6.3%) were two to three times the average growth rates experienced at the global level (2.9%) or in OECD countries (2%). This rapid economic growth is partly driven by large emerging economies, while other countries of the region have been left behind. In 2017, China dethroned the USA as the world's largest economy.[62] India, currently in third position, could surpass the USA before 2040, and Indonesia has entered the top 10. These countries are also progressively closing the gap in terms of GDP per capita.

Altogether, Southeast Asia, East Asia and Oceania form the world's third most innovative region just after Northern America and Europe. According to the World Intellectual Property Organization (WIPO), 11 of the top 20 offices for patent applications in 2018 are situated in the Asia-Pacific region (WIPO 2019b). The WIPO notes that knowledge creation is spreading to more and more countries and that new players, particularly Asian countries, are responsible for more and more scientific research and inventions (WIPO 2019a). The Global Innovation Index (GII), developed by Cornell University, INSEAD and the World Intellectual

61 See: https://databank.worldbank.org/reports.aspx?source=world-development-indicators [accessed 10 September 2021]

62 When GDP is expressed in purchasing power parity (constant 2017 international dollars). See WDI database.

Property Organization (WIPO) during the past decade, provides a very comprehensive view of the innovation potential and performance of 131 economies, covering 93.5% of the world population and 97.4% of the gross world product (Dutta et al. 2020). The GII, a composite indicator that ranks the innovation performance of global economies on an annual basis, highlights innovation strengths and weaknesses and particular gaps in innovation metrics. The GII comprises roughly 80 indicators grouped into seven thematic pillars and two sub-indices, including measures on the political environment, education, infrastructure and knowledge creation of each economy.[63] It is used by policymakers to develop national economic strategies and is recognized by the United Nations General Assembly (UNGA) as a yardstick to measure innovation in reference to the achievement of SDGs (see **Box 1**). The GII is also used by national governments to design appropriate innovation and intellectual property policies. The index provides impetus for governments to prioritize innovation and collect data on relevant innovation metrics (Dutta et al. 2020).

The latest GII ranking, even if still largely dominated by high-income countries in Europe and Northern America, confirms a progressive shift in the global innovation landscape from high-income to emerging economies in Asia. In 2020, the Republic of Korea joined Singapore in the top 10 for the first time, while Hong Kong (China) reached 11th position. Four countries, all situated in Asia and the Pacific, have experienced the most significant progress over time in their GII ranking: China (14th), Viet Nam (42nd), India (48th) and Philippines (50th). In total, 12 Asia-Pacific countries and territories appear in the top 50 (see **Figure 9**).[64] Some Asia-Pacific countries still do not rank in the top 50 but show encouraging results on some pillars,[65] with the potential for further progress in the future in terms of capacity development and innovation uptake and scaling up. On the other hand, some countries in the region still lag behind, and some are not yet covered by the GII exercise (Dutta et al. 2020). Overall, these metrics reinforce the perception that the Asia-Pacific region is well positioned as a burgeoning source of innovation.

The GII uses the average score of the top three universities in the QS world university ranking[66] (GII indicator 2.3.4) as a proxy for the quality of the tertiary education system in an economy. China is in third position for this indicator, after the USA and the United Kingdom (UK). Four other economies in the Asia-Pacific region appear in the top 10: Hong Kong (China) (fifth), Australia (sixth), Japan (eighth) and the Republic of Korea (ninth). Singapore follows in 12th position (Dutta et al. 2020). The GII also reflects school enrollment in tertiary education (GII indicator 2.2.1). According to the WDI database,[67] the fastest progress on this metric over the past decade occurred in Asia and the Pacific. Between 2010 and 2019, the tertiary school enrolment rate increased by almost 70% in East Asia and the Pacific and by almost 60% in South Asia. In comparison, it increased by about 30% globally and by just 10% in OECD countries. Nevertheless, this effort must continue because these two regions still lag far behind OECD countries (74%) in terms of tertiary school enrolment (47% and 25% respectively in 2019). Gross R&D expenditures (expressed in percent of GDP, GII indicator 2.3.2) can be used as a proxy of the effort consented by an economy to foster innovation. Using this metric, the Republic of Korea ranks second,

63 Namely: (i) institutions, (ii) human capital and research, (iii) infrastructure, (iv) market sophistication, (v) business sophistication, (vi) knowledge and technology outputs, and (vii) creative outputs. The first five pillars form the 'innovation input sub-index' and the last two the 'innovation output sub-index'. The full dataset, detailed by indicator and by economy, is accessible online at: https://globalinnovationindex.org/analysis-indicator [accessed 10 September 2021]

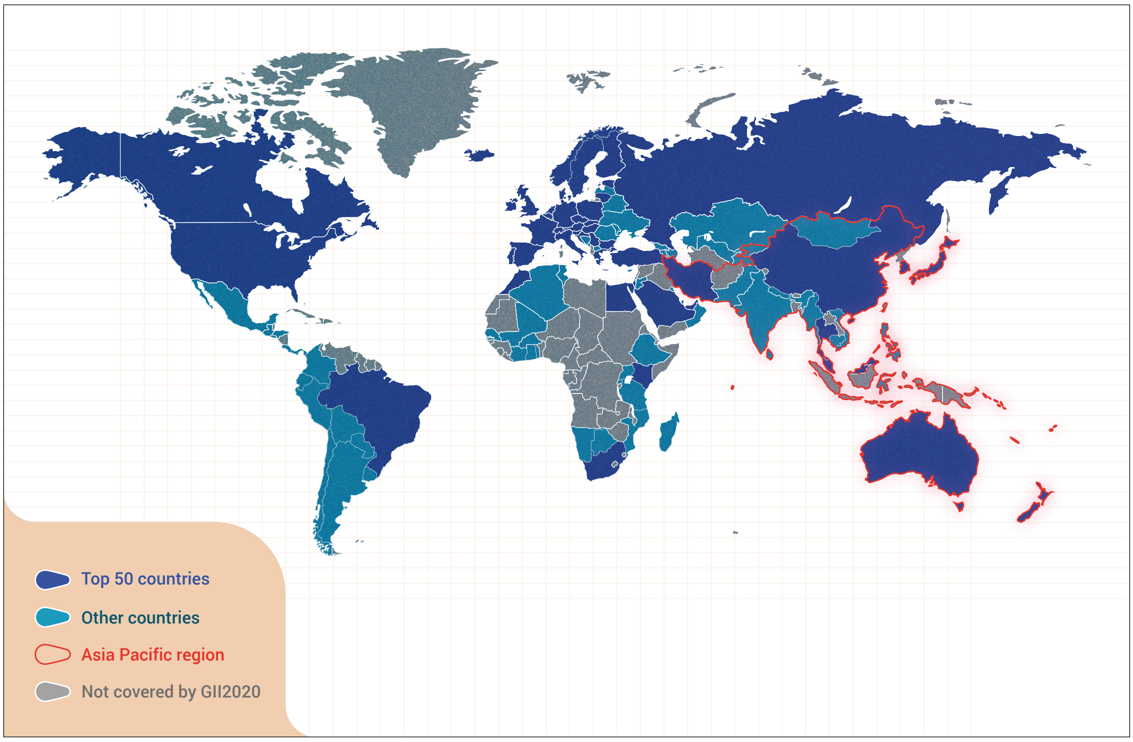
64 i.e.: Australia, China, Hong Kong (China), India, Japan, Republic of Korea, Malaysia, New Zealand, the Philippines Singapore, Thailand and Viet Nam.

65 Such as Mongolia (58th), the Islamic Republic of Iran (67th), Brunei Darussalam (71st), Indonesia (85th) or Nepal (95th).

66 See: https://www.topuniversities.com/university-rankings/world-university-rankings/2021 [accessed 10 September 2021]

67 Based on data from the UNESCO Institute for Statistics: http://data.uis.unesco.org

Figure 9. Global Innovation Index (GII2020): top 50 countries



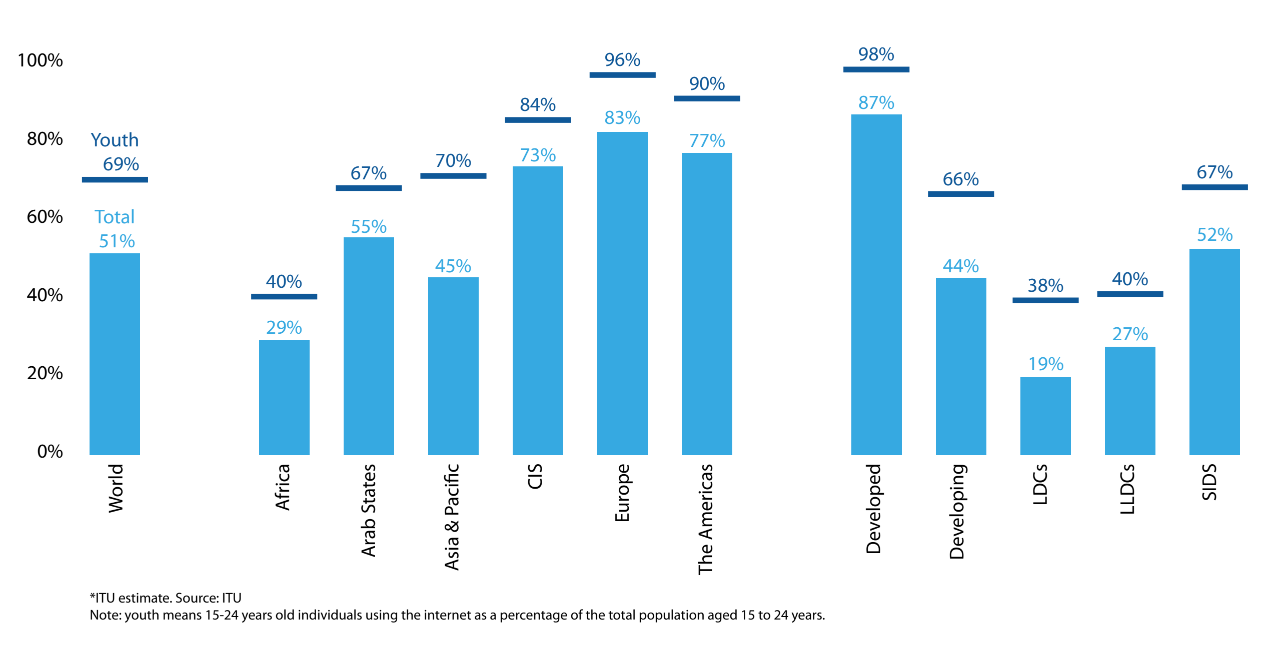
Source: Authors' elaboration based on data from Dutta et al. (2020)

just after Israel, with Japan in fifth (Dutta et al. 2020).

To complement the GII, Dutta et al. (2020), following a 'bottom-up' approach based on local geolocated data about patents and scientific publications, identifies the most vibrant S&T clusters, i.e. the geographical areas showing the highest density of inventors and scientific authors, regardless of administrative boundaries. They publish a list of the world top 100 S&T clusters each year. Notably, the four first clusters are all situated in Asia: Tokyo–Yokohama, Shenzhen–Hong Kong–Guangzhou, Seoul, and Beijing. Six of the top ten clusters are in Asia. The S&T intensity (or quality) of each cluster is assessed by dividing the number of patents and scientific publications by the local population. Using this metric, the UK and the USA still dominate the top 10 with seven clusters, while only one cluster, Daejeon (Republic of Korea), is located in Asia.

High internet connectivity is an indicator of effective access to information and facilitates the dissemination and adoption of innovative technologies. At the global level, almost all (95%) of the urban population is covered by a 4G mobile network. However, many discrepancies subsist between developed and developing countries. Rural areas still lag behind more connected urban areas, particularly in low-income countries. In the least developed countries (LDCs), 17% of the rural population have no mobile coverage at all, and 19% are covered only by a 2G network. With 94.2% of its total population (100% of its urban population and 89% of its rural population) covered by a 4G mobile network, the Asia-Pacific region has a similar level of coverage to that of developed countries: 97%, 100% and 86% respectively (ITU 2020). The capacity of the population to use the internet is as important as mobile network coverage. Important discrepancies exist across age classes and genders. In 2019, 51% of the world population was using the internet, including 69% of youth aged 15–24; 55% of the male population and only 48% of the female population. In Asia and the Pacific, these figures are 45%, 70%, 48% and 41% respectively (see **Figure 10**). The gender gap decreases with the level of development: in developed countries, both male (88%) and female (86%) were using the

Figure 10. Percentage of individuals using the internet in 2019*



Source: ITU (2020).

internet in 2019, whereas in the LDCs, these ratios fall respectively to 28% and 15%. In Asia and the Pacific, 60% of urban households but only 36% of rural households have internet access at home, compared to 87% and 81% in developed countries respectively, and only 25% and 10% in the LDCs, but these figures mask important disparities across countries in the region. In fully connected countries and territories,[68] over 85% of the households have internet access and a vast majority of people (over 75%) use internet. A second group of countries, including Indonesia, Viet Nam, Cambodia, and Brunei Darussalam, already have high levels of internet access and could attain full connection in the near future. In the remaining countries of the region, however,[69] improving access to the internet should be a major priority to support access to information, credit and markets, capacity development, technology transfer, innovation uptake and scaling up. A lack of ICT skills, as well as the high cost of ICT services, remain a significant barrier to the meaningful digital participation of the most vulnerable groups (e.g. elders, women, rural populations and the poor) (ITU 2020).

More specific global and regional data on innovation and related enabling factors in the forest sector are scarce and often incomplete. However, the last FAO Global Forest Resources Assessment (FRA2020: FAO 2020) collects national data on the number of students graduating from post-secondary education programs focusing on or related to forests. The data covers 119 countries and territories representing 86% of the current global forest area in 1990, 2000, 2010 and 2015.[70] Students graduating today will support and implement the uptake and scaling up of innovations in the forest sector of tomorrow. Globally, these data show a substantial increase in the number of forestry graduates, which more than doubled at all levels of education between 2000 and 2015. To facilitate cross-country comparison, the

68 i.e.: Australia, Hong Kong (China), Islamic Republic of Iran, Japan, Republic of Korea, Macao (China), Malaysia, Maldives, Singapore and Thailand.

69 In the following countries, less than 25% of the households have internet access at home and/or less than 25% of the population is using the internet: Bangladesh, India, Lao PDR, Myanmar, Pakistan, the Philippines and Samoa.

70 For each year, the figure given is based on the average observed over a three-year period.

FRA2020 expresses the number of students per million ha of forest. Asia has the highest ratio by far, with 336 forestry students per million ha in 2015, compared to the world average of 95. Oceania has the lowest ratio, with 4 students per million ha.[71] However, these figures mask important disparities within each region. The very high ratio observed in the Republic of Korea (613 students per million ha) and Viet Nam (504 students per million ha) show the importance given by these countries to innovation and sustainable management in the forest sector. Other countries in the region, show encouraging performance, with a ratio above the world average level, including: Bangladesh, Indonesia, the Islamic Republic of Iran, Nepal and the Philippines.

The International Union of Forest Research Organizations (IUFRO) is a non-profit and non-governmental international network of forest scientists seeking to interconnect forests, science and people, and strengthen global cooperation in forest-related research. Established in 1892, the network now unites over 15,000 scientists in around 650 member organizations in more than 125 countries.[72] The number of IUFRO member organizations in a country can give a sense of the present and future innovation capacity of the forest sector in that country and of its connection with the global scientific community. Twenty-five countries and territories in the Asia-Pacific region count at least one IUFRO member organization. Out of these, six countries or territories host ten or more IUFRO member organizations and are strongly involved in this global research and cooperation network: India, Japan, China, the Republic of Korea, Australia, and Taiwan (Province of China). Six other countries, Indonesia, Malaysia, Mongolia, Nepal, New Zealand and the Philippines, immediately follow with four to nine IUFRO member organizations each (see **Figure 11**).

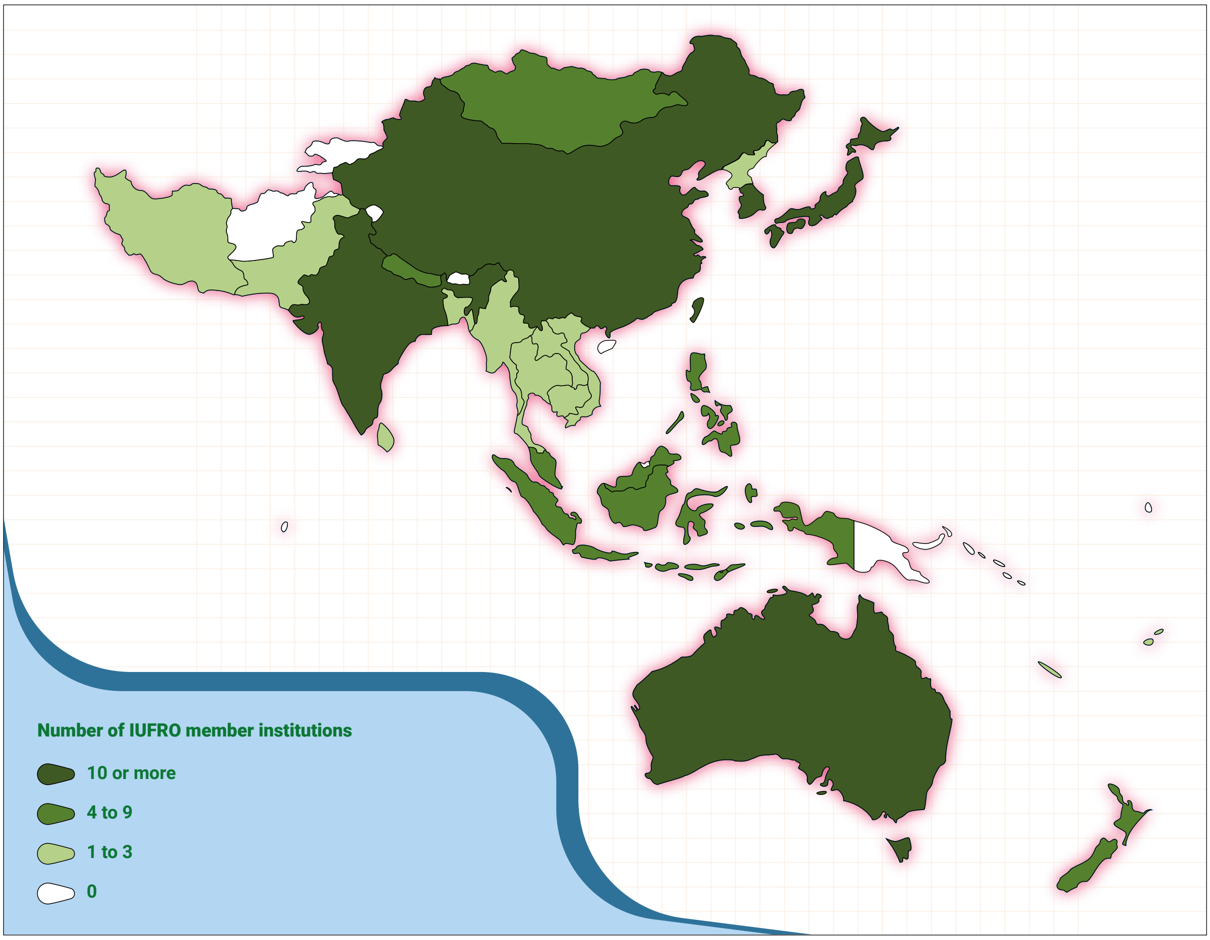
The COVID-19 pandemic has had an unprecedented impact, triggering a global economic shutdown that has slowed many national economies. The crisis hit as research and development (R&D) spending was still rebounding from the financial crisis of 2008–2009, growing faster than global GDP. The impacts of the pandemic on innovation remain under scrutiny. Technology and innovative development continue, particularly in R&D firms in the IT sector, where there is a drive to further enhance digitalization and related technologies, as well as in the pharmaceutical and medical biotechnology sectors. It is anticipated that there will be R&D investment in transportation, clean energy (including bioenergy), tourism, education and retail – all sectors mentioned in this report and that have a direct impact on SFM. However, direct R&D investment in the life sciences is expected to decline. Government investment in R&D has decreased, with some sponsored research efforts slowing to a halt; the exception being R&D support to the health sector (Dutta et al. 2020). This is not a surprise as governments are foremost responsible for the well-being of their citizens and national economies; understandably they have prioritized stimulus packages. The good news is that venture capital (VC) investment remains strong in VC hotspots, specifically China, Hong Kong (China), India, Israel, Luxembourg, Singapore, the UK and the USA (Dutta et al. 2020). Four of these eight hotspots are in the Asia-Pacific region, while two (UK and USA) have strong economic and political links with Asia-Pacific countries and territories. These VC hotspots and their sustained interest in innovation bode well for the region.

