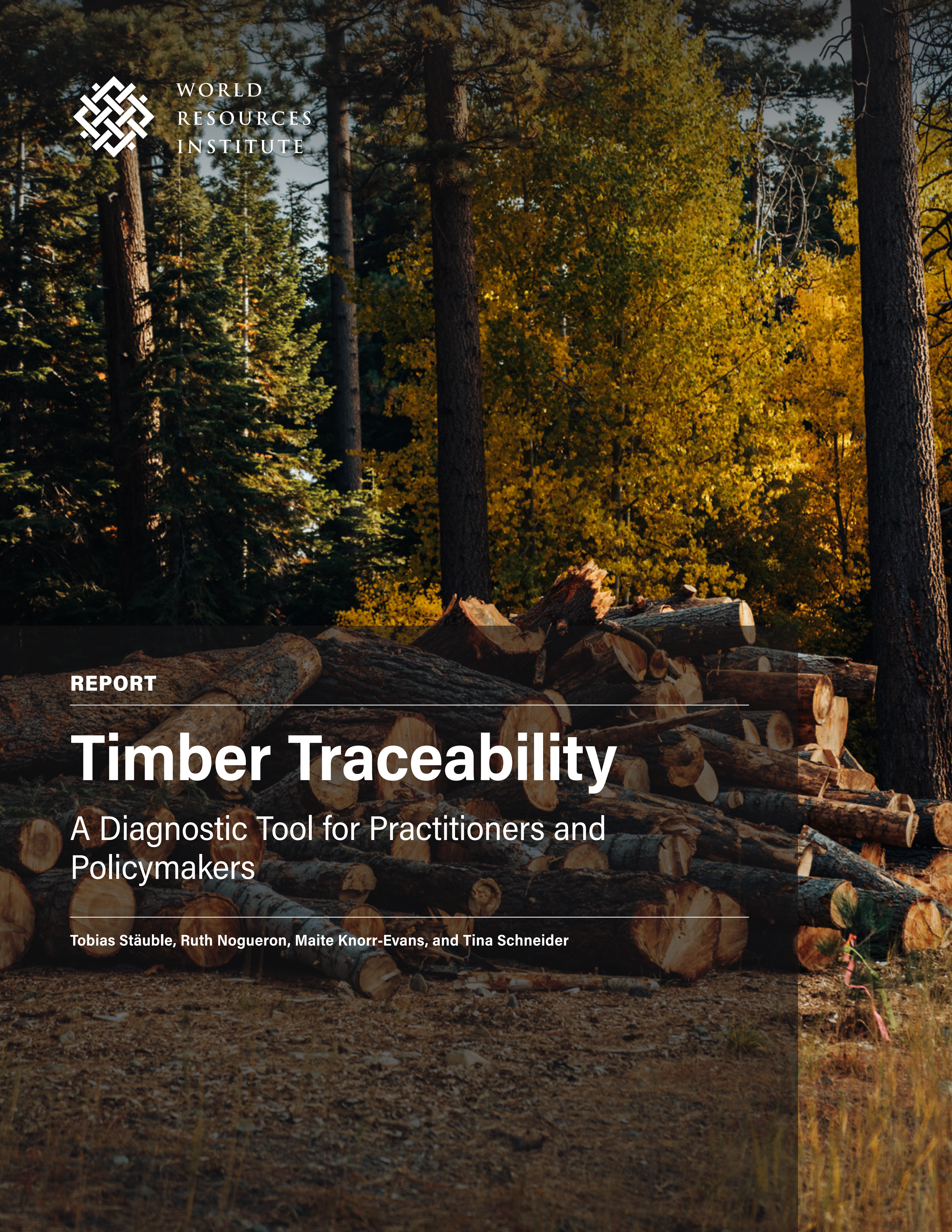

WORLD RESOURCES INSTITUTE

REPORT

Timber Traceability

A Diagnostic Tool for Practitioners and Policymakers

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Foreword

For decades, environmental activists have been calling for an end to the global destruction of tropical forests. Yet, the steps various corporations and governments have taken to limit deforestation have resulted in uneven progress, with tropical forest loss trends continuing to worsen between 2021 and 2022 despite recent international commitments.