In summary, this brief overview shows the very high potential for innovation in Asia and the Pacific economy-wide. However, it should be noted that most of the indicators presented here are not forest-specific and that a country's economy-wide potential for innovation will not necessarily translate in the forest sector. There are also specific constraints that are not well reflected in these indicators that often contain national and urban biases. The Asia-Pacific innovation potential is mainly concentrated in a few countries, with large divides remaining, in terms of innovative capacity, across countries

71 However, some countries provided data only for a few levels of education. As a consequence, aggregated numbers are probably underestimated at global level and in some regions, particularly in Oceania (FAO 2020).

72 See: https://www.iufro.org/fileadmin/material/science/divisions/toolbox/iufro-the-organization-en.pdf

Figure 11. Asia-Pacific countries hosting at least one IUFRO member organization



Source: authors' elaboration based on the list of IUFRO member organizations[73] as of 13 April 2021.

within the region. The indicators reviewed in this section allow the identification of three broad categories of countries and territories:

- The '**innovation tigers'**, show the highest potential and are driving most of the innovation uptake and scaling up observed in the region. This group includes Australia, China, Hong Kong (China), Japan, the Republic of Korea, New Zealand, and Singapore.
- The "**emerging innovators**", mainly upper middle-income to low-income emerging economies, show encouraging performances on some indicators. They are quickly catching up and show promising potential for innovation uptake and scaling up in the coming decades. This group includes: Brunei Darussalam, Cambodia, India, Indonesia, the Islamic Republic of Iran, Malaysia, Maldives, Mongolia, Nepal, the Philippines, Thailand, and Viet Nam. Priority areas to improve innovation capacities can be identified in these countries by focusing on their weakest performances on some indicators.[74]
- The third group includes countries where particular efforts are needed to build upon the assets they have and develop their own innovation potential. International and regional cooperation, including South–South cooperation, will be critical to foster innovation in these countries. The APFC can play a central role in that regards.

73 The list of IUFRO member organizations by country is publicly accessible and regularly updated on their website. See: https://www.iufro.org/fileadmin/material/membership/iufro-members-21-04.pdf [as of 13.04.2021].

74 For instance, huge potential could be unleashed in India and the Philippines by improving internet access, especially in rural and remote areas.

4.2 Key barriers to technology uptake and scaling up

During the technologies workshop, participants agreed that barriers hindering the uptake and scaling of innovative technologies in forestry can be grouped into two main categories: (i) a lack of capacity (e.g. limited access to natural resources, limited access to information, limited access to credit and markets, limited transparency and limited participation in decision making); and (ii) unaligned policies and regulations lagging behind the rapid evolution of technologies and the rapid shifts in wood demand (Pingault et al. 2020). Capacities are broadly interpreted to include conditions that facilitate and enable individuals and institutions to uptake and scale innovative technologies. Restrictive policies and regulations include both specific enforcement that constrain uptake and scaling up or a lack of germane policies and regulations.

A lack of capacity that constrains the uptake and scaling up of technologies includes those related to human, natural, physical, financial and social capital. Limits to human capital include a lack of skills, knowledge and experience with innovative technologies and, in some cases, may involve a wariness regarding innovation. Constraints to natural capital include an actual or perceived lack of access to forests, land, natural resources and their assets and products. Limits to physical capital encompass limited or lack of infrastructure – roads, markets, electrical power, internet, etc. – and of suitable equipment, including equipment and innovations not scaled for use by smallholders, small-scale operators or local communities. Constraints to financial capital include limited access to credit, markets and value chains. Restrictions to social capital include restricted governance and tenure, access and use rights to forests, land and other natural resources and limited access to institutions, networks and information. These different constraints are often combined to restrict innovative technologies uptake and scaling up.

Given the costs of developing and adopting innovations and the fact that innovations are often devised for large-scale ventures, there is a risk that disproportional benefits may go to individuals who are already well endowed with the five forms of capital, increasing their competitive advantage and pushing out smaller actors, who are particularly vulnerable to change. This risk needs to be balanced by public measures facilitating the access of small actors to innovation as well as by incentives to design innovations that are adapted to small scale actors.

This study finds that in some cases, policy development may lack the needed flexibility and reactivity, hence lagging far behind the rapid evolution of technologies. Relevant policies and regulations may be weak, nonexistent or incapable of adequately addressing the conditions fostered by the use of innovative technologies. Existing policies and regulations do not address current conditions because they were codified before current innovations were developed. Unsuitable policies and regulations are applied purposely or out of caution, in a manner restrictive to the adoption of innovative technologies.

Key capacity and policy constraints identified during the study are summarized in **Table 6**.

Many innovative technologies are not scale-neutral. Scaling down innovative technologies may be necessary so that they can also benefit smallholders and marginalized groups, indigenous peoples and local communities, even those with limited human and financial resources and those living in remote areas. Collectively, smallholders and small-scale enterprises are major land managers at the global level and significant suppliers of many forest commodities. Smallholder forest and farm producers, their communities and their families, are estimated to own and/or manage around 65% of the world's land (Verdone 2018). Hence innovative technologies need to be developed, adapted or adjusted specifically to their specific context, priorities and needs. The availability and suitability of the technologies will vary by scale (small to large), species and systems. There are financial and institutional barriers to the adoption and adaptation of the technologies, and thus there is a need for collaboration

Table 6. Key constraints that hinder the uptake and scaling up of innovative technologies

Capital	Constraint
Human capital	Lack of skills, knowledge and experience; wariness of 'new' technologies
Natural capital	Limited access to forests, land, natural resources and their assets and products
Physical capital	Lack of infrastructure – roads, markets, electrical power, internet, etc. – and suitable equipment and innovations to scale technologies to all levels of stakeholders
Financial capital	Limited access to capital, credit, and value chains
Social capital	Restrictive governance and tenure rights to forests, land natural resources and their assets/products, and limited access to institutions, networks and information
Policies	Absent, weak or restrictive legal and regulatory frameworks; inappropriate application or enforcement of those legal and regulatory frameworks

across the financial, industrial, development and government actors.

In other words, technologies should also benefit those who use and manage forests at the local level. Technology development should ensure value addition all along forest value chains and equitable benefit sharing across all stakeholders involved, especially the most vulnerable. To be adopted, a technology must be adapted to the local socioeconomic and biophysical context (e.g. income and education levels, labor market, infrastructure, cultural values, climatic and edaphic conditions). As a result, technology dissemination must follow a decentralized, bottom-up process, starting from local circumstances, priorities and needs and engaging local communities. Upfront costs may be high, with subsequent low operational costs. Investment, access to infrastructure (electricity and the internet) and the modernization of that infrastructure (to assure compatibility with new technologies), education and capacity building will be key not only to facilitating access to innovative technologies but also to supporting workers at risk of losing their jobs because of technology adoption (e.g. older, local, and unskilled workers).

During the inception workshop, participants mentioned that the forest sector can have a traditional 'old school' and conservative mentality that may limit the acceptance of new technologies and methods, in line with studies on innovation in the forest sector (Weiss et al. 2020; Innes 2009). There may be tensions between traditional experience-based field-oriented management and the acceptance of innovations. Committed and patient leadership is required to identify and implement the 'adaptation' of innovative technologies that can improve organizational performance, overcoming institutional inertia and preference for existing practices (Hansen and Breede 2016; Hansen 2010). Thus, besides technical capacity, the successful uptake and scaling up of innovative technologies in forestry and forest management requires clear demonstration of the advantages of the technology (Innes 2009), information and knowledge sharing among stakeholders, and adaptation of technologies to address relevant cultural and governance issues (HLPE 2018). Establishing trust and clear communications regarding the use, advantages and disadvantages of innovations can increase the use and adoption of forestry and agricultural technologies (Wang et al. 2019; HLPE 2018; Martini et al. 2017).

Ownership and IPRs can be a barrier to the development and dissemination of innovative technologies, including when public money is involved in generating those innovations. If IPRs are not clear at the start of technology development, there is the risk of innovations being parked on the shelf until questions of rights and access are settled. In Australia, there have been cases where public or public-supported institutions restricted the IPRs of universities. In some cases, rights have been transferred to private sector entities to make technologies available

(Pingault et al. 2021a). When considering access to land and genetic material, awarding IPRs to private sector entities, universities or other stakeholders should not infringe upon local rights and access to traditional crops and indigenous species (HLPE 2019). Some environmental NGOs have recently suggested a model of responsible governance for biotechnology products that address societal benefits, technology sharing and IPR (Gordon et al. 2021). There have also been private sector measures to transfer technology for humanitarian and environmental purposes and share benefits with outgrowers (Suzano 2021). The development of these arrangements is contextual and benefits from dialogue between the sector, government, research and academia, NGOs, and community actors.

A lot of innovation development and adoption is driven by profitability (Kubeczko et al. 2006). As individual companies are often the developers or modifiers of innovative technologies, they are unlikely to 'share' innovations developed through their own financial investment or that contribute to their profitability and competitive advantage. Adequate incentives will be necessary to encourage private companies to share their innovations. Engagement with corporate social responsibility (CSR) programs can be a conduit for mutually beneficial partnerships linked to technology dissemination.

4.3 Facilitating innovative technologies uptake and scaling up

Innovative technologies are changing many aspects of forestry and forest management, with more potential transformative changes yet to be realized. There is greater technology uptake in plantation forestry to increase productivity and industrial efficiency than in the management of natural forests. Governments and conservation organizations have leveraged innovative technologies to improve forest monitoring, land mapping, the management of land ownership information, reporting and forest governance. Improved internet coverage has enhanced the access to information and participation in forest monitoring, decision-making and governance by rural residents and local communities. However, the rate of uptake of innovative technologies is far from uniform. Adoption and use are highly context-specific, varying greatly across stakeholder groups, within countries, between countries and between sub-regions (FAO 2019).

In many countries, there is no clear strategy to support innovative technology dissemination and adoption in forestry, nor a long-term forestry research and development perspective. Governments have an essential role in supporting R&D and promoting the uptake and scaling up of innovative technologies. Some national governments, such as those of Bhutan, China and Viet Nam, strongly support the adoption and use of innovative technologies in the forest sector (see **Box 38**).

Governments should develop flexible and supportive policies that foster innovation, provide leadership in strategic planning, promote collaboration and coordination across sectors, actors and scales, and facilitate or provide incentives and subsidies in an equitable manner to support the forest sector and the actors involved. This requires foresight and vision, as the deployment of some innovations, particularly those that are transformative and may result in disruptions to the forest sector and negative impacts on employment (Weiss et al. 2020).

To facilitate the adoption of innovative technologies, the following factors should be considered: i) the technology and its characteristics; ii) the adopters, either individuals or organizations (private sector, government agencies, civil society, communities); iii) the larger economic, social and environmental context; iv) the demonstrated worth of the technology; and v) communication and dissemination channels that promote the technology (adapted from Rogers 2003).

Small-scale operators adopt innovations that fit their needs and provide economic benefits (Innes 2009, Song et al. 2004). Cooperating with other firms, large and small, up and down forest value chains, can enable the adoption or adaptation of innovations by small-scale firms (Hansen 2010; Weiss et al. 2020). Portable sawmills are an example of the innovative transformation of a technology for adoption at a small and local scale (see **Box 29**).

Depending on the types of innovations, and on their different uses in specific contexts, different types of stakeholders can play a leading role in promotion and dissemination. Government agencies, large land managers and conservation organizations are well suited to developing, disseminating and scaling forest monitoring and management technologies. These organizations have experience in service provision, technology transfer, awareness raising and capacity building. They also benefit from institutional support. With harvesting, processing, and product innovations, the private sector can play an important role in the development, dissemination and support of technology transfer mechanisms. Smallholders, local communities and support agencies are critical partners for adapting innovative technologies and their dissemination to smaller scales and to meet local needs, priorities and circumstances.

There is no simple answer to the question of what technology needs to be developed and where. For some innovations, government involvement will be essential due to scale and application across a broad jurisdiction. Innovations that are market-, business- or product-oriented require private sector leadership, particularly in addressing issues of industrial productivity and efficiency. Regardless of how or where the technology is developed or adapted, mechanisms are required for effective demonstration and dissemination. Venues for such exchanges can include demonstrations, workshops, field visits, trainings, educational events and visits with industrial partners. Public awareness and support for innovative technology development and dissemination is an important condition of success.

Box 29 Adoption of portable sawmills by local landowners requires capacity building and private sector collaboration

Environmentally unsustainable logging practices by industrial forest companies are often cited as a major cause of deforestation and forest degradation. The involvement of local communities in logging is supposed to be more sustainable and to enhance local incomes. During the early 1990s, PNG attempted to mitigate deforestation and forest degradation by facilitating small-scale forest management by indigenous forest landowners. An 'eco-forestry' approach was adopted, involving selective harvesting of timber combined with the milling of timber by Indigenous forest-landowners using portable sawmills. The lumber produced was sold into local and international markets as sustainable timber, certified under the Forest Stewardship Council (FSC) principles. The use of portable sawmills was also intended to provide landowners a greater financial return compared to the timber royalty payments they usually receive from logging companies.
A study of the six cases of eco-forestry found that all efforts were unsuccessful in developing a financially viable model for the management of forests by small-scale local forest landowners. None of the local landowners were able to continue their portable sawmill operations once donor funding of the eco-forestry organizations ceased. In addition, the operators of portable sawmills struggled to produce lumber that met the quality and quantity demands of buyers, who ultimately ceased to purchase the lumber. Furthermore, the local landowners struggled to adhere to FSC principles, resulting in the loss of FSC certification. The study identifies a need for a new small-scale management model for forest in PNG. Future efforts should include collaboration with private sector businesses and professionally trained operators to inform the development of a small-scale forest management model which is financially profitable while also adhering to the principles of eco-forestry.

Source: Scudder et al. (2018)

Photo 16. Computer simulation developed from the findings of time studies accelerate capacity building and familiarity with innovative harvesting technology (© CMO Group).

4.4 Capacity building, education and training: improving access to information

Access to knowledge and capacity building are key factors for wider acquisition, adoption and utilization of innovations. An emphasis on rural communities, and particularly youth, will ensure that communities are not left behind and made more vulnerable by technological advancement. Youth of both genders are the forest managers of the future. Even in rural areas, they are often technologically savvy. Addressing their interests is a way to keep them in rural economies and engaged in evolving career opportunities that can compete with labor or service employment in distant urban areas.

Besides capacity building in the use and adoption of innovative technologies, training in the safe operation of the technologies will be essential, particularly with process and product innovations, which offer new employment opportunities but can be dangerous to the inexperienced.

Opportunities will also appear as local economies evolve to service forest management and forest industry sectors. Training and skill acquisition will be required in a wide range of areas including institutional management, leadership, language proficiency, the integration of indigenous and technical knowledge, value chains, marketing and small business operations. Experience indicates that scientific knowledge and indigenous knowledge are complementary, and efforts to integrate them are synergistic (Urzedo et al. 2022; HLPE 2019; see also **Sections 3.1** and **3.7**).

In the digital age, and particularly during the COVID-19 pandemic, many opportunities for education, capacity building and access to information will be virtual, including massive open online courses (MOOCs), dependent on internet access. The Asia-Pacific region has fairly strong internet

Photo 17. Women and minorities have unique knowledge and roles in SFM, they should be provided equitable opportunity for capacity building (© James M Roshetko).

access (ITU, 2020), and the region's youth are particularly well skilled to engage in and pursue educational, capacity building and information opportunities available via the internet. However, these opportunities favor urban populations over their rural peers. Government agencies, the private sector, development organizations and all stakeholders should take note of this disparity and offer equitable capacity building and recruitment opportunities in rural areas where they are engaged (see **Sections 3.3, 3.4,** and **3.7**).

Demonstration to show the effect of innovative technologies is key to their successful dissemination and uptake. Successful demonstration requires adequate knowledge of the innovation, of the local and broader context in which it will be deployed, and of the adaptation required to meet local needs. Specialists with these capacities need to be engaged to assist with demonstrations. Government agencies, conservation organizations, universities and research institutions, the private sector, and local communities should also be involved in promoting and demonstrating technologies. The full engagement of stakeholders is important to achieve buy-in by key stakeholder groups and to comprehend the level of interest and demand for the innovation. Demonstrations can facilitate the creation of communities of practice and peer-to-peer (farmer-to-farmer) networks. There is a role for champions (both individuals and organizations) and extension services in demonstrating the innovation. Demonstration farms provide practical examples of the application of innovative technologies for smart farming (FAO 2020b). With commitment and effort, similar 'smart forest' programs could be developed to assist 'young foresters, forest managers and forest sector entrepreneurs' in the Asia-Pacific region.

The agricultural sector provides illustrative examples of online services for information exchange and capacity building regarding innovative technologies. The types of innovations available include digital advisory and digital financial services (access to services), e-commerce and digital procurement (access to markets) and smart farming (access to assets) (GSMA 2020). In the Republic of Korea and Thailand, ICT systems are supporting the training of young farmers who have developed and are operating smart farms that utilize innovative technologies. Smart farmers are able to access production and marketing information and training, support from start-ups and agro-tech entrepreneurs, and capital and incentives (FAO 2020b). An array of digital services is now available to farmers in Myanmar (see **Box 30**). Similar services could be developed for groups of smallholder farmers, community enterprises and SMEs in the forest sector and include farmer–private sector–consumer networks to further support the development of the bioeconomy.

Box 30 Digital services for farmers in Myanmar

Digital agriculture service providers in Myanmar offer a range of services including digital procurement, e-commerce for farm produce, access to assets such as mechanization, agronomic and market information services, weather and climate services, and access to digital finance products and services.

Greenway Green,[75] developed by Greenovator, provides farmers with practical information on market linkages, extension services, weather information, farming practices, pest and disease management for fish and livestock farming.

Village Link offers digital diagnostic services where farmers can upload photos of problems they face with their crops and receive guidance on how to address them. The firm also operates a satellite service through which it aggregates agricultural satellite data and translates it into practical information for farmers and businesses, including localized weather and flood monitoring and tracking of crop performance and growth stages.

Golden Paddy by Impact Terra collects from its users' farm data, such as planting dates and crop varieties, to provide farmers with practical advice based on crop models and weather forecasts. The company has also developed a digital credit scoring service to assess whether farmers qualify for microfinancing, based on information such as farm size, machinery, varieties and past yield performance. Based on the data collected, the application can identify what types of loans farmers may need so as to connect them with the right financial institutions.

Tun Yat is an online platform that connects farmers to mechanization service providers, including individual owners of tractors and harvesters, to help them access mechanization services. The platform was founded in 2017 and has approximately 1500 users, mainly smallholder farmers owning less than five acres of land. The company has grown its following by organizing regular village visits to present its services to farmers, collecting data and running workshops and training sessions in collaboration with civil society organizations. The company monitors its impacts, including cost and time savings in harvesting and reductions in crop loss.

Source: Jalonen et al (2021)

A recent review of digital climate services for farmers in Southeast Asia found that the services were driven by foreign investment, while partnerships between national governments and farmers are rare. The study recommends broader engagement to ensure that services address farmers' conditions and priorities and support government efforts to achieve commitments to global climate, biodiversity, and sustainability goals. The effectiveness of digital services can be enhanced if developers integrate farmers' indigenous knowledge and government programs from the design stage (Simelton and McCampbell 2021).

A strong cadre of forestry-educated professionals is essential to enable global society and individual countries to achieve SFM and address a plethora of related issues: climate change, sustainable energy, environmental restoration, biodiversity conservation, and adaptation to changing economic, social and environmental conditions. Forestry graduates receive a broad education in field management, science, business and ICT to address these issues. In 2015, 330,912 students graduated with forestry degrees across the world. Asia had the largest number of forestry graduates at 193,623, or 59% of the global total. Of the Asian students, 60% graduated with technical certificates or diplomas, 33% with Bachelor's degrees, 7% with Master's degrees and 1% with PhDs.[76] The number of forestry graduates in China accounted for 82% of the Asian total and 42% of the global total (FAO 2020a). Forestry education in Asia is moving in the right direction, indicating that the region, its countries and their young professionals are

75 https://play.google.com/store/apps/details?id=greenway_myanmar.org&hl=en_US&gl=US

76 The data for the Pacific is incomplete and thus not included here.

and will be well suited to adopting and using innovative technologies to implement SFM.

Capacity building opportunities should be available to women, ethnic minorities and marginalized groups to ensure equity. Women now account for 42% of forestry graduates (FAO 2020a), and they will account for an increasing proportion of forestry professionals in the future. In rural areas, women and minorities often have unique knowledge and experience regarding natural resource management. Inclusivity will benefit both sustainable management and local economies. Social equity in capacity building opportunities can be enriched through the following measures: raising the issue in community forums, setting aside an agreed percentage of training slots for the target groups, and holding trainings at times and locations that meet the target groups' availability. For example, as women are generally responsible for household management, capacity building activities should be scheduled at times when women are available. As minority and marginalized groups may live in specific locations, capacity-building activities should be organized near those areas. It is beneficial to plan the capacity building outreach strategy with recognized leaders and respected members of the target groups.

4.5 Sustainable value chains: improving access to credit and markets

Forest rents are the contribution of forests (or natural resources) to GDP. They are important components of analytical frameworks for sustainable development. Rents are revenues above the cost of extracting the resources. Natural resources can provide high economic rents because they are not produced in the same sense as manufactured goods. For manufactured goods and services, supply expands until economic profits are driven to zero; for many natural resources, returns (rents) are well in excess of their cost of production. Forest rent is calculated as the difference between the price of forest commodities and their average production cost.[77] The global average forest rent in 2019 was 0.139% of GDP; most Asia-Pacific economies are above this average. Enabling the uptake and scaling up of innovative technologies in the region can simultaneously promote SFM and enhance the contribution of forest to GDP. Sustainable forest management avoids overreliance on non-renewable resources to the detriment of natural environment or the overharvesting of renewable forest resources; both actions can lead to the liquidation of a country's capital. SFM should include reinvestment in the resource base.

Besides capacity building for all stakeholders, the successful deployment of innovative technologies requires adequate infrastructure, equipment, and financial resources (Wang et al. 2019; Pingault et al. 2021a). This section revisits findings discussed above regarding the unique investment environment of the forest sector, the need for integrated planning, physical and ICT infrastructure needs, and the potential of PES and shared-value business strategies.

Financial, market, regulatory, biological and environmental risks are all high in the forest sector. As a result, specialized financial mechanisms, including blended finance, green and social bonds and crowdfunding, have emerged as potential options for investment in SFM (see **Sections 2.4.1** and **3.1**). There are a number of barriers associated with innovative finance mechanisms. While beginning to receive more exposure, these mechanisms are not yet widely used or understood. The design and implementation of the mechanisms require strong financial capacity and infrastructure. Another challenge is identifying scalable projects that meet the criteria (risks, guarantees, profitability, etc.) and objectives of the diverse project partners.

77 This is done by estimating the price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs. These unit rents are then multiplied by the physical quantities countries extract or harvest to determine the rents for each commodity as a share of gross domestic product (GDP). https://databank.worldbank.org/metadataglossary/adjusted-net-savings/series/NY.GDP.FRST.RT.ZS

The diverse objectives and roles of the financing partners (see **Table 2**) could result in disjointed multifarious operations, opposed to an integrated approach. Early examples of success may represent cherry picking of the best opportunities and might not yield lessons learned that can be replicated to broader conditions.

Blended finance is considered particularly useful to facilitate investments in community development, including infrastructure establishment or improvement (roads, energy, internet, value chains and capacity building), needed to support the adoption of innovative technologies. It is important that planning include input from local communities regarding their priorities and concerns. Local involvement from planning through implementation is essential to ensure that communities benefit from the value chains, infrastructure and financial resources developed to support the adoption of innovative technologies. To enable local integration in the evolving value chains, investment priorities are likely to include business capacity building for local people and ICT infrastructure development, which includes compatible software and hardware packages and access to open-source data, tools, applications and platforms (Pingault et al. 2021a).

Similarly, PES mechanisms can be designed to include support for value chain development infrastructure development, capacity building and equipment. Forest carbon financing is being tested in Lao PDR, Viet Nam and other countries as a mechanism to enhance access to the international finance market for local communities (Pingault et al. 2021a). The use of climate and green bonds for mitigation, adaptation and environmental investment are summarized in **Box 31**.

ICT-enabled mobile banking, crowdfunding, blockchains e-commerce services and other innovative financial mechanisms (see **Section 2.4.1**) can facilitate transactions, improve value chain access, decrease costs, minimize the role of middlemen, increase price margins received by product service providers, and enable lower prices for the consumer. To further strengthen their market position, producers can engage in group marketing and the development of shared-value business strategies with traders. These approaches also enable producers and traders to reduce transaction costs, facilitate product supply, and increase returns for both parties. Proper documentation of trade volumes and values can verify the importance and potential of a commodity and its derived products (see **Box 32**).

4.6 Forest sector governance and land tenure security: improving transparency, participation and access to forests and natural resources

Digital technologies and institutional changes can help strengthen participation, transparency and accountability in forest governance, and support the sustainable management of natural resources. Remote sensing and sensor networks are among the technologies that improve transparency and accountability and advancing forest conservation and sustainable management. Digital technologies facilitate community involvement in forest monitoring and citizen science, information sharing with other stakeholders, and participation in decision making and innovative governance (see **Box 33)**. They can also be used to improve access to forest resources and support tenure claims for communities. These technologies can all be used in real time, further enhancing transparency and accountability. Barriers to digital technologies reaching their full potential are inadequate regulations (see **Section 4.7**) and recognition by relevant government agencies of the technologies and resultant data legitimacy (Bahar and Wicaksono 2021; Kamran et al. 2021).[78]

DNA identification is widely used for timber tracking and conservation monitoring. It can provide strict forensic validation of genetic origin, chain of custody, and compliance with certification schemes and trade

78 These technologies, their use and function for forest governance, forest tenure and other purposes are further discussed in Sections 2.1 and 2.5.

Box 31 Climate and green bonds for mitigation, adaptation and environmental investment

Climate bonds and green bonds are fixed-income financial instruments invested to generate positive environmental or climate benefits. They are a relatively new financial mechanism with a growing presence and popularity. In 2016, the total amount of climate bonds issued was estimated at USD 160 billion, with approximately 45% those bonds issued that year. The amount of climate bonds issued in 2019 alone grew to USD 255 billion.

There is some differentiation between climate and green bonds. Climate bonds are issued to raise finance for emissions reductions and climate change mitigation and adaptation projects or programs. Green bonds are issued to invest in environmental projects more broadly. Like normal bonds, climate and green bonds can be issued by national to local governments, multinational banks and corporations. The issuing entity guarantees to repay the bond over a certain period of time, plus interest at a fixed or variable rate. Most climate bonds are backed by assets, with investors guaranteed that the funds raised will finance specified climate- or environmental-related project or asset.

The establishment of climate and green bonds strengthen opportunities to finance the implementation of the Sustainable Development Goals (SDGs), Nationally Determined Contributions (NDCs) and other green or climate projects. They offer a vehicle to both access finance from capital markets and deliver climate and green impacts that can be verified against standards. In developing countries, they have been used to implement renewable energy, urban mass transit systems, water distribution and mitigation-adaptation projects.

Source: Louman et al. (2020)


Photo 18. Drones use by communities and civil society organizations facilitates local stakeholders contribute to participatory forest monitoring and governance (© RECOFTC).

regulations and provides a valuable tool for documenting the legality of forest product value chains and combating illegal trade. However, there are multiple barriers to its use. Testing is conducted along the value chain, necessitating multiple partners with reliable DNA sampling capacity. Meticulous documentation is required, and the genetic databases and traceability systems that support DNA tracking can be expensive to establish and maintain, requiring capital, equipment and capacity building. Strong technical and managerial skills are essential for the tool to be used appropriately (see **Sections 2.2** and **2.5**).

Process innovations such as precision forestry, winch assisted harvesting and forest management software packages (e.g. IPTIM and Heureka DSS), while not yet widely

Box 32 Harmonized system code for monitoring bamboo and rattan trade

Prior to 2007, most bamboo and rattan products were mixed with other products of similar materials in international trade statistics. Efforts by INBAR, FAO and the China Customs Authority resulted in the approbation of 24 harmonized system (HS) codes for bamboo and rattan products by the World Customs Organization effective in 2017. The newly produced HS codes identify the majority of bamboo and rattan products, including raw materials, bamboo shoots, bamboo and rattan baskets, curtains and furniture, as well as products such as bamboo panels, charcoal, pulp and paper articles, and construction materials. The new HS codes provide a comprehensive understanding of the bamboo and rattan trade and identify options for strengthening the sector. Equally importantly, the adoption of these new codes recognizes the significance of bamboo and rattan products, encouraging countries to support and stimulate their national enterprises.

Bamboo and rattan products generate a trade value of USD 70 billion per year, most of it in domestic economies. UN Comtrade estimates that exports of bamboo and rattan commodities amounted to USD 3.25 billion in 2018. China is the largest producer, consumer and exporter of bamboo and rattan products, with a market share of more than 70%. Current trends indicate this share will increase. Many Asian countries, including Indonesia, Viet Nam, Malaysia, and the Philippines maintain important domestic and international markets. The EU, the USA, Japan and Canada are key importers of bamboo and rattan products in the world. The EU and the USA also export a number of 'processed' bamboo products made from imported materials.

The bamboo and rattan sector employs millions of people around the world in an industry valued at USD 700 billion per year – ten times its trade value. Monitoring the trade of bamboo and rattan products is an essential part of supporting and developing the industry. The development of HS codes for bamboo and rattan commodities has positive impacts on the sector and trade. This is a long-term process that will require further development of HS codes and international cooperation to accept, adapt and use them.

A barrier to this process is negotiation and discussion within the large diverse global community involved in bamboo and rattan management, production and conservation, including governments, research organizations, NGOs and the private sector (producers, exports and importers). This diverse group of actors may have different objectives and incentives. There may also be opposition from other or sectors (wood or plastic products) with which bamboo and rattan products compete.

Source: Wu (2021a)

used in the region, hold huge potential for improving forest governance by integrating economic, environmental, sociocultural and sustainability objectives. However, these innovations require strong technical and financial capacity and may have high investment costs in terms of capital, training and time.

Innovative finance mechanisms such as blended finance, green and social bonds, crowdfunding and PES can strengthen participatory forest governance and forest tenure through integrated community development planning (see **Sections 2.4.1,** and **3.1** and **Boxes 16** and **34).**

CF has become well established in the region, with experiences in Nepal, India, Indonesia and the Philippines often cited as successful examples. Key factors that favor the successful adoption include conducive national regulations and legislation that promote co-management by communities, supportive government agencies, engaged local communities involved in agricultural and forest management, capacity building to facilitate understanding of CF mechanisms and options, and NGOs (development and conservation) and international donors that advocate for the programs and community rights. CF schemes can facilitate the development of community nurseries to produce quality seedlings for local planting and market sales (Mandawali 2021), motivate

Box 33 Citizen science for enhanced forest monitoring, reporting and governance

Forest Watcher in Nepal

Forest Watcher is a mobile phone application that supports citizen science by strengthening community involvement in forest governance. A small grant from Global Forest Watch (see **Box 3**) supported the use of Forest Watcher by rural communities, enabling the community forest user groups (CFUGs) in Nepal to collect critical information on forest status, change and threats. The initiative trained 68 elected CFUG members from 34 community forests in seven districts in the use of the Forest Watcher app. Users uploaded forest monitoring reports and accessed online platforms. The documentation of deforestation and other illegal activities increased, while the quality, timeliness and cost-effectiveness of monitoring were improved, and data losses were reduced. The app's deployment demonstrated significant potential to enhance conservation efforts and devise effective long-term forest conservation plans and SFM.

Source: Lama et al. (2021)

SMART Forest Monitoring in Asia and the Pacific

The Spatial Monitoring and Reporting Tool (SMART), developed through the combined efforts of nine global conservation agencies, is an innovative digital technology aiming to support and facilitate patrolling and law enforcement in forests and biodiversity hotspots. SMART is an open-source monitoring tool that collects, stores, communicates, analyses data on illegal activities, wildlife, patrol routes, and management actions. It can be used to evaluate the implementation of forest management plans and supports adaptive management of natural resources by providing accurate and real-time data. SMART can be used by government agencies, the private sector and community groups supporting the concept of Citizen Science. As of 2018, SMART was used in over 400 protected areas in 20 countries of the Asia-Pacific region. An evaluation showed that SMART enhanced forest law enforcement and governance (FLEG) through efficient monitoring. The tool improved transparency of forest governance, accountability of agencies implementing forest management, and effectiveness of forest personnel by facilitating efficient data collection, analysis and reporting. Barriers include the lack of political commitment to adopt, accept and disseminate SMART technology. To attain the tool's full potential, government and conservation institutions need to develop a shared vision for the application of SMART and its data. Effective forest law enforcement is essential for forest and wildlife conservation, forest management and good governance.

Source: Gabriel and Ravindran (2021)

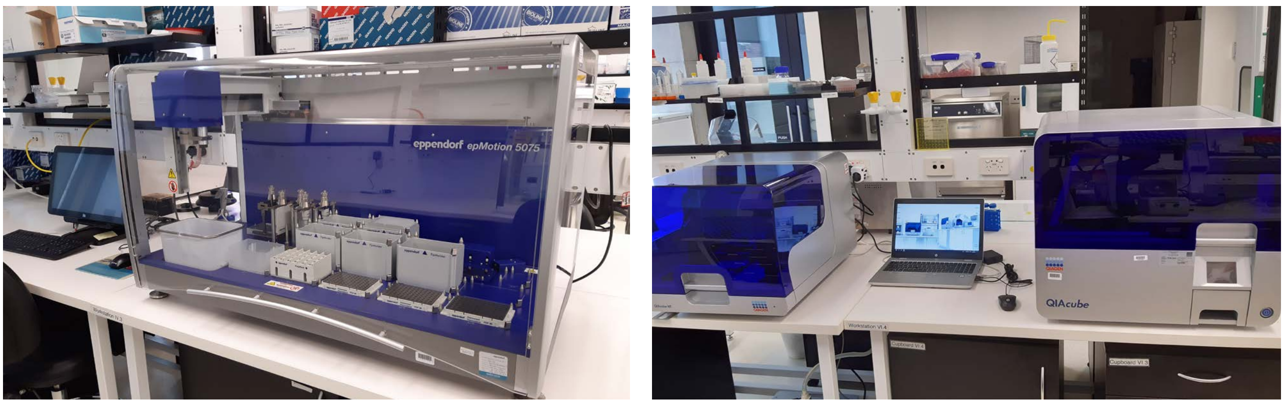


Photo 19. Strategic planning and investment may be necessary to establish DNA laboratories, procure equipment, and support capacity building and stable operational management (© University of Adelaide).

Box 34 Southeast Asia's first corporate sustainability bond

The TLFF announced its inaugural transaction in February 2018, a landmark USD 95 million loan to help finance a sustainable natural rubber plantation in two heavily degraded landscapes. The transaction integrates clearly defined social and environmental objectives and safeguards. A long-term sustainability bond arranged by BNP Paribas (BNPP) and issued through TLFF supports PT Royal Lestari Utama (RLU), a joint venture between the **Michelin Group** and Indonesia's **PT Barito Pacific, to develop a sustainable natural rubber plantation** in Jambi and East Kalimantan, Indonesia. ADM Capital acts as facility and ESG (environment, social and corporate governance) manager. The project is monitored annually by a third-party consultant against an Environmental and Social Action Plan (ESAP).

A nucleus plantation will be established on 28,026 ha of degraded land in Jambi **(39% of the total**), and **5,974 ha** in East Kalimantan **(30% of the total).** By using high-yield clones and adopting smart rubber production practices, commercial plantations and smallholder plantings aim to reach annual rubber yields of 1.7 tons per ha, double Indonesia's current average of 0.8. tons per ha.

Of the total project area of 88,000 ha, 34,000 ha will be planted with commercial rubber, the remaining 54,000 ha is set aside for conservation and community livelihood purposes, which includes a 9,700-ha wildlife conservation reserve. In Jambi, the commercial plantations also serve as a buffer zone protecting the 143,000 ha Bukit Tigapuluh National Park, home to indigenous and endemic biodiversity, including endangered Sumatran elephants and tigers. When the project is in full operation, RLU will employ 16,000 local residents, thus improving the livelihoods of 50,000 community members. This transaction creates Indonesia's first sustainable rubber plantation and is the first corporate sustainability bond issued in Southeast Asia.

Challenges to the program include: addressing significant past deforestation and social conflict issues; engaging large rural populations with diverse holdings, conditions, and objectives; and managing the expectations of external stakeholders who may demand the inclusion of additional issues into the program scenario.

Weblink: www.tlffindonesia.org

communities to control invasive species and process the biomass into compost for landscape restoration (Tamang and Sharma 2021) and support the development of forest- and tree-based community enterprises.

Capacity and regulatory barriers exist that hinder the adoption of CF. To overcome these barriers, it is suggested to simplify community forestry registration and licensing procedures, increase program flexibility to fit real opposed to idealized conditions (including management dynamics), expand community involvement to assure equity of opportunities for all community members (particularly women and marginalized groups), and continue technical and financial assistance beyond when registration and licensing have been awarded to enable communities to develop and implement comprehensive management plans. The benefits and challenges of CF mechanisms for local forest governance are illustrated in **Box 35.**[79]

4.7 Supportive policies and regulations

The uptake and scaling up of innovative technologies in the forest sector in Asia and the Pacific should be supported by conducive policies and regulations. The policy environment should facilitate the adoption of innovative technologies and support agile governance, improved communication, public investment in technology dissemination, strengthen research and development of innovative technologies, support education

79 Additional information regarding CF mechanisms are found in Section 2.4.2 and in Boxes 18 and 28.

Box 35 Community based forest management in Indonesia

The Indonesian government committed to allocating 12.7 million hectares of forest land to local communities through community-based forest management (CBFM) schemes, under which management licenses are issued for 35 years and renewable for another 35 years. The CBFM is a paradigm shift towards renegotiating control of state forest resources away from the dominant role of the state to the active involvement of communities, advocated for by numerous NGOs and donors engaged in the country. The devolution of forest rights to communities through CBFM policies is an attempt to promote social justice by transferring property rights and thus giving opportunities for communities to benefit from forest resources. It is a way to create new opportunities for the inclusion of forest people because changes in statutory rights would allow them to gain rights to land from which they have been historically excluded.

De Royer (2018) found examples where the process of allocating CBFM licenses was cumbersome and local communities have had difficulty completing the application process without the support of a committed external third party. Generally, participation during the design and preparation phases is often limited to well-connected village elites. Additionally, participating communities are subject to restrictions on the forest areas and management options they can use, limiting their development aspirations. Once management rights have been received, technical support remains limited or completely lacking. Communities are generally left to themselves without the financial or technical skills, or assistance, required to support the forest planning and management. This leads to poor results from communities' actions and initiatives. Additionally, the land allocated for CBFM are often degraded areas where most of the valuable forest resources have been previously extracted.

To overcome these barriers and enable the CBFM program to achieve its intended goals, it is recommended that support does not end after CBFM licenses are issued but continues in the long term, assisting communities in develop and implementing comprehensive management plans. During the licensing phase, support should focus on developing an informed, committed, and capable management group and clearly explaining the communities' rights, responsibilities, and limitations under the license. After the license has been granted, technical capacity building should be provided regarding nursery production, small-scale forestry management (including possibly agroforestry issues), harvesting and processing, marketing and small business operations. The specifics of the capacity building program should be identified by the community forest. The capacity building programs can be implemented by extension agencies, research organizations, universities, NGOs, private sector entities, donors or a combination of these stakeholders.

Source: De Royer et al. (2018).

and capacity building in innovative technologies, and promote strategic partnerships with the private sector and other generators of innovative technologies. Similarly, policies and regulations should balance the disincentives that discourage the adoption of innovative technologies – particularly by individuals, communities and SMEs – and possible negative social and environmental impacts. Supportive policies will have a catalyzing effect on technology adoption (Bahar and Wicaksono 2021; Sarziyski et al. 2021; FAO 2019). Policymakers should be proactive in developing policies and regulations that are conducive to the adoption of technologies for the benefit of the forest sector and of its workforce (Hansen 2010). Policies and regulations must be flexible to remain relevant as application environment expands (Innes 2009).

Policy development is often responsive to prevailing conditions; consequentially, they may lag behind technology development. Existing policies can act as barriers or disincentives. Policies appropriate for new technologies may not yet be in place. Additionally, policies often target the operations of government agencies, private sector entities and other large-scale enterprises, overlooking smallholders, communities and SMEs. Such environments can limit the adoption of new technologies and their ability to reach their full potential and effectively contribute to sustainable development.

Examples of policy voids include the following. A lack of drone-relevant policies leads to restrictions on drone flights or the use of the data generated by drones (Jones 2017). In this situations, individual agencies may develop their own regulations that are inconsistent between agencies and potentially in conflict with national legislation (Kamran et al. 2021). In these cases, regulations can be applied in a manner to restrict monitoring technologies or use of the data (see **Box 36**). In another example, existing regulations, created when composite woods lacked their current characteristics, restricted the use of CLT and mass timbers in commercial building and housing, limiting the potential benefits of these innovations (Harun 2021). Timber regulations created in the context of the forest industry inadvertently impose barriers to smallholder and community participation in the forest sector (Sapkota 2021; Page 2021; Smith et al. 2017; Perdana et al. 2012) or access to and production of improved-quality germplasm by smallholders and local communities (Page 2021; Lua et al. 2015). By limiting their rights, these barriers diminish the ability or willingness of local actors to assume responsibility for forest governance and CF schemes (Sapkota 2021; De Royer et al. 2018). Additionally, conducive policies and regulations are needed to support the utilization of biotechnology and biofuels (Pingault et al. 2021a).