In May 2023, the European Union (EU) adopted a historic regulation that marked the beginning of a new approach. It was the first substantial international attempt to address deforestation at its roots: human consumption. The EU took a system-wide approach by aiming to eliminate the region's consumption of products and commodities linked to deforestation and forest degradation.

To address the role of human consumption in driving global deforestation, governments, corporations, and consumers must be able to trace which products are tied to forest loss. This kind of traceability has already become crucial in policies covering a wide range of commodities and products, from valuable minerals to seafood and more. But it is the forest—and more specifically the timber sector—where a number of countries have already been pushing traceability through government-owned systems.

Over the past two decades, governments in at least 20 countries have established or are in the process of developing mandatory timber traceability systems. These efforts have grown in response to calls for better stewardship of natural resources, demands of international markets, and a desire to capture taxes and royalties.

Building on the recent experiences and lessons from different countries, including seven recent case studies from Latin America, this report offers a practical analytical framework to plan, develop, implement, and maintain robust government-led timber traceability systems. The framework breaks down the various aspects of a traceability system and offers guidance to engage and get buy-in from private sector actors that need to report information, and to tailor data collection and verification approaches to their context. This report also offers guidance on maintaining the financial sustainability of traceability systems while meeting broader objectives that support positive outcomes for people, nature, and climate.

As time passes, more and more consumers are looking for alternatives to unsustainable and unethical products. The early experiences in the forest sector can provide valuable lessons going forward. While this framework focuses on the timber sector, much of the guidance can also be adapted to other commodity supply chains. Stakeholders in the initial stages of developing and implementing these systems have a starting point for a successful road map. Global deforestation cannot be stopped unless we understand and tackle it from the roots.

ANI DASGUPTA

President and CEO
World Resources Institute

Executive summary

Traceability is recognized as important for the legitimacy and credibility of natural resource management, and as a tool to support and demonstrate compliance with legality and sustainability requirements.

Many governments have considered, or are developing, traceability systems to better monitor legal compliance, facilitate exports to regulated markets, formalize the sector, or enhance forest resources management.

This guide supports the implementation of government-led timber traceability systems by providing practical guidance and discussion on the key considerations that must be assessed to develop and implement systems that are appropriate to their context and responsive to the needs of stakeholders.

HIGHLIGHTS

- Traceability is increasingly recognized as important for the legitimacy and credibility of natural resource sectors, with the forest sector leading the development of traceability systems in many countries. However, in many agencies in charge of oversight there is limited capacity and know-how to plan, develop, and implement traceability systems and, in some cases, limited political will (Stäuble et al. 2022).
- This guide seeks to support the implementation of government-led timber traceability systems by providing practical guidance and discussion on the key considerations decision-makers and system designers must assess to develop and implement systems that are appropriate to their context and responsive to their needs.
- To ensure timber traceability systems meet expectations, system developers need to make appropriate choices regarding the scope of the system, data collection, reporting methods, monitoring and verification methods and tools, as well as level of transparency.
- The guide defines key terms and concepts to provide forest oversight agencies with a knowledge base, and it provides a flexible technical framework for designing and implementing timber traceability systems.