There are also examples of dynamic policy environments developed to support the use of innovative technologies or to enhance the benefits resulting from those technologies. Government, research and development agencies have individually and collaboratively supported the development of smallholder and community germplasm enterprises to strengthen national supply chains by producing and supplying quality seed and seedlings of priority tree species (Harun 2021; Lillesø et al. 2018; Lua et al. 2015; Nyoka et al. 2015; Catacutan et al, 2008). The establishment and fluctuating fortunes of a community-based germplasm enterprise in the Philippines is featured in **Box 37**.

In Nepal, the government developed policies encouraging community involvement in forest governance and management to generate local livelihood benefits (see **Box 18**). In Bhutan, forest data generated from spatial analysis is used by government agencies to strengthen SFM and related policies (see **Box 5**). The government of Viet Nam developed policies encouraging the use of remote sensing for forest monitoring and management, biotechnology for developing superior genetic material, and process innovation to improve wood processing (Phuong 2021). China promotes the use of 5G wireless communications, spatial analysis, AI and machine learning to enhance productivity, improve worker safety, optimize wood utilization, and reduce waste and energy consumption in forest industries (Wu 2021b). These cases of government support for innovative technology adoption and utilization in Bhutan, Viet Nam and China are expanded in **Box 38**. The Malaysian government uses the geospatial capacity of its space agency to strengthen the capacity of its forest and environmental sectors (see **Box 39**).

Effective policies and laws are needed to address the potential negative impacts associated with innovative technologies, such as illegal surveillance, loss of privacy or control over data, identity theft, breaches of ethics, misinformation, and particularly potential impacts on the environment as well as on employment. It is essential that these issues be addressed during policy development.

Forestry agencies must adapt to rapid technological change, which requires agility in their administration and management. 'National innovation systems' are the flow of technology and information among people, enterprises and institutions which underpins the innovative process at national levels; the concept holds that innovation and technology development and dissemination result from the multifaceted relationship among national stakeholders, specifically government agencies, research and academic institutions, and the private sector (Freeman 1995;

Box 36 Legal frameworks for monitoring technologies

Satellite and other remote sensing technologies can serve important roles in monitoring compliance with environmental laws, providing real-time data and information (evidence) to regulators and other stakeholders. However, the evidence must comply with laws, regulations, and even recognized legal practices. The use of imagery needs often to be complemented with other evidence and investigative measures. For example, imagery might detect pollution discharges or illegal deforestation without being able to categorically identify the source or offender. In many jurisdictions, proof of a breach of environmental law alone is not sufficient to justify the proactive investigation of various possible offenders. This could be considered intrusive without tangible evidence of involvement; a breach of privacy or other laws. However, imagery could be used to deter environmental crime by alerting regulators and law enforcement of prevailing circumstances, which could prompt useful complementary investigations.

In Indonesia, individuals and organizations can be prosecuted for illegal land clearing through the use of fire. Remote sensing imagery have been used as evidence of illegal action during court proceedings. However, in some cases, the legal status of imagery as evidence has been questioned, as such imagery is not specified in laws and regulations. Resourceful judges have arranged site visits with experts to review the evidence in situ to clarify issues and strengthen legal standing.

In Pakistan, remote sensing technologies have not reached their full potential due to absent, weak or inappropriate regulatory frameworks. The ownership of UAVs is legal, but the adoption of these innovative technologies is hampered by licensing, utilization and flight pattern restrictions. Security agencies view UAVs with suspicion as potential threats to national sovereignty. There is a risk of privately owned UAVs being confiscated or held in customs even after a permit has been issued and ownership and import duty requirements have been satisfied. Furthermore, there are restrictions on sharing the data and information generated by privately operated UAVs and related digital technologies, limiting the development of a viable private sector that could provide essential domestic services to improve sustainable land management. NGOs, research institutions and the private sector have called for transparency in the application and enforcement of regulatory frameworks and open support for technology transfer to strengthen sustainable resources management and governance for the benefit of the country.

In Malaysia, NGOs, researchers and other stakeholders working in the environmental sector have been frustrated by limited access to reliable maps. Data and information may be available but is scattered across various national and local government agencies, NGOs and other institutions – with many of these actors reluctant to share them. Map building tools (e.g. from Global Forest Watch, Google Earth Engine) enable users to amass data from various sources to create customized maps that integrate or overlay their own data. However, when deforestation or degradation is identified by environmental actors, government agencies and concession land managers may be reluctant to accept the input as the information and imagery do not agree with their own records. In some cases, land may be under the jurisdiction of or been transferred to another agency or land manager; requiring greater effort in approaching the pertinent party. Collaborations between government agencies, universities, NGOs and other stakeholders have been initiated to establish an open platform that contains accurate maps that have been accepted and provided by the forestry agencies. Development and testing are in progress.

Source: Bahar and Wicaksono (2021), Kamran et al. (2021), Barad and Jamil (2019), EC (2016).

Chung 2002). Agencies should not work in isolation in disseminating and promoting the adoption of innovative technologies. These efforts should involve other stakeholders, including technology developers, users and beneficiaries. At the national level, there should be coordination by relevant agencies and sectors to harmonize national standards regarding the dissemination, promotion, and adoption of innovative technologies. These cross-sectoral coordination efforts should embrace a broad range of relevant agencies and sectors, including forestry, natural resources, agriculture, water, social

Box 37 The Agroforestry tree seeds association of Lantapan (ATSAL) in Bukidnon, Mindanao, the Philippines

The Agroforestry Tree Seeds Association of Lantapan (ATSAL) in Bukidnon province in Mindanao, Philippines was established in 1998, facilitated by ICRAF with support from government agencies and communities. Farmers were trained in germplasm collection, seed processing and the marketing of agroforestry tree seeds and seedlings. ATSAL successfully marketed seeds and seedlings of various priority species. It also provided training in seed collection and nursery management to farmers, government technicians, and NGO staff. An evaluation of the association found that during the early years of its existence, ATSAL's market share of priority timber tree species grew rapidly, facilitating the widespread dissemination of germplasm of important species among farmers. NGOs, government agencies and projects became customers, some located in other parts of the country. ICRAF's technical support was an advantage, increasing the association's name recognition and market credibility. Subsequently, ATSAL extended its market to the central Philippines, but the extended market territory could not be maintained due to organizational limitations. Other challenges also evolved, including market competition; a non-member was able to capture and serve a market territory larger than that covered by the association. Nonetheless, ATSAL established a respected name as a viable community-based seed and seedling producer, maintaining a stronghold on some local and regional markets. Collective action by members was important for the association to gain market access, but it could not sustain sales. The members who contributed most to the association began to feel unappreciated and shifted their efforts to private endeavors. Institutional and business capacity building and technical support proved necessary to build ATSAL's market position.

Source: Catacutan et al. (2008)

development, infrastructure, education, and health. Collaboratively, the agencies should seek to promote transparency and minimize bureaucracy, streamlining technology dissemination and the adoption of technologies for the benefit of individuals, organizations and the country as a whole.

At the regional level, the innovation systems concept is also applicable and mutually advantageous. Countries should work together, sharing lessons learned regarding effective strategies for utilization and scaling of innovative technologies and mistakes to avoid. Regional and international cooperation to align and harmonize national priorities, investment plans, policies, regulations and standards on the dissemination and adoption of innovative technologies would benefit all parties. Significant investments in funds, skills and time will be required. Each country's resources will have a greater impact when jointly deployed with those of regional partners, governments and organizations, who confront similar conditions and challenges. A critical issue is research in technology development. Research funding remains low, but regional cooperation can boost the impact of these limited resources (Wang et al. 2019). Additionally, many countries, organizations and sectors may have insufficient capacity – knowledge, finances, staff, etc. – to effectively undertake alone the challenge of innovative technology development and utilization (Aerni et al. 2015). The efforts of individual countries, organizations and sectors are often fragmented due to such limited capacity. Collaborative approaches between countries and organizations can present a more coherent approach to the development and deployment of innovative technologies (Wang et al. 2019).

4.8 Concluding comments on uptake, scaling up and enabling conditions

Innovative technologies and their potential applications are rapidly evolving. The long-timeframe of tree growth does not match the rapid evolution of technologies, shifts in wood demand and transformation in the forest sector. In this changing context,

Box 38 Government support for the adoption and utilization of innovative technologies

Bhutan has adopted remote sensing innovations to strengthen forest monitoring, mapping and management. ICT, including online data storage and management, are used to expand the amount and availability of data to enhance planning, reporting and management. The conservation of wildlife and other environmental resources are specifically prioritized to ensure social, economic, and environmental well-being and the happiness of present and future generations, which are enshrined in a national principle. Improved forest mapping, planning and access to accurate data has facilitated the adoption of low-impact logging principles and technologies to improve planning and control of timber harvesting, increase log recovery, increase productivity and profitability, reduce damage to residual forests, and improve worker safety. The benefits accrued from the adoption of these innovative technologies have coincided with the design and implementation of SFM and environmental conservation policies that receive strong support from government agencies, the forest industry and the wider public. The national wood processing industries are recognized as underdeveloped and in need of analysis to identify innovative technologies that can enhance the sector's productivity and profitability, achieve competitiveness in international markets, and improve human resource capacity and safety.

Source: Dorji (2021)

In **China**, the government promotes a broad array of innovative technologies in the forest sector. Tree breeding and the clonal propagation of industrial tree species are used to expand timber production, reduce pressure on natural forests, restore environmental functions, and support SFM. Innovations in the manufacture of engineered bamboo products have been developed and adopted. Products include bamboo panels, cross-laminated bamboo (CLB), bamboo scrimber, engineered bamboo beams, engineered bamboo flooring, and engineered bamboo veneer. Expanding the utilization of bamboo resources has improved resource use efficiency, strengthened the forest product industry, and reduced pressure on forests. 5G wireless communications are being used to facilitate the use of AI, machine learning, and automation in the forest industry to improve resource use and reduce energy consumption. The adoption of innovative technologies in China does not solely target domestic forest management; the government also promotes a responsible purchase policy and timber legality verification to identify and combat illegal trade of forest resources, supporting regional SFM.

Source: Wu (2021b)

In **Viet Nam**, the Ministry of Agriculture and Rural Development issued decisions in 2007 to promote the adoption of innovative technologies in the forest sector. Remote sensing technology is now commonly used to detect land cover changes and facilitate forest planning and management. Key functions conducted through remote sensing include the identification of fire and other threats, monitoring of GHG emissions and timber removals (both legal and illegal), and implementation of the national forest inventory (conducted every five years with ground truthing). Tree breeding and biotechnology are being used and endorsed to developed superior genetic material and germplasm of priority species to enhance forest productivity, strengthen SFM, and conserve indigenous species and genetic diversity. There are approximately 4,500 facilities in the national wood processing sector, with most using traditional technologies. The government is supporting companies are utilizing CNC technology to optimize the design of wood products and improve resource utilization. Other companies are using thermal and microwave technology to modify wood properties to enhance appearance, strength, and durability to meet market expectations for lucrative products, improving profitability. Solar power innovations are being used to improve wood drying processes, reducing energy costs, and reduce pressure on the national power grid.

Source: Phuong (2021)

Box 39 Malaysian Space Agency and sustainable management plans

A major function of the Malaysian Space Agency (MYSA, Agensi Angkasa Malaysia) is implementing research and development of space technology, space science and their applications. This includes collecting satellite data and manage information systems to assist other government agencies in planning, development and management of the nation's natural resources (MYSA 2021). MYSA assists the Forestry Department of Peninsular Malaysia in utilizing this information to develop and implement detailed multi-stakeholder sustainable management plans for coastal areas, including parks, ecotourism sites, mangroves and fisheries. These plans include a precise and cost-effective monitoring and evaluation system. The traditional fishery- and mangrove-based livelihoods of local people have been protected. A new eco-tourism business sector has evolved, including income-generating opportunities for local people. This development has enhanced participation and inclusiveness while strengthening the sustainable management of the forest and other natural resources.

Sources: Pingault et al. (2021a) and MYSA (2021).

capacities and policies often lag far behind technological advancements.

Capacity building in the utilization of innovative technologies will be needed to facilitate and accelerate their uptake and scaling up. Capacity building should include training in the safe operation of the technologies, particularly with process and product innovations which offer productivity enhancement, resource use efficiency and employment opportunities but can be dangerous to the inexperienced. Capacity building will also be beneficial to local economies that service forest management and forest industry sectors. These areas would include institutional management, leadership, language proficiency, the integration of Indigenous and technical knowledge, value chains, marketing and small business operations. Additionally, there will be a need for a strong cadre of young forestry professionals with tertiary educations proficient in the use of innovative technologies as the forest and forest resources managers of the future.

Restrictive and unaligned policies limit the use of innovative technologies, restricting their application and potential benefits. These include legal restrictions over drone flights and the use of wood-based products in tall-building construction. Strong regulations are also needed to limit the negative impacts of innovative technologies and to facilitate their acceptance and adoption by users and society at large. Regional and international cooperation, including efforts to increase the harmonization and interoperability of national rules, norms and standards, is needed to support the uptake and scaling up of innovative technologies for the mutual benefit of national and regional economies.

This chapter presents enabling conditions that can address these capacity and policy constraints. These conditions, combined with the key expected positive impacts and potential negative impacts from adopting innovative technologies summarized in **Table 5**, provide a solid basis from which to elaborate overarching recommendations with specific options for decision makers to support the adoption and dissemination of innovative forest technologies in the Asia-Pacific region. These recommendations and options are presented in the next chapter.

5. Innovative technologies for sustainable forestry: overarching recommendations

This chapter provides 10 overarching recommendations with 59 specific options to support the uptake and scaling up of innovative technologies for SFM in Asia and the Pacific, as well as a practical way forward for roadmap implementation.

The recommendations and options emerge from the discussions, evidence and case studies gathered in the previous chapters, as well as from the inclusive and participative process followed during the elaboration of this study, starting from the inception workshop (July 2020) and ending with the validation workshop (November 2021), which involved a wide range of key regional decision makers and technical experts, as well as students and young people involved in the forest sector.

In particular, this set of recommendations builds upon the draft recommendations developed during the expert online workshop, co-organized by FAO and FTA on innovative technologies (Pingault et al. 2021a). These draft recommendations were directed separately to five main categories of actors: (i) international actors; (ii) governments; (iii) private actors; (iv) civil society and local communities; and (v) research and academic institutions. However, during the discussions, workshop participants reflected that these recommendations should not be considered in isolation but should be properly articulated and implemented as a whole. In particular, they highlighted the importance of collaboration and coordination across scales, sectors and categories of actors to enhance synergies and balance trade-offs. Hence, they suggested organizing the recommendations by intended use or impact of the innovations, thematic domain, or by context, rather than by stakeholder group.

A few areas of specific interest have recurrently emerged in the discussions around this roadmap, including: the monitoring of forest resources; improved productivity and resource use efficiency; research and development; extension and capacity building; infrastructure and finance; access to innovative technologies and safeguards against their negative impacts; international and regional cooperation; governance and policy coordination; network building and stakeholder engagement; attention to youth, small and vulnerable actors, and local communities. They have been used to structure the recommendations and options below.

The recommendations and options, presented in this chapter, are structured around the two following questions: (i) What are the objectives for harnessing the innovative technologies? (ii) How can the current constraints be overcome to support the uptake and scaling up of innovative technologies?

These recommendations and options provide a framework to support the uptake and scaling up of innovative technologies to enhance SFM in the Asia-Pacific region. Obviously, given the diversity of situations across the region, it is impossible to craft a short set of actionable recommendations that are adapted to all national or local circumstances (context, priorities and needs) at the same time. Nevertheless, participants at the workshop agreed that generic recommendations will not suffice to address the challenges ahead. To be useful for policymakers and decision makers on the ground, recommendations must be actionable and adapted to the local context. They must cover the 'how', not only the 'why', and go beyond general principles and consensual objectives and suggest clear targets, impact assessment mechanisms, and concrete means of implementation.

This is why FAO and FTA suggest two complementary tools to address this need and help governments and other actors build upon this common framework and develop their own roadmap adapted to their own context, priorities and needs:

- first, a four-step guideline for practical roadmap implementation, is presented in the last section of this chapter;
- second, a detailed matrix linking each recommendation and option to the evidence and case studies presented in the report, is presented as **Table 7** also in the last section of this chapter.

5.1 What are the objectives for harnessing the innovative technologies?

As developed in Chapter 2 and Chapter 3, depending on the situation (local conditions, local or national priorities and needs), a range of innovative technologies can be used to fulfill different functions and help various actors pursue different objectives. In particular, the recommendations and options below identify four key areas in which harnessing the potential of innovative technologies could support sustainable development, making the forest sector more productive, ecological and attractive, in particular for young people.

1. **Improve the monitoring of forest resources and track illegal logging and illegal trade of forest products**
   a) Encourage the use of digital technologies to allow more efficient, cost-effective, accurate and real-time monitoring of forest and land resources and facilitate data collection, pooling and sharing.
   b) Facilitate the use of drones to monitor forest status, trends and threats, particularly in remote, inaccessible, or cloudy areas.
   c) Deploy optical, acoustic or other sensor networks to monitor physical, biological or climatic parameters in forest stands and provide real-time information on forest conditions, while minimizing collateral disturbance to wildlife and their habitats.
   d) Combine remote sensing and geo-spatial technologies, social media, open-source tools, mobile applications, and collaborative platforms with big data analysis, deep learning models and AI to develop real-time monitoring and early warning systems that can track and help combat various natural or human-induced threats such as wildfires or climatic events; pest, disease or invasive species outbreaks; deforestation and illegal activities.
   e) Develop mobile applications to make spatial datasets and alert systems easily accessible in the field, even offline, to optimize forest patrol routes, and to facilitate data collection, sharing and centralized reporting.
   f) Encourage the use of DNA profiling and of advanced microscopy identification technologies to track illegal logging and illegal trade of forest products.

2. **Raise awareness of and enhance citizen participation in forest monitoring and sustainable forest management**
   a) Encourage the use of social media and other communication innovations to raise awareness regarding the importance of SFM and conservation, facilitate participation and enhance transparency and accountability in forest monitoring, forest management and along forest value chains.
   b) Develop mobile applications, as well as open and collaborative online platforms and tools, to encourage citizen science initiatives and facilitate the participation of citizen and local communities in forest monitoring, forest patrolling and SFM.

c) Use mobile applications and online platforms to connect small-scale producers to forest value chains (e.g. banks, traders, processing companies, distribution networks and consumers), facilitating their access to markets and credit.
d) Develop innovative finance mechanisms, such as crowdfunding platforms or impact investments, that facilitate citizen investment in forest conservation or sustainable management and create a stronger link between borrowers and lenders, thus strengthening stakeholder engagement and sense of ownership.
e) Support and scale community forestry, community nurseries, multi-stakeholder fora, focus group discussions, and other social innovations that empower local communities, indigenous people, women and other marginalized actors to improve their access to information, give them a stronger voice in decision making processes, strengthen their control over local forest resources, and support their livelihoods.

3. Improve productivity and resource use efficiency

a) Harness the potential of biological and technical innovations on processes and products to: reduce operational costs; increase productivity and profitability; improve energy and resource use efficiency, reduce waste and preserve natural resources; and open new markets and new uses for forest products.
b) Invest in low-input multiple species domestication, selection and breeding approaches, more systematically exploring the potential of native or underutilized forest wood and non-wood species to produce germplasm of high genetic and physical quality, with improved characteristics adapted to different uses and to different climate change scenarios, and to preserve biodiversity, especially of threatened or endangered species.
c) Disseminate supplies of improved-quality germplasm, adapted to local conditions, to farmers, local communities, and development agencies to enhance local livelihoods, facilitate land restoration, and secure a sustainable supply of forest and tree commodities.
d) Optimize the use of forest resources by limiting collateral environmental damage during harvest and reducing waste along forest value chains through innovative processes such as precision forestry, reduced-impact logging (RIL), winch-assisted harvesting on steep slopes, computer numerical control (CNC), or spindle-less lathe technology.
e) Develop a new generation of innovative wood and non-wood bioproducts that are more environmentally-friendly or can substitute more energy-, GHG- or resource-intensive materials for a wide range of uses, including cross-laminated timber, mass timber, medium-density fiberboard (MDF), particleboard (including binderless particleboard), oriented strand board (OSB), veneer and plywood, engineered bamboo products, bioplastics, modern bioenergy products, transparent wood and/or cellulose nanomaterials.
f) Develop innovative applications for previously undervalued woods, underutilized species, small-diameter logs (including thinnings) from plantations and farms, or wood scraps from processing industry to meet increasing demand for wood while reducing the pressure on natural forests.

4. Generate new job opportunities and support livelihoods

a) Encourage the use of innovative technologies (e.g., digital technologies, biological, technical and social innovations) and innovative finance mechanisms (e.g., blended finance, green/social/climate funds, payments and rewards for ecosystem services) to generate additional income and employment opportunities, improve working conditions and reduce the workload.

b) Develop appropriate education courses at primary, secondary and tertiary levels, as well as initial and continuing training programs in forestry, natural resources and innovative technologies, paying a specific attention to young people, women, small-scale producers, ethnic minorities and other marginalized groups. Besides the use of innovative technologies, beneficial training topics could include: language proficiency, organizational and leadership skills, marketing, enterprise development, worker safety, and small-business operations.

c) Accelerate technology transfer and capacity-development to disseminate the new skills needed to apply for innovative, safer and greener jobs (e.g.: data collection and reporting through mobile applications, drone operation, remote sensing imagery interpretation, big data analysis, tree-nursery operation and maintenance, automated control of wood processing, engineering of bioproducts, or management of innovative funding and governance mechanisms).

d) Develop innovative job opportunities, internships and fellowships in the forest sector, to make it more attractive for youth.

e) Seize the opportunities offered by the development of a circular bioeconomy to generate new and greener job opportunities, support the livelihoods and resilience of local communities, while reducing pollution, GHG emissions, and improving energy- and resource-use efficiency.

f) Facilitate the automation of physical tasks, building upon the new possibilities offered by digital technologies and technical innovations (e.g., wireless communications and remote-control technologies, robotics and AI), to reduce the workload and work drudgery, improve worker safety, and optimize wood processing, while saving energy and natural resources.

g) Use innovative finance mechanisms, such as green and social bonds, crowdfunding and impact investment, to prioritize and support capacity-development and employment generation in local communities and small-scale forest enterprises to enhance their resilience and livelihoods.

h) Develop shared-value business strategies, mutually beneficial for the private sector and local communities, that facilitate the efficient supply of high-value commodities that meet market specifications and bring local benefits.

5.2 How to overcome current constraints to support the uptake and scaling up of innovative technologies

Chapter 4 explored the main constraints that hinder technology dissemination and adoption. These include: lack of capacity (skills, knowledge and experience); lack of physical or intangible infrastructure (road network, electrical power, internet connection, access to credit or markets); lack of land tenure security and limited access to forest resources; limited access to information, lack of transparency and limited participation in decision-making; restrictive policies and regulations lagging behind the rapid evolution of technologies and the rapid shifts in wood demand, or weak governance and law enforcement.

These constraints and their relative importance vary across countries and contexts. Technology adoption is highly context-specific and very uneven across the region. To be adopted, a technology must be adapted to the local context (e.g. income and education levels, labor market, infrastructure, cultural values). As a result, access to technology dissemination must follow a decentralized, bottom-up process, starting from local needs and engaging local communities.

The recommendations and options below aim to overcome these constraints and support the uptake and scaling up of innovative technologies in the forest sector in the Asia-Pacific region and ensure that they effectively contribute to SFM.

5. **Ensure policy coordination across sectors, actors and scales and create innovative governance mechanisms at all scales**

The successful dissemination and adoption of innovative technologies requires integrated planning and implementation across sectors, actors and scales, as well as innovative governance mechanisms.

In this context, governments are encouraged to:

a) Establish a national advisory group on innovative forest technologies, gathering all relevant actors (from public and private sectors, civil society and research institutions; from researchers to final users) to assess the potential of available or emerging technologies in the national context; to identify priority areas for action and investment in an evidence-based way as well as data needs; and to help the government adapt its policies and regulations to the rapid evolution of innovative technologies.
b) Conduct, in collaboration with the other actors in the advisory group, an initial assessment of the current situation regarding the application of innovative forest technologies at national and sub-national levels, as well as of their positive and negative impacts for different stakeholder groups, to identify the constraints and needs and define national priorities and plan of actions.
c) Elaborate and implement, in collaboration with the other actors in the advisory group, a national roadmap for the uptake and scaling up of innovative forest technologies, articulating the relevant sectors, actors and scales, building upon the recommendations suggested here, and adapting them to their national circumstances, priorities and needs. This roadmap should identify research priorities, priority technologies, priority actions and investments, the priority transformations needed in policies and regulations, and the roles and responsibilities of the actors involved.
d) Create innovative governance mechanisms at all scales and support social innovations that promote networking between governments and other actors at national to local levels and create the enabling conditions for the engagement of all relevant actors, particularly youth, women, small-scale producers and local communities, in the development, dissemination and adoption of innovative technologies, as well as in their adaptation to different contexts and actors.

6. **Invest in innovative research, extension and capacity development models**

a) Elaborate a national research, development and extension action plan to identify priority areas for research, facilitate the development, uptake and scaling up of prioritized innovative forest technologies, enhance coordination between different actors (e.g. ministries, private sector, research and academic institutions and civil society organizations), and facilitate or guide the allocation of limited available resources.
b) Adopt a 'blended' multi-stakeholder R&D system, connecting private research to public needs, national priorities and global objectives and facilitating the application and dissemination of findings from public research institutions, including by private actors and civil society organizations.
c) Develop transdisciplinary, collaborative and participatory research projects (e.g. citizen science initiatives) and offer internships and fellowships in research projects to people with field experience to better consider the specific context, priorities and needs of local actors, particularly small-scale actors, better integrate scientific and local knowledge, and better support knowledge co-generation and sharing.

d) Invest in research and development on emerging technologies that have not yet been commercialized and on the conditions under which they can contribute to sustainable development.
e) Invest in innovative research, development, extension and capacity development models regarding the use of innovative technologies in the forest sector (e.g. big data analysis; participatory research and data collection; field and virtual demonstrations of innovative technologies; community of practices; farmer-to-farmer networks; MOOCs and other innovative learning models).
f) Mobilize additional resources for research, development, extension and capacity development on innovative forest technologies, particularly in developing countries, including through blended finance, impact investments, corporate social responsibility (CSR) programs, and other innovative funding mechanisms.
g) Link national forestry education efforts (including research and extension aspects) with the emerging Global Forest Education Project.

7. Elaborate conducive policies and regulations and develop the infrastructure needed to boost innovation and sustainable development in the forest sector

Innovative technologies and their potential applications are rapidly evolving. The long timeframe of tree growth does not match the rapid evolution of technologies and rapid shifts in wood demand. In this changing context, limited infrastructure, as well as policies and regulations, often lag behind technological advancements (e.g. legal restrictions on drone flights or on the use of wood-based products in tall building construction) and may restrict the use of innovative technologies, thus limiting their potential benefits.

In this context, governments are encouraged to:

a) Harness the improved monitoring capacities offered by innovative technologies (e.g. participatory data collection, drones, satellites, sensor networks, automation or AI) to develop flexible policies, strategies and rules to address the multiple threats and challenges faced by forests and forest value chains in a more reactive and timely manner.
b) Ensure that the legal framework on intellectual property rights (IPRs): strikes the right balance between the incentive to innovate and technology dissemination; considers national priorities and general public interest; and facilitates access of small-scale actors and marginalized groups to innovation. In particular, IPR regulations (e.g. on biological innovations) should not infringe the rights or control of local populations and indigenous peoples Indigenous Peoples over their local genetic resources, traditional crops or land.
c) Harness the possibilities offered by innovative technologies to facilitate law enforcement. In particular, the legal framework should facilitate the use of remote sensing or crowdsourced data and of DNA profiling and fingerprinting as forensic evidence in legal cases.
d) Maximize the potential of drones while considering privacy and security issues by adopting transparent regulations adapted to various UAV models and various activities (e.g. forest monitoring, land tenure claims, pest and disease control, insect sampling) in various sectors (e.g. ecology, forestry and agriculture).
e) Develop national standards for the use of digital (geospatial and ICT) technologies for forest monitoring to ensure equipment (hardware and software) compatibility and facilitate cost-efficient data pooling and sharing.
f) Identify lacking physical, virtual and institutional infrastructure at national to local level to boost innovation and facilitate technology transfer, dissemination and adoption (e.g. road network, electricity and energy grids, internet and communication

infrastructure, markets and finance infrastructure, tree nurseries and wood processing plants, R&D and extension systems, governance and institutions, law enforcement system); invest and mobilize resources for infrastructure modernization to address the identified gaps.

g) Use innovative finance mechanisms such as blended finance to mitigate the risks (biological, climatic, social, market and political), attract additional resources and facilitate the long-term investments needed to support technology uptake and scaling up in the forest sector, including capacity development and the establishment or improvement of infrastructure.

8. Consider the economics of innovation to facilitate the adoption of innovative technologies across contexts and scales

Many innovative forest technologies have been designed for large-scale operations in specific contexts. Hence innovative technologies could increase the competitive advantage of large companies, further marginalizing small-scale forest enterprises and local communities, which manage a large part of the forest resources and employ most of the labor force, formally or informally involved in the sector. The challenge is then to 'think small' and 'scale down' innovative technologies so that they can be adapted to various contexts and also benefit traditional users, small-scale enterprises and local communities, even those with limited human and financial resources and those living in remote areas.

To support technology dissemination, adoption and utilization, research and extension actors (from public and private sectors and civil society) need to:

a) Demonstrate the social, economic and environmental benefits of innovative technologies in different contexts and for different stakeholder groups, particularly for youth, women, small-scale producers, local communities, ethnic minorities, and other marginalized actors.

b) Adopt a 'bottom-up' approach to facilitate technology transfer and dissemination, starting from an assessment of the needs of smallholders, small-scale enterprises, and local communities, and considering their socioeconomic context, traditions and culture.

c) Consider local culture and traditional knowledge and the perceptions and experience of local actors to facilitate technology adaptation and adoption in a specific context.

d) As appropriate, provide external support (technical, human, and financial) to small-scale enterprises, local communities or other targeted or vulnerable groups (e.g. youth, women, or indigenous peoples) to improve their access to information and to innovative technologies.

e) Support the dissemination of high-quality germplasm through participatory multiple species improvement and delivery programs with smallholders and local communities, including through donations or sales at affordable prices, as well as through the establishment of tree nurseries, seed orchards or clonal cutting gardens to develop local seed/germplasm production capacity.

f) Adopt innovative harvesting, transportation and processing technologies (e.g. portable sawmill) for use by smallholders and small-scale operators, considering small-business operations, on-site processing, and modern safety standards, and facilitating the use of small diameter logs and under-utilized species.

9. Assess the negative impacts of innovative technologies and establish appropriate social and environmental safeguards

Innovative technologies, if not sustainably used, can produce negative economic, social and environmental impacts, such as: accelerated deforestation and forest degradation; water pollution; soil degradation; the loss of unskilled jobs and local employment opportunities; poverty; food insecurity; increased inequalities and further marginalization of less powerful actors, with limited human or financial capacities to adapt; ethical issues related to privacy, security, control over data, misinformation. The destruction of natural habitats threatens not only biodiversity but also the traditional knowledge, culture and livelihoods of indigenous peoples and forest-dependent communities. In this context, strong regulations are needed to limit the negative impacts of technologies and enforce appropriate social and environmental safeguards.

a) Governments should create and enforce necessary social and environmental safeguard measures to ensure that innovative technologies contribute to the SDGs and do not harm natural ecosystems and vulnerable and marginalized groups.
b) Private actors, as part of their CSR, should comply with these social and environmental safeguards and respect the culture and welfare of indigenous peoples, ethnic minorities and local communities when deploying and using innovative technologies.
c) Civil society, local communities, and research and academic institutions should join efforts in assessing the various negative impacts of innovative technologies, improving monitoring and reporting, strengthening transparency and accountability of public and private actors, suggesting appropriate safeguards and defending the rights and welfare of small-scale actors, local communities and marginalized groups (including women and indigenous peoples).

10. Strengthen regional cooperation

Countries and other actors should work together at the regional level to facilitate technology uptake and scaling up, coordinating their efforts, sharing their experiences, and harmonizing their regulations and standards. Regional cooperation, in a world of limited resources, can be more efficient for technology uptake and scaling up than fragmented action by individual countries, which often lack the technical, human and financial capacities to act. The Asia-Pacific Forest Commission (APFC) could play a central role in strengthening regional cooperation to support the uptake and scaling up of innovative technologies in the forest sector.

In particular, the APFC and other regional fora/organizations are encouraged to:

a) Raise awareness on the potential of innovative technologies to advance the SDGs and encourage global sharing of information on innovative technologies in forestry through all member countries and other relevant actors of regional importance (e.g. donors, private companies, research institutions, non-governmental organizations).
b) Develop regional plans on issues of regional importance (such as: technology transfer; international finance for innovative forest technologies; IPRs; interoperability of databases, data pooling and sharing; regional and international timber trade; prevention and tracking of illegal activities; forest conservation transboundary issues; conflicts over natural resources; cross-border challenges such as climate change, pest control, or water management) and on the possibilities offered by innovative technologies to address these issues.
c) Encourage and facilitate the exchange of experience and lessons learned across member countries about the dissemination and utilization of various innovative technologies in specific contexts.
d) Align and harmonize regional objectives and national efforts, investment plans, policies, regulations and standards regarding the dissemination and adoption of innovative technologies.
e) Assist member countries in developing a national roadmap for the uptake and scaling up of innovative forest technologies, building upon these recommendations and adapting

them to their national circumstances, priorities and needs.

f) Encourage, advise and support member countries in adapting their legal frameworks to maximize the social, environmental and economic benefits of innovative technologies, limit their negative impacts, and harness their capacities to facilitate data collection, reporting and analysis; improve monitoring and law enforcement; enhance participation, transparency and accountability; improve productivity and resource use efficiency; and generate income and employment opportunities.

g) Encourage South–South cooperation on the development, dissemination and use of innovative forest technologies and mobilize resources (human and financial) to support, in particular, the least developed countries in the region.

5.3 Innovative technologies for sustainable forestry: a practical way forward for roadmap implementation

With this study, FAO and FTA propose a practical way forward for the implementation of a roadmap to support the uptake and scaling up of innovative technologies that support SFM in Asia and the Pacific. Such a roadmap should be comprised of four steps as illustrated in **Figure 12**, namely: (i) conduct a diagnosis, or initial assessment of the current situation; (ii) develop a strategy and set priorities; (iii) create an enabling environment; and (iv) act collectively and individually.

To further assist in roadmap implementation, **Table 7** (following **Figure 12**) presents a detailed matrix linking each recommendation and option to the evidence and case studies. The matrix can be used: (i) to sort the recommendations and associated options by actors, technology categories, or functions in the value chain; and (ii) to link the recommendations and associated options with evidence and case studies in this report, the youth volume (Pingault et al. 2021b) and the APFSOS III (FAO, 2019). Case studies developed in this report illustrate how different recommendations and options have been successfully implemented in a specific situation. These examples can inspire by demonstrating practical and solution-oriented pathways to be adapted to and implemented in their own context. The matrix can hence facilitate the use of the recommendations and options to develop a practical roadmap adapted to each specific context and to the priorities and needs of each group of actors.

Roadmap implementation can be supported by existing initiatives such as FAO's digital village initiative (DVI)[80] which targets Asia-Pacific rural transformation through digitalization. DVI principles are: *Feasibility* – low-cost technology connectivity and internet access with a supportive policy, institutional and educational environment; *Inclusiveness* – productive links between users, technology developers, digital service providers, government agencies and enabling actors (banks, private sector entities, academia, education and research; and *Sustainability* – adaptable and affordable technology with broad access to small scale farmers and rural residents, digital literacy with viable capacity building and training infrastructure, and self-sustaining digital platforms capable of dynamic expansion and scaling.

The process of roadmap implementation can be deployed regionally, nationally, in single sectors or within value chains, following the concept of 'innovation systems' facilitating cooperation, collaboration and coordination between actors, countries and sectors at different scales and contexts.

At the regional level, it could be based on the findings of APFSOS III (FAO 2019) and of this study. The APFC could discuss the findings, recommendations and associated options of the present study and set regional priorities. It could also invite member countries to conduct the same exercise at national level and to report back in the next meeting of

80 Digital Village Initiative: Digital rural transformation to combat hunger, poverty and inequality https://www.fao.org/asiapacific/perspectives/digital-villages/en/

the APFC. The APFC could then finalize a regional strategy and plan of action. Regional priorities would be adjusted, in each member country, to national circumstances, priorities and needs (5c; 10e[81]). Regional cooperation, including South–South cooperation, will be paramount at this stage given the very unequal rates of innovation and technology adoption across countries in the Asia-Pacific region (10).

National roadmaps would be led by the government in collaboration with a national advisory group on innovative forest technologies gathering all relevant actors (from public and private sectors, civil society, and research institutions; from researchers to final users) (5a). As appropriate, plans of actions would be attuned at sub-national levels, in different sectors and forest value chains.

Lessons learned from the elaboration and implementation of these national roadmaps could be periodically discussed at national and regional levels to foster exchanges in experience across sectors, actors and countries. Based on this feedback, national and regional strategies and plans of action could be revised and adjusted as appropriate.

At the broader global level, the recommendations and roadmap implementation support the FAO Science and Innovation Strategy (CL 168/22),[82] which foresees a world free of hunger and malnutrition, where science and innovation contribute to overcoming complex social, economic and environmental challenges of agriculture, food and natural systems in an equitable way while maximizing synergies and minimizing trade-offs and risks.

81 In this section, the numbers between brackets refer to the recommendations presented above.

82 Update on the FAO Science and Innovation Strategy – Information Note 1 – December 2021. https://www.fao.org/3/nh974en/nh974en.pdf

Figure 12. A four-step guideline for practical roadmap implementation

1. Diagnosis: initial assessment of the current situation (5b)

Identify the challenges and needs for sustainable forest management (SFM) (5b).

- Assess the potential contribution of innovative technologies to SFM: opportunities and challenges (5a).
- Identify the actors affected (positively or negatively) by the implementation of innovative technologies in the forest sector (5b).
- Identify the main barriers to technology dissemination and adoption.

2. Develop a strategy and set priorities

Identify research priorities, including priority areas for action and investment, as well as priority transformations needed in policies and regulations (5a; 5c), focusing on:

- the most promising innovative technologies given the identified challenges and needs (5c);
- the most vulnerable groups of actors (e.g., indigenous peoples, local and rural communities, small-scale producers, women, youth); and
- the forest ecosystems or forest value chains that are the most fragile, socially, economically and/or environmentally.

3. Create an enabling environment

- Raise awareness and enhance citizen participation in forest monitoring and sustainable forest management (2).
- Elaborate conducive policies and regulations (7) to address/overcome the barriers identified above.
- Mobilize the resources and develop the infrastructure needed to boost innovation and sustainable development in the forest sector (6f; 7).
- Support/invest in research and development, extension and capacity development (6).

4. Act collectively and individually

- Define the roles and responsibilities of the different actors involved (5c).
- Develop action plans at different levels (regional, national, local) in different sectors for different stakeholder groups.
- Ensure policy coordination across sectors, actors and scales and create innovative governance mechanisms at all scales (5).
- Experiment and share the lessons learned.
- Adapt strategies and action plans accordingly.

Note: Numbers between parentheses in this figure refer to the recommendations above

Table 7. Matrix linking recommendations and options to relevant actors, technology categories, forest functions and key evidence from this report, youth volume (Pingault et al. 2021b) and APFSOS III (FAO 2019)

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
What are the objectives for harvesting the innovative technologies?							
1	**Improve the monitoring of forest resources and track illegal logging and illegal trade of forest products**						
1.a	Encourage the use of digital technologies to allow more efficient, cost-effective, accurate and real-time monitoring of forest and land resources and facilitate data collection, pooling and sharing.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	Digital technologies	Forest monitoring	FAO (2019) Section 1.2.2 Section 2.1 Section 3.3	All boxes listed under Recommendation 1.	##1 Bahar and Wicaksono (2021) ##2 Lama et al. (2021) ##3 Sarzynski et al. (2021)
1.b	Facilitate the use of drones to monitor forest status, trends and threats, particularly in remote, inaccessible, or cloudy areas.	Governments and public agencies Academia and research institutions NGOs and civil society organizations	Digital technologies	Forest monitoring	Section 2.1 Section 4.7	Box 6 Box 36	##6 Lee (2021) ##7 Saputra et al. (2021) ##8 Kamran et al. (2021)
1.c	Deploy optical, acoustic or other sensor networks to monitor physical, biological or climatic parameters in forest stands and provide real-time information on forest conditions, while minimizing collateral disturbance to wildlife and their habitats.	Governments and public agencies Academia and research institutions Private actors NGOs and civil society organizations Local communities	Digital technologies	Forest monitoring	Section 2.1 Section 3.3	Box 6 Box 19	

83 The study identifies 4 technology categories presented in **Sections 2.1** to **2.4.**

84 The forestry functions that can be fulfilled, along the value chain, by innovative technologies are presented in **Table 3**. At the second level, Table 3 distinguishes the following functions: forest monitoring; forest management; harvesting of forest products; wood processing; distribution and trade; product final utilization; community participation and governance.

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
1.d	Combine remote sensing and geo-spatial technologies, social media, open-source tools, mobile applications, and collaborative platforms with big data analysis, deep learning models and AI to develop real-time monitoring and early warning systems that can track and help combat various natural or human-induced threats such as wildfires or climatic events; pest, disease or invasive species outbreaks; deforestation and illegal activities.	Governments and public agencies Academia and research institutions Private actors NGOs and civil society organizations	Digital technologies	Forest monitoring	Section 2.1 Section 3.3	Box 4 Box 6 Box 20	##3 Sarzynski et al. (2021) ##4 de Jesus (2021) ##5 Gabriel and Ravindran (2021)
1.e	Develop mobile applications to make spatial datasets and alert systems easily accessible in the field, even offline, to optimize forest patrol routes, and to facilitate data collection, sharing and centralized reporting.	Governments and public agencies Academia and research institutions Private actors NGOs and civil society organizations	Digital technologies	Forest monitoring	Section 2.1		##1 Bahar and Wicaksono (2021) ##2 Lama et al. (2021) ##5 Gabriel and Ravindran (2021)
1.f	Encourage the use of DNA profiling and of advanced microscopy identification technologies to track illegal logging and illegal trade of forest products.	Governments and public agencies Private actors NGOs and civil society organizations	Biological technologies	Forest monitoring Distribution and trade	Section 2.2.2 Section 3.3	Box 11 Box 12 Box 13	##12 Gupta et al. (2021)

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
2	**Raise awareness of and enhance citizen participation in forest monitoring and sustainable forest management**						
2.a	Encourage the use of social media and other communication innovations to raise awareness regarding the importance of SFM and conservation, facilitate participation and enhance transparency and accountability in forest monitoring, forest management and along forest value chains.	Governments and public agencies Academia and research institutions Extension agencies NGOs and civil society organizations Local communities	Digital technologies	Forest monitoring Forest Management Community participation and governance	Section 2.1 Section 2.4.2 Section 4.6		##1 Bahar and Wicaksono (2021)
2.b	Develop mobile applications, as well as open and collaborative online platforms and tools, to encourage citizen science initiatives and facilitate the participation of citizen and local communities in forest monitoring, forest patrolling and SFM.	Governments and public agencies Academia and research institutions Private actors NGOs and civil society organizations	Digital technologies	Forest monitoring Forest Management Community participation and governance	Section 2.1 Section 2.4.2 Section 3.3 Section 4.6	Box 3 Box 5 Box 6 Box 33	##1. Bahar and Wicaksono (2021) ##2 Lama et al. (2021) ##5 Gabriel and Ravindran (2021)
2.c	Use mobile applications and online platforms to connect small-scale producers to forest value chains (e.g. banks, traders, processing companies, distribution networks and consumers), facilitating their access to markets and credit.	Governments and public agencies Private actors Financial institutions (public or private) NGOs and civil society organizations Local communities	Digital technologies & Innovative finance	Distribution and trade Community participation and governance	Section 2.1 Section 2.4.1 Section 2.4.2 Section 4.5	INBAR mobile app (Section 2.1)	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
2.d	Develop innovative finance mechanisms, such as crowdfunding platforms or impact investments, that facilitate citizen investment in forest conservation or sustainable management and create a stronger link between borrowers and lenders, thus strengthening stakeholder engagement and sense of ownership.	Governments and public agencies Academia and research institutions Private actors Financial institutions (public or private) NGOs and civil society organizations	Innovative finance	Forest monitoring Forest Management Community participation and governance	Section 2.4.1	Box 16 Box 17 Box 31	
2.e	Support and scale community forestry, community nurseries, multi-stakeholder fora, focus group discussions, and other social innovations that empower local communities, indigenous people, women and other marginalized actors to improve their access to information, give them a stronger voice in decision making processes, strengthen their control over local forest resources, and support their livelihoods.	Governments and public agencies Academia and research institutions NGOs and civil society organizations Local communities	Social innovations	Community participation and governance	Section 2.4.2 Section 3.6 Section 4.6	Box 18 Box 28 Box 35	##2 Lama et al. (2021) ##9 Tamang and Sharma (2021) ##10 Mandawali (2021)

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
3	**Improve productivity and resource use efficiency**						
3.a	Harness the potential of biological and technical innovations on processes and products to: reduce operational costs; increase productivity and profitability; improve energy and resource use efficiency, reduce waste and preserve natural resources; and open new markets and new uses for forest products.	Governments and public agencies Academia and research institutions Private actors Local communities	Biological technologies & Technical innovations (processes and products)	Forest management Harvesting of forest products Wood processing	FAO (2019) Section 1.2.2 Section 2.2 Section 2.3 Section 3.2 Section 3.5 Section 3.6	All boxes listed under Recommendation 3	
3.b	Invest in low-input multiple species domestication, selection and breeding approaches, more systematically exploring the potential of native or underutilized forest wood and non-wood species to produce germplasm of high genetic and physical quality, with improved characteristics adapted to different uses and to different climate change scenarios, and to preserve biodiversity, especially of threatened or endangered species.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	Biological technologies	Forest management	Section 2.2.1 Section 3.6	Box 10 Box 25 Box 26 Box 27	##10 Mandawali (2021) ##11 Almoite and Togado (2021)

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
3.c	Disseminate supplies of improved-quality germplasm, adapted to local conditions, to farmers, local communities, and development agencies to enhance local livelihoods, facilitate land restoration, and secure a sustainable supply of forest and tree commodities.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	Biological technologies	Forest management Community participation and governance	Section 2.2.1 Section 3.6 Section 4.6	Box 9 Box 25 Box 26 Box 37	##10 Mandawali (2021) ##11 Almoite and Togado (2021)
3.d	Optimize the use of forest resources by limiting collateral environmental damage during harvest and reducing waste along forest value chains through innovative processes such as precision forestry, reduced-impact logging (RIL), winch-assisted harvesting on steep slopes, computer numerical control (CNC), or spindle-less lathe technology.	Governments and public agencies Academia and research institutions Private actors	Process innovations	Forest management Harvesting of forest products Wood processing	Section 2.3.1 Section 3.5	Box 14 Box 21 Box 22	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
3.e	Develop a new generation of innovative wood and non-wood bioproducts that are more environmentally-friendly or can substitute more energy-, GHG- or resource-intensive materials for a wide range of uses, including cross-laminated timber, mass timber, medium-density fiberboard (MDF), particleboard (including binderless particleboard), oriented strand board (OSB), veneer and plywood, engineered bamboo products, bioplastics, modern bioenergy products, transparent wood and/or cellulose nanomaterials.	Governments and public agencies Academia and research institutions Private actors	Product innovations	Wood processing	Section 2.3.2 Section 3.5	Box 15 Box 23 Box 24	##13 Ramatia et al. (2021)
3.f	Develop innovative applications for previously undervalued woods, underutilized species, small-diameter logs (including thinnings) from plantations and farms, or wood scraps from processing industry to meet increasing demand for wood while reducing the pressure on natural forests.	Governments and public agencies Academia and research institutions Private actors	Process innovations	Wood processing	Section 2.3 Section 3.5	Box 15 Box 22 Box 27	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
4	**Generate new job opportunities and support livelihoods**						
4.a	Encourage the use of innovative technologies (e.g., digital technologies, biological, technical and social innovations) and innovative finance mechanisms (e.g., blended finance, green/social/climate funds, payments and rewards for ecosystem services) to generate additional income and employment opportunities, improve working conditions and reduce the workload.	Governments and public agencies Extension agencies Private actors Financial institutions (public and private) NGOs and civil society organizations Local communities	All	All	FAO (2019) Section 1.2.2 Section 2.4.1 Section 3.7 Section 4.4	Box 1 Box 16 Box 31 Box 34	
4.b	Develop appropriate education courses at primary, secondary and tertiary levels, as well as initial and continuing training programs in forestry, natural resources and innovative technologies, paying a specific attention to young people, women, small-scale producers, ethnic minorities and other marginalized groups. Besides the use of innovative technologies, beneficial training topics could include: language proficiency, organizational and leadership skills, marketing, enterprise development, worker safety, and small-business operations.	Governments and public agencies Academia and research institutions Extension agencies NGOs and civil society organizations	All	All	Section 3.7 Section 4.4	Box 30	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
4.c	Accelerate technology transfer and capacity-development to disseminate the new skills needed to apply for innovative, safer and greener jobs (e.g.: data collection and reporting through mobile applications, drone operation, remote sensing imagery interpretation, big data analysis, tree-nursery operation and maintenance, automated control of wood processing, engineering of bioproducts, or management of innovative funding and governance mechanisms).	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	All	All	Section 3.7 Section 4.3 Section 4.4	Box 30	
4.d	Develop innovative job opportunities, internships and fellowships in the forest sector, to make it more attractive for youth.	Governments and public agencies Private actors NGOs and civil society organizations Local communities	All	All	Section 3.7 Section 4.4		
4.e	Seize the opportunities offered by the development of a circular bioeconomy to generate new and greener job opportunities, support the livelihoods and resilience of local communities, while reducing pollution, GHG emissions, and improving energy- and resource-use efficiency.	Governments and public agencies Private actors Financial institutions (public and private, including international donors) Conservation sector NGOs and civil society organizations Local communities	All	Forest management Product final utilization	Section 3.2 Section 3.7		

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
4.f	Facilitate the automation of physical tasks, building upon the new possibilities offered by digital technologies and technical innovations (e.g., wireless communications and remote-control technologies, robotics and AI), to reduce the workload and work drudgery, improve worker safety, and optimize wood processing, while saving energy and natural resources.	Governments and public agencies Private actors Extension agencies Local communities	Digital technologies & Process innovations	All	Section 1.3 Section 2.3.1 Section 2.3.2 Section 3.7	Box 38	
4.g	Use innovative finance mechanisms, such as green and social bonds, crowdfunding and impact investment, to prioritize and support capacity-development and employment generation in local communities and small-scale forest enterprises to enhance their resilience and livelihoods.	Governments and public agencies Donors Financial institutions (public or private) Private actors NGOs and civil society organizations Local communities	Innovative finance	All	Section 2.4.1 Section 3.7	Box 16 Box 31 Box 34 Kiva platform (Section 2.4.1)	
4.h	Develop shared-value business strategies, mutually beneficial for the private sector and local communities, that facilitate the efficient supply of high-value commodities that meet market specifications and bring local benefits.	Private actors Financial institutions (public or private) NGOs and civil society organizations Local communities	Social innovations	Distribution and trade Community participation and governance	Section 2.4.2 Section 4.5		

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
How to overcome the current constraints tp support the uptake and scaling up of innovative technologies							
5	**Ensure policy coordination across sectors, actors and scales and create innovative governance mechanisms at all scales**						
5.a	Establish a national advisory group on innovative forest technologies, gathering all relevant actors (from public and private sectors, civil society and research institutions; from researchers to final users) to assess the potential of available or emerging technologies in the national context; to identify priority areas for action and investment in an evidence-based way as well as data needs; and to help the government adapt its policies and regulations to the rapid evolution of innovative technologies.	Governments and public agencies	All	All			
5.b	Conduct, in collaboration with the other actors in the advisory group, an initial assessment of the current situation regarding the application of innovative forest technologies at national and sub-national levels, as well as of their positive and negative impacts for different stakeholder groups, to identify the constraints and needs and define national priorities and plan of actions.	Governments and public agencies	All	All			

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
5.c	Elaborate and implement, in collaboration with the other actors in the advisory group, a national roadmap for the uptake and scaling up of innovative forest technologies, articulating the relevant sectors, actors and scales, building upon the recommendations and options suggested here, and adapting them to their national circumstances, priorities and needs. This roadmap should identify research priorities, priority technologies, priority actions and investments, the priority transformations needed in policies and regulations, and the roles and responsibilities of the actors involved.	Governments and public agencies	All	All			

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
5.d	Create innovative governance mechanisms at all scales and support social innovations that promote networking between governments and other actors at national to local levels and create the enabling conditions for the engagement of all relevant actors, particularly youth, women, small-scale producers and local communities, in the development, dissemination and adoption of innovative technologies, as well as in their adaptation to different contexts and actors.	Governments and public agencies	Social innovations	Community participation and governance	FAO (2019) Section 1.2.2 Section 3.7 Chapter 4		
6	**Invest in innovative research, extension and capacity development models**						
6.a	Elaborate a national research, development and extension action plan to identify priority areas for research, facilitate the development, uptake and scaling up of prioritized innovative forest technologies, enhance coordination between different actors (e.g. ministries, private sector, research and academic institutions and civil society organizations), and facilitate or guide the allocation of limited available resources.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations	All	All	Section 4.7		

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
6.b	Adopt a 'blended' multi-stakeholder R&D system, connecting private research to public needs, national priorities and global objectives and facilitating the application and dissemination of findings from public research institutions, including by private actors and civil society organizations.	Governments and public agencies Donors Academia and research institutions Private actors NGOs and civil society organizations	All/ Social innovations	All	Section 4.3 Section 4.6 Section 4.7	Box 33	
6.c	Develop transdisciplinary, collaborative and participatory research projects (e.g. citizen science initiatives) and offer internships and fellowships in research projects to people with field experience to better consider the specific context, priorities and needs of local actors, particularly small-scale actors, better integrate scientific and local knowledge, and better support knowledge co-generation and sharing.	Governments and public agencies Donors Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	All/ Social innovations	All	FAO (2019) Section 1.2.2		
6.d	Invest in research and development on emerging technologies that have not yet been commercialized and on the conditions under which they can contribute to sustainable development.	Governments and public agencies Donors Academia and research institutions Private actors Financial institutions (public or private)	All	All			

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
6.e	Invest in innovative research, development, extension and capacity development models regarding the use of innovative technologies in the forest sector (e.g. big data analysis; participatory research and data collection; field and virtual demonstrations of innovative technologies; community of practices; farmer-to-farmer networks; MOOCs and other innovative learning models).	Governments and public agencies Academia and research institutions Extension agencies Private actors Financial institutions (public or private)	All/ Social innovations	All	Section 3.6 Section 4.2 Section 4.3 Section 4.4 Section 4.7	Box 30	
6.f	Mobilize additional resources for research, development, extension and capacity development on innovative forest technologies, particularly in developing countries, including through blended finance, impact investments, corporate social responsibility (CSR) programs, and other innovative funding mechanisms.	Governments and public agencies Academia and research institutions Extension agencies Private actors Financial institutions (public or private)	Innovative finance	All	Section 2.4.1 Section 3.7 Section 4.5 Section 4.6		
6.g	Link national forestry education efforts (including research and extension aspects) with the emerging Global Forest Education Project.	Governments and public agencies Academia and research institutions Extension agencies	All	All			

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
7	**Elaborate conducive policies and regulations and develop the infrastructure needed to boost innovation and sustainable development in the forest sector.**						
7.a	Harness the improved monitoring capacities offered by innovative technologies (e.g. participatory data collection, drones, satellites, sensor networks, automation or AI) to develop flexible policies, strategies and rules to address the multiple threats and challenges faced by forests and forest value chains in a more reactive and timely manner.	Governments and public agencies	Digital technologies	Forest monitoring Community participation and governance	Section 3.3 Section 4.2 Section 4.7	Box 7 Box 8 Box 9 Box 36 Box 39	
7.b	Ensure that the legal framework on intellectual property rights (IPRs): strikes the right balance between the incentive to innovate and technology dissemination; considers national priorities and general public interest; and facilitates access of small-scale actors and marginalized groups to innovation. In particular, IPR regulations (e.g. on biological innovations) should not infringe the rights or control of local populations and indigenous peoples Indigenous Peoples over their local genetic resources, traditional crops or land.	Governments and public agencies	All/ Social innovations	Community participation and governance	Section 3.3 Section 3.8 Section 4.2	Box 10	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
7.c	Harness the possibilities offered by innovative technologies to facilitate law enforcement. In particular, the legal framework should facilitate the use of remote sensing or crowdsourced data and of DNA profiling and fingerprinting as forensic evidence in legal cases.	Governments and public agencies	All	Forest management Community participation and governance	Section 2.1 Section 2.2.2 Section 3.3 Section 4.7	Box 11 Box 12 Box 13 Box 36	##1 Bahar and Wicaksono (2021) ##2 Lama et al. (2021) ##3 Sarzynski et al. (2021) ##5 Gabriel and Ravindran (2021)
7.d	Maximize the potential of drones while considering privacy and security issues by adopting transparent regulations adapted to various UAV models and various activities (e.g. forest monitoring, land tenure claims, pest and disease control, insect sampling) in various sectors (e.g. ecology, forestry and agriculture).	Governments and public agencies	Digital technologies	Forest monitoring Community participation and governance	Section 2.1 Section 3.3 Section 4.7	Box 36	##8 Kamran et al. (2021)
7.e	Develop national standards for the use of digital (geospatial and ICT) technologies for forest monitoring to ensure equipment (hardware and software) compatibility and facilitate cost-efficient data pooling and sharing.	Governments and public agencies	Digital technologies	Forest monitoring Forest management	Section 3.3 Section 4.7		

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
7.f	Identify lacking physical, virtual and institutional infrastructure at national to local level to boost innovation and facilitate technology transfer, dissemination and adoption (e.g. road network, electricity and energy grids, internet and communication infrastructure, markets and finance infrastructure, tree nurseries and wood processing plants, R&D and extension systems, governance and institutions, law enforcement system); invest and mobilize resources for infrastructure modernization to address the identified gaps.	Governments and public agencies	All/ Social innovations	All	Section 2.4.1 Section 4.2 Section 4.3 Section 4.5		
7.g	Use innovative finance mechanisms such as blended finance to mitigate the risks (biological, climatic, social, market and political), attract additional resources and facilitate the long-term investments needed to support technology uptake and scaling up in the forest sector, including capacity development and the establishment or improvement of infrastructure	Governments and public agencies	Innovative finance	All	FAO (2019) Section 1.2.2 Section 2.4.1 Section 3.2 Section 4.5	Box 31 Box 34	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
8	**Consider the economics of innovation to facilitate the adoption of innovative technologies across contexts and scales**						
8.a	Demonstrate the social, economic and environmental benefits of innovative technologies in different contexts and for different stakeholder groups, particularly for youth, women, small-scale producers, local communities, ethnic minorities, and other marginalized actors.	Academia and research institutions Extension agencies NGOs and civil society organizations	All	All	Section 4.2 Section 4.3 Section 4.4		
8.b	Adopt a 'bottom-up' approach to facilitate technology transfer and dissemination, starting from an assessment of the needs of smallholders, small-scale enterprises, and local communities, and considering their socioeconomic context, traditions and culture.	Academia and research institutions Extension agencies NGOs and civil society organizations	All	All	Section 4.2 Section 4.4	Box 30	
8.c	Consider local culture and traditional knowledge and the perceptions and experience of local actors to facilitate technology adaptation and adoption in a specific context t.	Academia and research institutions Extension agencies NGOs and civil society organizations	All	All	Section 4.4		

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
8.d	As appropriate, provide external support (technical, human, and financial) to small-scale enterprises, local communities or other targeted or vulnerable groups (e.g. youth, women, or indigenous peoples) to improve their access to information and to innovative technologies.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations	All	Community participation and governance	Section 3.7 Section 4.4		
8.e	Support the dissemination of high-quality germplasm through participatory multiple species improvement and delivery programs with smallholders and local communities, including through donations or sales at affordable prices, as well as through the establishment of tree nurseries, seed orchards or clonal cutting gardens to develop local seed/germplasm production capacity.	Governments and public agencies Academia and research institutions Extension agencies Private actors NGOs and civil society organizations Local communities	Biological technologies	Forest management Community participation and governance	Section 2.2.1 Section 3.6 Section 4.7	Box 10 Box 25 Box 26 Box 37	##10 Mandawali (2021) ##11 Almoite and Togado (2021)
8.f	Adopt innovative harvesting, transportation and processing technologies (e.g. portable sawmill) for use by smallholders and small-scale operators, considering small-business operations, on-site processing, and modern safety standards, and facilitating the use of small diameter logs and under-utilized species.	Academia and research institutions Extension agencies Private actors NGOs and civil society organizations	Process innovations	Harvesting of forest products Wood processing Distribution and trade	Section 2.3.1 Chapter 3	Box 29	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
9	**Assess the negative impacts of innovative technologies and establish appropriate social and environmental safeguards**						
9.a	Governments should create and enforce necessary social and environmental safeguard measures to ensure that innovative technologies contribute to the SDGs and do not harm natural ecosystems and vulnerable and marginalized groups.	Governments and public agencies	All	All	Section 3.8	Box 18 Box 34	
9.b	Private actors, as part of their CSR, should comply with these social and environmental safeguards and respect the culture and welfare of indigenous peoples, ethnic minorities and local communities when deploying and using innovative technologies.	Private actors	All	All	Section 3.8 Section 4.2	Box 34	
9.c	Civil society, local communities, and research and academic institutions should join efforts in assessing the various negative impacts of innovative technologies, improving monitoring and reporting, strengthening transparency and accountability of public and private actors, suggesting appropriate safeguards and defending the rights and welfare of small-scale actors, local communities and marginalized groups (including women and indigenous peoples).	Academia and research institutions NGOs and civil society organizations Local communities	All	Forest monitoring Community participation and governance	Section 3.3 Section 3.8	Box 18 Box 34	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
10	**Strengthen regional cooperation**						
10.a	Raise awareness on the potential of innovative technologies to advance the SDGs and encourage global sharing of information on innovative technologies in forestry through all member countries and other relevant actors of regional importance (e.g. donors, private companies, research institutions, non-governmental organizations).	APFC and other regional fora/organizations	All	Community participation and governance	Section 1.2.2	Box 1	
10.b	Develop regional plans on issues of regional importance (such as: technology transfer; international finance for innovative forest technologies; IPRs; interoperability of databases, data pooling and sharing; regional and international timber trade; prevention and tracking of illegal activities; forest conservation transboundary issues; conflicts over natural resources; cross-border challenges such as climate change, pest control, or water management) and on the possibilities offered by innovative technologies to address these issues.	APFC and other regional fora/organizations	All	All	Section 4.2 Section 4.7 Section 4.8	Box 7 Box 8 Box 9 Box 32	

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
10.c	Encourage and facilitate the exchange of experience and lessons learned across member countries about the dissemination and utilization of various innovative technologies in specific contexts.	APFC and other regional fora/organizations	All	Community participation and governance	Section 4.1 Section 4.7 Section 4.8		
10.d	Align and harmonize regional objectives and national efforts, investment plans, policies, regulations and standards regarding the dissemination and adoption of innovative technologies.	APFC and other regional fora/organizations	All	All	Section 4.7 Section 4.8		
10.e	Assist member countries in developing a national roadmap for the uptake and scaling up of innovative forest technologies, building upon these recommendations/options and adapting them to their national circumstances, priorities and needs.	APFC and other regional fora/organizations	All	All			

#	Recommendation and option	Key actors	Technology cluster[83]	Function[84]	Section of the report	Box in the report	Youth volume
10.f	Encourage, advise and support member countries in adapting their legal frameworks to maximize the social, environmental and economic benefits of innovative technologies, limit their negative impacts, and harness their capacities to facilitate data collection, reporting and analysis; improve monitoring and law enforcement; enhance participation, transparency and accountability; improve productivity and resource use efficiency; and generate income and employment opportunities.	APFC and other regional fora/organizations	All	All			
10.g	Encourage South–South cooperation on the development, dissemination and use of innovative forest technologies and mobilize resources (human and financial) to support, in particular, the least developed countries in the region.	APFC and other regional fora/organizations	All	Community participation and governance			

Conclusion

In contrast to global trends, Asia and the Pacific have experienced an increase in forest area over the past decades as a result of strong afforestation and reforestation policies in some countries, such as China, India and Viet Nam. The area of forests under protection, certification schemes or long-term management plans is continuously increasing, showing the strong commitment of the region to advance SDG 15 (sustainable forest management). As illustrated in this study, forests and trees and their products and services make important contributions to most of the SDGs, contributing not only to protecting life on land (SDG 15) but also to reducing poverty (SDG 1) and food insecurity (SDG 2). They provide clean water (SDG 6) as well as affordable and renewable energy (SDG 7) and play a central role in climate action (SDG 13). They open new avenues to building a circular bioeconomy, supporting sustainable production and consumption (SDG 12), and create opportunities for decent work and economic growth, particularly for local rural communities (SDG 8). SFM aims to pursue these multiple objectives while addressing concomitant challenges including: climate change, deforestation and forest degradation, and biodiversity loss.

FAO gives great importance to innovation as a mean to address current challenges. The findings and recommendations of this study can be extremely useful for the ongoing development of FAO science and innovation strategy.[85] This strategy, which aims at strengthening the use of science and innovation in FAO's technical interventions and normative guidance, will be a key tool for the implementation of FAO's Strategic Framework 2022–2031. Innovative technologies also strongly support the development of the circular bioeconomy, which, according to APFSOS III (FAO 2019), will be a major area of future scientific research in the Asia-Pacific region.

Innovative technologies have the potential to revolutionize forest management and to make critical contributions to sustainable development in the forest sector. Innovative technologies are often considered inherently beneficial, with advantages largely outweighing the risks. In particular, as illustrated by the evidence and case studies collected during the development of this study,[86] innovative technologies have the potential to: improve forest monitoring and forest management; reduce waste and increase resource use efficiency, productivity and profitability along forest value chains; enable the development of a circular bioeconomy contributing to climate change mitigation, SFM, recycling, and waste reduction; create new skilled job opportunities, making the forest sector more attractive in particular for youth; provide new products and services or develop new uses for previously underutilized and undervalued wood species; enhance traceability and transparency along forest value chains; support participation, capacity development and information sharing; and enable new governance and investment models.

However, technology adoption can also generate negative collateral social and

85 See: http://www.fao.org/director-general/news/news-article-2/en/c/1440353/

86 See previous chapters, but also the workshop reports (Pingault et al. 2020, 2021a) and the collection of youth contributions (Pingault et al. 2021b)

environmental impacts, such as the loss of unskilled jobs, the destruction of natural ecosystems, or the loss of access to natural resources. These forms of collateral damage are likely to disproportionately affect the most vulnerable groups and communities, which face the risk of being further marginalized by technology adoption and hence need specific support. When considering the adoption of an innovation, it is thus essential to consider not only the main objective for its adoption but also all of its potential impacts, as well as all of the potential synergies and trade-offs with other development objectives. This can lead to linking adoption and scaling up of innovations to environmental and social safeguards or, as appropriate, to design compensatory or accompanying measures, such as training plans for laid-off workers or support to small enterprises in adopting the technology to avoid being left behind large companies.

The study also identified two main barriers to the uptake and scaling up of innovative technologies: (i) a lack of capacity (in terms of human, natural, physical, financial and social capitals); and (ii) rigid legal frameworks (policies and regulations) that often lag far behind rapidly evolving technologies. Governments have a central role to play in supporting the uptake and scaling up of innovative technologies while limiting collateral damage. Additionally, to enable the ‘scaling down’ of technologies, namely their adaptation to local conditions, priorities and needs, and to support capacity development and technology transfer, governments will need to work in collaboration with other actors with complementary skills and expertise (private companies, civil society, indigenous peoples and local communities, academia and research institutions) and develop innovative and inclusive governance mechanisms at different scales.

Ten overarching recommendations have emerged from the collective process of elaboration of this study:

1. Improve the monitoring of forest resources and track illegal logging and illegal trade of forest products.
2. Raise awareness of and enhance citizen participation in forest monitoring and sustainable forest management.
3. Improve productivity and resource use efficiency.
4. Generate new job opportunities and support livelihoods.
5. Ensure policy coordination across sectors, actors and scales and create innovative governance mechanisms at all scales.
6. Invest in innovative research, extension and capacity development models.
7. Elaborate conducive policies and regulations and develop the infrastructure needed to boost innovation and sustainable development in the forest sector.
8. Consider the economics of innovation to facilitate the adoption of innovative technologies across contexts and scales.
9. Assess the negative impacts of innovative technologies and establish appropriate social and environmental safeguards.
10. Strengthen regional cooperation.

These recommendation topics provide a framework to support innovative technologies uptake and scaling up in the forest sector in Asia and the Pacific. A total of 59 specific options are provided under the 10 recommendations (three to eight options per recommendation). This study highlighted the immense potential for innovation across Asia and the Pacific and specifically in the forest sector, as well as the large divides still persisting across countries in the region. Asia-Pacific’s innovation potential is mainly driven by a few countries, referred to as the ‘innovation tigers’ (e.g. Australia, China, Hong Kong (China), Japan, the Republic of Korea, New Zealand, and Singapore). Other countries in the region, the ‘emerging innovators’, are quickly catching up and show promising potential for innovation uptake and scaling up in the coming decades. A third group consists of countries where particular efforts to foster innovation are needed and that could benefit from international and regional cooperation, including South–South cooperation. This diversity of national situations calls for renewed and strengthened regional cooperation, positioning the APFC as a central actor to lead the elaboration of a regional innovation roadmap. The framework presented above now needs to be 'scaled down' and adapted to national and local circumstances, priorities and needs.

To support this endeavor, FAO and FTA suggest here a practical way forward for the development and implementation of such a roadmap, consisting of four steps: (i) conduct a diagnosis, or initial assessment of the current situation; (ii) develop a strategy and set priorities; (iii) create an enabling environment; (iv) act collectively and individually. This practical way forward can be deployed and articulated at different scales: at regional and national levels, in different sectors and value chains, by different groups of actors. Lessons learned and feedback from these experiences conducted at different scales could foster exchanges of experience across sectors, actors and countries and feed updated national and regional strategies. Evidence and case studies gathered during the development of this study can illustrate how different recommendations and options have been successfully implemented in specific situations. These examples can inspire other actors, showing them practical and solution-oriented pathways that can be adapted to and implemented in their own context (see **Table 7**).

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Annexes

Annex 1. Process for the development of the study

This study has been developed through an inclusive and participatory process that involved a wide range of key regional experts and decision makers from governments and international organizations, from the private sector and civil society, as well as from academia and research institutions. Young students and young professionals were given a central role in this process as they will be the forest managers of tomorrow.

This process was launched on 30 July 2020, through an online inception workshop that gathered 89 participants from 29 countries (full list of participants in **Annex 2**). This workshop showed the high level of interest and enthusiasm shared by many stakeholders in the region for the study. The workshop: (i) presented the regional context and the two aforementioned topics; (ii) presented the participative process of development of the roadmaps; (iii) received feedback on the two corresponding scoping notes circulated as background documents ahead of the workshop; and (iv) launched and organized the technical work on each topic. Pingault et al. (2020) present the discussions held and the main results of this inception workshop in greater depth. Particular thanks to the colleagues who contributed to the preparation of the workshop or served as speakers, chairs or rapporteurs during the discussions: Amos Amanubo, Illias Animon, Anne Branthomme, Stephen Elliott, Vincent Gitz, Thomas Hofer, Rodney Keenan, Yves Laumonier, Yanxia Li, Rao Matta, Mike May, Alexandre Meybeck, CTS Nair, Robert Nasi, Marco Piazza, Nathanaël Pingault, Edmund Leo Rico, James M. Roshetko, Maria Paula Sarigumba, Vaeno Vigulu, Shengfu Wu and Makino Yamanoshita.

A second online technical workshop on innovative technologies was organized on 30 November, 1 December and 3 December 2020 to take stock of the progress made in the study and pursue more in-depth discussions among experts. The workshop was by invitation. It gathered 52 participants from 19 countries (full list of participants in **Annex 3**). During this workshop, participants: (i) identified the main promising innovative technologies for the forest sector in the region; (ii) explored the different functions they can perform along the value chain; (iii) illustrated their associated challenges and opportunities in different contexts with some specific case studies; and (iv) discussed the main technical, socioeconomic and institutional bottlenecks to technology dissemination and adoption and the needed transformations. Based on these very rich discussions, participants collectively suggested possible recommendations for decision makers, directed specifically to four different stakeholder groups: (i) public actors; (ii) private actors; (iii) civil society and local communities; (iv) research and academic institutions. Detailed results of this workshop are gathered in Pingault et al. (2021a). The following colleagues, who actively contributed to the success of this workshop as organizers, speakers, chairs or rapporteurs, deserve particular thanks: Illias Animon, Lyndall Bull, Oliver Coroza, Lobzang Dorji, Vincent Gitz, Jalaluddin Harun, Thomas Hofer, Shahrukh Kamran, Yanxia Li, Bas Louman, Andrew Lowe, Rao Matta, Alexandre Meybeck, CTS Nair, Tony Page, Marco Piazza, Nathanaël Pingault,

Vu Tan Phuong, Ravi Prabhu, James M. Roshetko, Lok Mani Sapkota, Nguyen Quang Tan, Junqi Wu and Shengfu Wu.

In parallel, a web consultation and individual interviews were conducted, which attracted further contributions from 69 people (full list in **Annex 4**). Special thanks to Tran Thi Minh Ngoc and Duong Minh Tuan, from the ICRAF Office in Hanoi, Viet Nam, who conducted the interviews with experts and compiled the information from the interviewers and surveys. A call for abstracts was also organized, directed specifically at young students and young people engaged in activities related to the forest sector in the Asia-Pacific region. The 71 abstracts submitted were carefully screened and evaluated by a team of CIFOR/ICRAF experts based on a set of criteria including clarity, originality and potential for transformative impact on the forest sector in the region. Some of the authors of the selected abstracts were invited to participate in the November-December 2020 technologies workshop, where they brought unique contributions and a forward-looking perspective (Pingault et al. 2021a). Twenty young authors were invited to develop a full paper illustrating the application of innovative technologies in the forest sector in Asia and the Pacific. A publication gathers the 13 papers that were successfully developed through the process of abstract submission, drafting, paper submission, review, revision, edition and final validation. Their main authors deserve warm thanks for having participated in this difficult and demanding exercise: Clarence Gio S. Almoite, Nur Bahar, Marie Jessica Gabriel, Prachi Gupta, Cecille de Jesus, Shahrukh Kamran, Sony Lama, Kyuho Lee, June Mandawali, Deasy Ramatia, Angga Saputra, Thuan Sarzynski, Sanjaya Raj Tamang. Similar thanks are extended to all of their co-authors (full list of youth paper authors and titles in **Annex 5**). We wish them all a brilliant career in the forest sector.

At the end of the process, an expert online validation workshop was organized from 23–24 November 2021 to present the main findings and overarching recommendations emerging from this study and discuss the way forward. The workshop attracted a diversified audience of 85 experts from 26 different countries, representing all key stakeholder groups, including international organizations, governments, private sector, civil society, research and academia (full list of participants in **Annex 6**). During this workshop, participants highlighted the huge potential of innovative technologies to improve the performance of the forest sector in Asia and the Pacific. They also called for the adoption of innovative and people-centered approaches to primary forest conservation. During this workshop, the APFC, its member countries and relevant stakeholders were encouraged to roll out the roadmap process proposed in this study. This collective process needs to be properly coordinated and articulated across sectors, actors and scales. The following colleagues, who actively contributed to the success of this workshop as organizers, speakers, chairs or rapporteurs, deserve particular thanks: Keiran Andrusko, Nadine Azzu, Federica Coccia, Lobzang Dorji, Vincent Gitz, Monika Kiczkajlo, Rao Matta, Alexandre Meybeck, Robert Nasi, Nathanaël Pingault, Fabio Ricci, James M. Roshetko and Sheila Wertz-Kanounnikoff.

Annex 2. List of participants to the inception workshop

Table 8 contains basic information on the people who registered for or attended the inception workshop, as provided by the participants themselves in the registration form.

Table 8. Participants to the inception workshop

Name, Given name	Gender	Country	Organization
Amanubo Amos	Male	Uganda	International Forestry Students Association (IFSA)
Animon Illias	Male	Thailand	FAO
Baldwin Brian	Male	Italy	Consultant
Barbour Liz	Female	Australia	University of Western Australia
Binti Farazi	Female	Bangladesh	FAO
Bontuyan Philip	Male	Lao PDR	GIZ
Branthomme Anne	Female	France	FAO
Brawner Jeremy T.	Male	USA	University of Florida
Brown	Male	Australia	Forest Research Institute – USC
Bull Lyndall	Female	Italy	FAO
Byambasuren Oyunsanaa	Male	Mongolia	Department of Forest Policy and Coordination, Ministry of Environment and Tourism, Mongolia
Coroza Oliver	Male	Philippines	Center for Conservation Innovations
De Lu	Male	China	Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet)
Durst Patrick	Male	Thailand	Asia Forests
Edirisinghe Nishantha	Male	Sri Lanka	Forest Department
Ei Ei Swe Hlaing	Female	Myanmar	Forest Research Institute
Elliott Stephen	Male	Thailand	Chiang Mai University
Endozo Claudett	Female	Philippines	Department of Environment and Natural Resources-Forest Management Bureau
Evans Melissa	Female	New Zealand	Scion
Faisal Hussain	Male	Maldives	Ministry of Fisheries, Marine Resources and Agriculture
Gan Kee-Seng	Male	Malaysia	Asia Pacific Association of Forestry Research Institutions (APAFRI)
Gerrand Adam	Male	Indonesia	FAO
Gitz Vincent	Male	Indonesia	CIFOR/FTA
Hampton Ross	Male	Australia	Australian Forest Products Association (AFPA)
Hansen Eric	Male	USA	Oregon State University
Herbohn John	Male	Australia	University of the Sunshine Coast
HJ. Abdul Khalim Bin HJ. Abu Samah	Male	Malaysia	Forestry Department Peninsular Malaysia
Hofer Thomas	Male	Thailand	FAO

Name, Given name	Gender	Country	Organization
Inthirath Baisone	Female	Lao PDR	National Agriculture and Forestry Research Institute (NAFRI), Ministry of Agriculture and Forestry (MAF)
Jadin Jenna	Female	Thailand	RECOFTC - The Center for People and Forests
Jigme Dorji	Male	Bhutan	Department of Forest and Park Services
Johnson Kristofer	Male	Bangladesh	FAO
Joowon Park	Female	Republic of Korea	Asian Forest Cooperation Organization (AFoCO)
Kabigting Ray Thomas	Male	Philippines	Department of Environment and Natural Resources-Forest Management Bureau
Keenan Rodney	Male	Australia	University of Melbourne
Kong Young-Ho	Male	Cambodia	Korea-Mekong Forest Cooperation Center
Kono Marija	Female	USA	US Forest Service International Programs
Laumonier Yves	Male	Indonesia	Center for International Forestry Research (CIFOR)
Lee Stephanie	Female	Canada	Independent Consultant
Li Yanxia	Female	China	International Bamboo and Rattan Organisation (INBAR)
Mahoney Jesse	Male	Australia	Australian Government Department of Agriculture, Water and the Environment
Mateboto Jalesi	Male	Fiji	Pacific Community (SPC, formerly the South Pacific Commission)
Matta Rao	Male	Thailand	FAO
May Mike	Male	Brazil	Suzano/FuturaGene
Meechantra Kallaya	Female	Thailand	FAO
Meybeck Alexandre	Male	Italy	CIFOR/FTA
Nair CTS	Male	India	none - Formerly FAO
Nasi Robert	Male	Indonesia	Center for International Forestry Research (CIFOR)
Nguyen Manh Hiep	Male	Viet Nam	Department of Protected Forest Management
Norbu Chencho	Male	Bhutan	Asian Forest Cooperation Organization (AFoCO)
Norbu Wangdi	Male	Bhutan	Department of Forests and Park Services
Nyi Nyi Kyaw	Male	Myanmar	Forest Department
Ogawa Shun	Male	Japan	Forestry Agency
Page Tony	Male	Australia	University of the Sunshine Coast
Pauig Cathy	Female	Philippines	Department of Environment and Natural Resources-Forest Management Bureau
Payn Tim	Male	New Zealand	Scion
Payuan Edwin	Male	Lao PDR	RECOFTC - The Center for People and Forests
Piazza Marco	Male	Thailand	FAO
Pingault Nathanaël	Male	Italy	CIFOR/FTA
Putz Jack	Male	USA	University of Florida

Name, Given name	Gender	Country	Organization
Quyen Nguyen	Female	Viet Nam	Asian Disaster Preparedness center
Rico Edmund Leo	Male	Philippines	Center for Conservation Innovations
Rocas Nelissa Maria B.	Female	Philippines	Department of Environment and Natural Resources-Forest Management Bureau
Roshetko James M.	Male	Indonesia	ICRAF, World Agroforestry
Sapkota Lok Mani	Male	Thailand	RECOFTC - The Center for People and Forests
Sarigumba Maria Paula	Female	Philippines	University of Saskatchewan
Shengfu Wu	Male	China	China National Forest Products Industry Association
Silori Chandra	Male	Thailand	RECOFTC - The Center for People and Forests
Sinha Rakesh	Male	India	FAO
Smithies Chris	Male	Lao PDR	Earth Systems
Suntra Hang	Male	Cambodia	Forestry Administration
Tacconi Luca	Male	Australia	The Australian National University
Tandin	Male	Bhutan	Department of Forest and Park Services
Thaung Naing Oo	Male	Myanmar	Forest Department
Ugyen	Male	Bhutan	Jomotsangkha Wildlife Sanctuary
Ujihashi Ryosuke	Male	Japan	Forestry Agency of Japan
Uzzaman Arfan	Male	Bangladesh	FAO
Vave Uatea	Male	Tuvalu	Department of Agriculture
Vigulu Vaeno	Male	Solomon Islands	Solomon Islands Government
Vongsouthi Kevaly	Female	Lao PDR	Earth Systems
Walter Sven	Male	Italy	FAO
Woodgate	Male	Australia	SmartSat CRC
Xi Luo	Female	China	Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet)
Yamanoshita Makino	Female	Japan	Institute for Global Environmental Strategies
Yasmi Yurdi	Male	Cambodia	International Rice Research Institute (IRRI)
Yong Harry	Male	Malaysia	Forestry Department Peninsular Malaysia
Yutaka Machida	Male	Japan	Forestry Agency
Zahari bin Ibrahim	Male	Malaysia	Forestry Department Peninsular Malaysia
Zhe Kong	Female	China	Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet)

Annex 3. List of participants to the technologies workshop

Table 9 contains basic information on the people that registered for or attended the technologies workshop, as provided by the participants themselves in the registration form.

Table 9. Participants to the innovative technologies workshop

Family Name	Given Name	Gender	Duty country	Organization
Abdul Bahar	Nur Hazwani	Female	Malaysia	Tropical Rainforest Conservation and Research Centre
Almoite	Clarence Gio	Male	Philippines	Benguet State University
Animon	Illias	Male	Thailand	FAO
Aziz	Dania	Female	Malaysia	UPM
Bontuyan	Philip	Male	Lao PDR	GIZ
Bull	Lyndall	Female	Italy	FAO
Coroza	Oliver	Male	Philippines	Center for Conservation Innovation, Philippines
Dickinson	Chris	Male	Republic of Korea	Global Green Growth Institute (GGGI)
Dorji	Lobzang	Male	Bhutan	Department of Forest and Park Services
Gabriel	Marie Jessica	Female	Denmark	University of Copenhagen
Ganguly	Indroneil	Male	United States	University of Washington
Ganz	David	Male	Thailand	RECOFTC
Gitz	Vincent	Male	Indonesia	Center for International Forestry Research (CIFOR)/FTA
Harun	Jalaluddin	Male	Malaysia	Academy of Science Malaysia (ASM)
Hasna Farhatani	Naura	Female	Indonesia	International Forestry Students Association (IFSA)
Hofer	Thomas	Male	Thailand	FAO
Jinger	Dinesh	Male	India	ICAR-Indian Institute of Soil and Water Conservation, Research Centre-Vasad, Anand, Gujarat
Kamran	Shahrukh	Male	Germany	Eberswalde University for Sustainable Development
Keenan	Rod	Male	Australia	University of Melbourne
Kieft	Johan	Male	Indonesia	UN Environment, Tropical Landscape Finance Facility
Lee	Kyuho	Male	Thailand	Environmental Science Program, Chiang Mai University
Li	Yanxia	Female	China	International Bamboo and Rattan Organisation (INBAR)
Liagre	Ludwig	Male	Luxembourg	Rio Impact
Louman	Bas	Male	the Netherlands	Tropenbos

Lowe	Andrew	Male	Australia	University of Adelaide
Matta	Rao	Male	Thailand	FAO
Mavinkal Ravindran	Krishnanunni	Male	Denmark	University of Copenhagen
Meybeck	Alexandre	Male	Italy	CIFOR/FTA
Midgley	Stephen	Male	Australia	Salwood Asia Pacific Pty Ltd
Nair	C T S	Male	India	Independent Consultant - Formerly FAO official
Nasi	Robert	Male	Indonesia	CIFOR
Nguyen	Quang Tan	Male	Viet Nam	World Agroforestry (ICRAF)
Oetomo	Bangkit	Male	Indonesia	Tropical Landscapes Finance Facility
Page	Tony	Male	Australia	University of the Sunshine Coast
Payn	Tim	Male	New Zealand	Scion
Phuong	Vu Tan	Male	Viet Nam	Viet Nam Academy of Forest Sciences
Piazza	Marco	Male	Thailand	FAO
Pingault	Nathanaël	Male	Italy	CIFOR/FTA
Prabhu	Ravi	Male	Kenya	ICRAF
Reza	Selim	Male	Ethiopia	INBAR
Roshetko	James	Male	Indonesia	ICRAF/FTA
Sapkota	Lok Mani	Male	Thailand	RECOFTC
Saputra	Angga	Male	Indonesia	IPB University
Sarzynski	Thuan	Male	Viet Nam	CIRAD
Sheikh Ab Kadir	Abdul Aziz	Male	Malaysia	IRRDB
Sihanath	Dalaphone	Female	Laos	International Finance Corporation (IFC)
Steel	E. Ashley	Female	Italy	FAO
Togado	Raiza Mae	Female	Philippines	Department of Environment and Natural Resources
Wicaksono	Satrio Adi	Male	Malaysia	European Forest Institute
Wu	Junqi	Female	China	INBAR
Wu	Shengfu	Male	China	China National Forest Products Industry Association
Yong	Harry	Male	Malaysia	Forestry Department of Peninsular Malaysia

Annex 4. List of experts participating in interviews or contributing to web consultation

Table 10. Experts consulted through interviews or web-consultation

Name, Given name	Gender	Country	Organization
Bin Ibrahim Hassan	Male	Singapore	National Park Board
Bin Wan Ahmad Wan Mohd. Shukri	Male	Malaysia	Forest Research Institute Malaysia (FRIM)
Bounpasakxay Khamphoumi	Male	Laos	Forestry Research Center, National Agriculture and Forestry Research Institute
Catacutan Delia	Female	Philippines	ICRAF
Coroza Oliver	Male	Philippines	Center for Conservation Innovations
De Royer Sebastien	Male	Indonesia	Transitions / Livelihood Ventures
Dewi Sonya	Female	Indonesia	ICRAF
Durst Patrick	Male	Thailand	Independent Consultant
Dziafa Etonam	Male	Ghana	Kwame Nkrumah University of Science and Technology
Elayaraja Arjunan	Male	India	AALAMARAM (36150)
Enow Andrew Egbe	Male	Cameroon	University of Buea
Gan Kee Seng	Male	Malaysia	Forest Research Institute Malaysia (FRIM)
Ganz David	Male	Thailand	RECOFTC – The Center for People and Forests
Gavin Matthew	Male	Australia	Australian Forest Products Association (AFPA)
Gupta Pramod	Male	USA	Trees for the Future Lcc
Haagan Anders	Male	Philippines	Lionheart Agrotech Ltd
Hansen Eric	Male	USA	Oregon State University
Holt Lania	Female	New Zealand	SCION
Inthirath Baisone	Female	Laos	Forestry Research Center (FRC), National Agriculture and Forestry Research Institute (NAFRI), Ministry of Agriculture and Forestry (MAF)
Jalonen Riina	Female	Malaysia	Bioversity International
Johana Feri	Male	Indonesia	ICRAF
Kamran Shahrukh	Male	Pakistan	Eberswalde University for Sustainable Development, Germany; Warsaw University of Life Sciences, Poland
Kieft Johan	Male	Netherlands	UNEP / Tropical Landscape Finance Facility
Kinga Veye Estlla	Female	Cameroon	UN Women
Keenan Rodney	Male	Australia	University of Melbourne
Kleine Michael	Male	Germany	IUFRO
Kyaw Nyi	Male	Myanmar	Forest Research Center
Lee Soon Leong	Male	Malaysia	Forest Research Institute Malaysia (FRIM)
Lu De	Male	China	APFnet

Name, Given name	Gender	Country	Organization
Maharjani Sajeen	Male	Nepal	Environment Nepal
Mahoney Jesse	Male	Australia	Department of Agriculture Water and the Environment
Malahayati Marissa	Female	Indonesia	National Institute for Environmental Studies (NIES)
Mbangilwa Michel	Male	Congo	ICCN (government agency)
McWhirter Luke	Male	Laos	Burapha Agro-Forestry Co. Ltd.
Melo Jorge Alvarez	Male	Peru	Universidad Nacional Agraria de la Selva
Muhammad Thoha Zulkarnain	Male	Indonesia	ICRAF
Nair CTS	Male	India	Independent Consultant /Farmer
Nguyen Mai Phuong	Female	Viet Nam	ICRAF
Nguyen Nghia Bien	Male	Viet Nam	Forest Inventory and Planning Institute (FIPI) of Viet Nam
Nguyen Quyen Hanh	Female	Viet Nam	Asian Disaster Preparedness center (ADPC)
Norbu Chencho	Male	Republic of Korea	Asian Forestry Cooperation Organization (AFoCO)
Nugraha Alfa	Male	Indonesia	ICRAF
Oetomo Bangket	Male	Indonesia	Tropical Landscapes Finance Facility
Olajide Alaba Joseph	Male	Nigeria	Blackcamel Energy Ltd
Oli Bishwa Nath	Male	Nepal	Ministry of Forests and Environment
Page Tony	Male	Australia	University of the Sunshine Coast
Palomar Audrey	Male	Philippines	Center for Conservation Innovations
Pandiwijaya Arga	Male	Indonesia	ICRAF
Payn Tim	Male	New Zealand	SCION
Perdana Aulia	Male	Indonesia	ICRAF
Sapkota Lok Mani	Male	Thailand	RECOFTC - The Center for People and Forests
Shengu Wu	Male	China	China National Forest Products Industry Association
Sin Thant	Male	Myanmar	Forest Department, Ministry of Natural Resources and Environmental Conservation
Smithies Chris	Male	Laos	Earth Systems Laos
Stone Christine	Female	Australia	New South Wales Department of Primary Industries
Subedi Suman	Male	Nepal	Ministry of Forests and Environment
Syaharani	Female	Indonesia	Student
Tan Lorraine	Female	Singapore	National Parks Board
Thammavong Bansa	Male	Laos	Forest Research Centre, NAFR
Trinh Long Thang	Male	China	INBAR
Vo Dai Hai	Male	Viet Nam	Viet Nam Academy of Forest Sciences (VAFS)
Wancour Lindsay	Female	USA	Adventure Scientists
Warman Russell	Male	Australia	University of Tasmania

Name, Given name	Gender	Country	Organization
Wesonga Frank	Male	Kenya	African Alliance for Healthy Research and Economic Environmental Development
Woodgate Peter	Male	Australia	SmartSat Cooperative Research Centre
Wultof Ndong Bass Innocent	Male	Cameroon	Independent Consultant
Yamanoshita Makino	Female	Japan	Institute for Global Environmental Strategies
Yanxia Li	Female	China	INBAR
Institutional response		Australia	Department of Agriculture, Water and the Environment, and Primary Industries (South Australia)

Annex 5. List of authors and titles of the youth papers

Table 11. Youth contributions to the roadmap of innovative forest technologies

Pages*	Authors	Title
5-19	Bahar, NHA & Wicaksono, SA	How to effectively engage youth in satellite-based tropical forest monitoring?
21-34	Lama, S, Shrestha, S & Sherpa, AP	Forest Watcher: Employing citizen science in forest management of Nepal
35-41	Sarzynski, T, Rege, A, Warnekar, SB, Wu, S & Lee, JSH	Google Earth Engine, an innovative technology for forest conservation
43-47	de Jesus, C	Follow the water: Advanced technologies for demonstrating forest–water–community relationships
49-59	Gabriel, MJ & Ravindran, KM	Spatial Monitoring and Reporting Tool (SMART) for innovative forest governance: Insights from Asia-Pacific countries
61-74	Lee, K	UAV-derived forest degradation assessments for planning and monitoring forest ecosystem restoration: towards a forest degradation index
75-87	Saputra, A, Prasetyo, LB & Rahadian, A	Estimating tree height, canopy cover, and tree diameter with unmanned aerial vehicle (UAV) technology
89-105	Kamran, S, Linde, A & Ullmann, W	Development, testing and implementation of insect catching drones
107-116	Tamang, SR & Sharma, L	Invasive species management in Nepal; a pathway to sustainable forest management
117-126	Mandawali, J	Factors affecting community-based tree nurseries in the Ramu-Markham Valley of Papua New Guinea
127-137	Almoite, CGS & Togado, RML	Building back for Philippine biodiversity through geotagging mother tree species for modernized and mechanized forest nurseries
139-148	Gupta, P, Bisht, D, Kandpal, V & Gupta S	Advances in the wood anatomical studies with innovations in microscopy: A review
149-164	Ramatia, D, Syamani, FA & Hermawan D	Literature review of production process and self-bonding mechanisms in binderless particleboard

*Source: Pingault N, Roshetko JM, Meybeck A. eds. 2021. Asia-Pacific forest sector outlook: Innovative forestry for a sustainable future. Youth contributions from Asia and the Pacific. Working paper No. 10. Bogor, Indonesia: CGIAR Research Program on Forests, Trees and Agroforestry and Rome, Italy: Food and Agriculture Organization of the United Nations. DOI: 10.17528/cifor/008199

Annex 6. List of participants to the validation workshop

Table 12 contains basic information on the people who registered for the validation workshop, as provided by the participants themselves in the registration form.

Table 12. Participants to the validation workshop

Name Surname	Gender	Country	Organization
Almoite Clarence Gio	Male	Philippines	Benguet State University
Andrusko Keiran	Male	Australia	Australian Department of Agriculture, Water and the Environment
Arjunan Elayaraja	Male	India	Aalamaram-banyan tree
Azzu Nadine	Female	Italy	CIFOR-ICRAF/FTA
Bajaj Megha	Female	Nepal	Asian Institute of Technology
Bounithiphonh Chaloun	Male	Lao PDR	National Agriculture and Forestry Research Institute (NAFRI)
Branthomme Anne	Female	Italy	FAO
Bull Lyndall	Female	Italy	FAO
Coccia Federica	Female	Italy	CIFOR/FTA
Coroza Oliver	Male	Philippines	Center for Conservation Innovation Ph Inc.
De Lu	Male	China	APFNet
Dorji Lobzang	Male	Bhutan	Department of Forests and Parks Services, Ministry of Agriculture and Forests
Durst Patrick	Male	Thailand	Independent consultant
Esguerra Elise Gabrielle	Female	Philippines	Forest Management Bureau
Faisal Hussain	Male	Maldives	Ministry of Fisheries, Marine Resources and Agriculture
Gabriel Marie Jessica	Female	Philippines	University of the Philippines Los Baños
Game Edward	Male	Australia	The Nature Conservancy
Gan Kee Seng	Male	Malaysia	Asia-Pacific Association of Research Institutions (APAFRI)
Gerrand Adam	Male	Indonesia	FAO
Gitz Vincent	Male	Italy	CIFOR-ICRAF/FTA
Hansen Eric	Male	USA	Oregon State University
Inthirath Baisone	Female	Lao PDR	National Agriculture and Forestry Research Institute (NAFRI)
Ioannou Anna	Female	Thailand	FAO
Jalaluddin Harun	Male	Malaysia	Academy of Science Malaysia (ASM)
Jalonen Riina	Female	Malaysia	Alliance of Bioversity International and CIAT
Johnson Kristofer	Male	United States of America	FAO

Name Surname	Gender	Country	Organization
Kamran Shahrukh	Male	Germany	Eberswalde University for Sustainable Development
Kasturi Devi Kanniah	Female	Malaysia	Universiti Teknologi Malaysia
Keenan Rodney	Male	Australia	University of Melbourne
Kotru Rajan	Male	India	Trestle Management Advisors
Lama Sony	Female	Nepal	Red Panda Network
Laumonier Yves	Male	Indonesia	CIFOR-ICRAF/FTA
Li Yanxia	Female	China	International Bamboo and Rattan Organisation
Louman Bas	Male	Netherlands	Tropenbos International
Machida Yutaka	Male	Japan	Forestry agency
Mackey Brendan	Male	Australia	Griffith University
Maharjan Sajeen	Male	Nepal	Environment Nepal
Mandawali June	Female	Papua New Guinea	Papua New Guinea Forest Research Institute
Masigan Jennica Paula	Female	Philippines	Center for Conservation Innovation Ph Inc.
Mateboto Jalesi	Male	Fiji	Pacific Community (SPC)
Matta Rao	Male	Thailand	FAO
May Mike	Male	Spain	FuturaGene Suzano
Meybeck Alexandre	Male	Italy	CIFOR-ICRAF/FTA
Name Surname	Gender	Country	Organization
Nair C T S	Male	India	Freelance Consultant
Nasi Robert	Male	Indonesia	CIFOR-ICRAF
Negi Vikram	Male	India	Govind Ballabh Pant National Institute of Himalayan Environment
Oyunsanaa Byambasuren	Male	Mongolia	Department of Environment and Forest Engineering, National University of Mongolia
Palomar Jamila Audrey	Female	Philippines	Center for Conservation Innovation
Park Joowon	Female	Republic of Korea	Asian Forest Cooperation Organization
Patriarca Chiara	Female	Italy	FAO
Payn Tim	Male	New Zealand	Scion
Perkin Scott	Male	Thailand	IUCN Asia Regional Office
Pham Thu Thuy	Female	Viet Nam	CIFOR-ICRAF
Phongoudome Chanhsamone	Male	Lao PDR	National Agriculture and Forestry Research Institute (NAFRI)
Piazza Marco	Male	Thailand	FAO
Pin Kar Yong	Male	Malaysia	Asia-Pacific Association of Research Institutions (APAFRI)

Name Surname	Gender	Country	Organization
Pingault Nathanaël	Male	Italy	CIFOR-ICRAF/FTA
Pouli Tolusina	Male	Samoa	Forestry Division, Ministry of Natural Resources and Environment
Prabhu Ravi	Male	India	CIFOR-ICRAF
Rai Arun	Male	Bhutan	FRMD, DoFPS, MoAF
Ramatia Deasy	Female	Indonesia	IPB
Roshetko James M.	Male	Indonesia	CIFOR-ICRAF/FTA
Sapkota Lok	Male	Nepal	RECOFTC
Sarigumba Maria Paula	Female	Philippines	University of Saskatchewan
Sarzynski Thuan	Male	Viet Nam	CIRAD
Satkuru Sheam	Female	Japan	International Tropical Timber Organization
Sihanath Dalaphone	Female	Lao PDR	IFC
Silori Chandra Shekhar	Male	Thailand	RECOFTC
Sobhan Md Istiak	Male	Bangladesh	World Bank
Steel Ashley	Female	Italy	FAO
Tamang Sanjaya Raj	Male	Nepal	ForestAction Nepal
Temphel KJ	Male	Bhutan	Department of Forests and Parks Services, Ministry of Agriculture and Forests
Tenneson Karis	Female	United States of America	Spatial Informatics Group
Togado Raiza Mae	Female	Philippines	Department of Environment and Natural Resources
Triraganon Ronnakorn	Male	Thailand	RECOFTC
Tshering Ugyen	Male	Bhutan	Department of Forests and Parks Services, Ministry of Agriculture and Forests
Vongvilay Vongkhamsao	Male	Lao PDR	National Agriculture and Forestry Research Institute (NAFRI)
Wertz-Kanounnikoff Sheila	Female	Thailand	FAO
Wijaya Arief	Male	Indonesia	WRI Indonesia
Woodgate Peter	Male	Australia	Esus Pty Ltd
Wu Junqi	Female	China	International Bamboo and Rattan Organisation
Xi Luo	Female	China	APFNet
Yudi Setiawan	Male	Indonesia	Environmental Research Center, IPB University
Zangpo Dawa	Male	Bhutan	Department of Forests and Parks Services, Ministry of Agriculture and Forests
Zhang Shiyi	Female	China	APFNet

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Innovative technologies – from digital technologies, biological technologies, processing technologies and new wood-based products, to social innovations and innovative finance mechanisms – have the potential to revolutionize forest management and to make critical contributions to sustainable development along forest value chains. Innovation will be key in the coming decades, to meet an increasing demand for wood and forest products and services while halting and reversing deforestation, in line with the commitment taken at COP26 in Glasgow by the international community. However, innovative technologies uptake has been slow and uneven in the Asia-Pacific region and divides remain between political commitments and the required investments, in education, capacity building and infrastructure development, required to facilitate adoption on the ground. To address these issues, FAO and the Center for International Forestry Research (CIFOR), lead center of the CGIAR research programme on Forests, Trees and Agroforestry (FTA) have developed a roadmap for the uptake and scaling up of innovative technologies in the forest sector in Asia and the Pacific, building upon state-of-the-art knowledge, and extensive consultation of key regional stakeholders. This publication explores possible ways and suggests concrete recommendations for policy- and decision-makers to support the dissemination and adoption of innovative technologies' dissemination and adoption in Asia and the Pacific and to overcome current barriers.

The CGIAR Research Program on Forests, Trees and Agroforestry (FTA) is the world's largest research for development program to enhance the role of forests, trees and agroforestry in sustainable development and food security and to address climate change. CIFOR leads FTA in partnership with Bioversity International, CATIE, CIRAD, ICRAF, INBAR and TBI.

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CIFOR

foreststreesagroforestry.org

cgiarforestsandtrees@cgiar.org

@FTA_CGIAR

foreststreesagroforestry

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