BACKGROUND

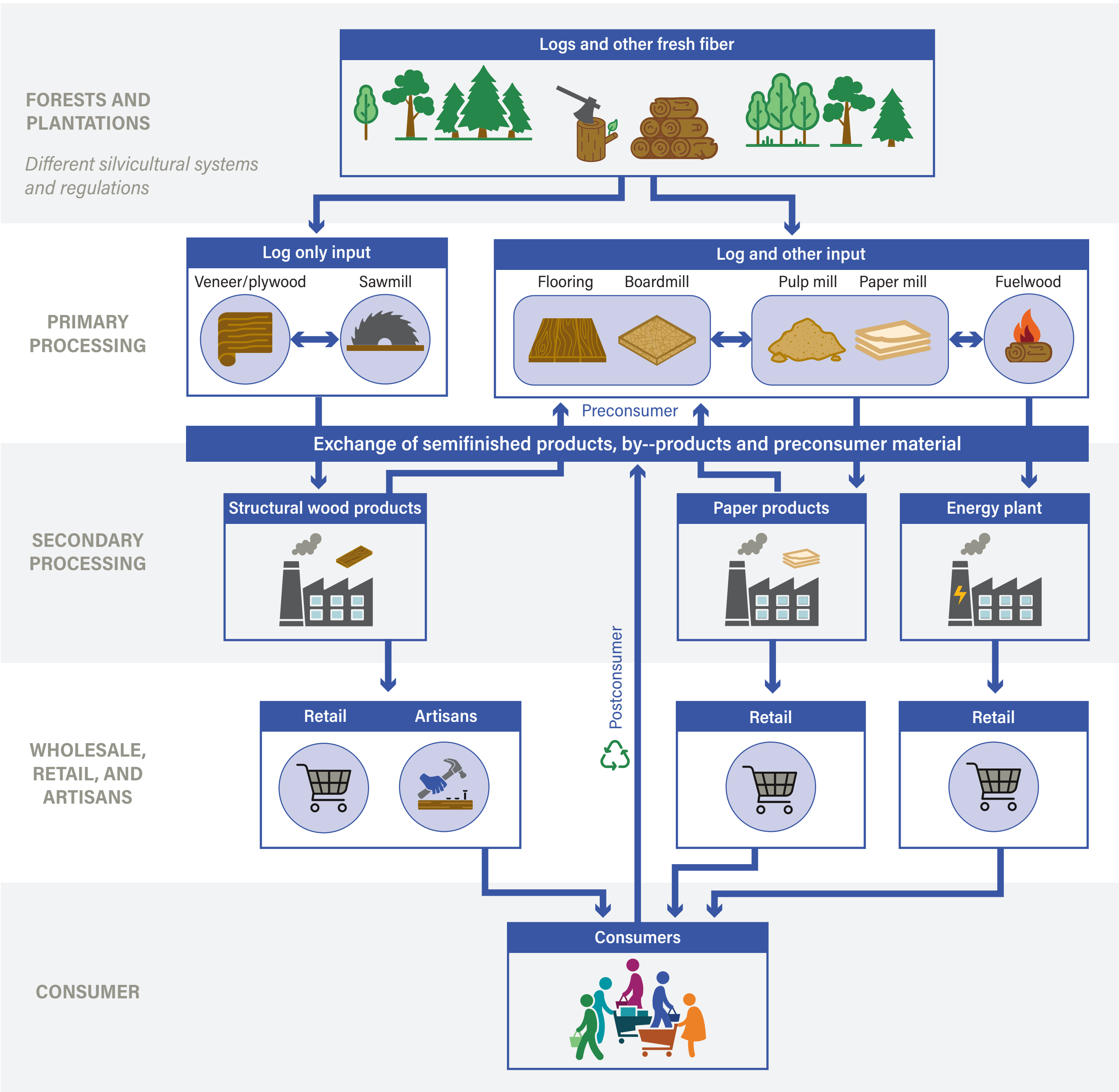
For the purposes of this report, we define *traceability* as the "ability to trace the history, application or location of a product" (GS1 2017; ISO 2015). Traceability can be upstream or downstream. Upstream refers to tracing the product from any given point in the supply chain toward the primary production and processing history. Downstream refers to further processing, distribution, use, recycling, or disposal of the product after delivery. This publication focuses only on traceability for timber.

Traceability is increasingly recognized as an important tool to support business operations' management and quality control, as well as to support and demonstrate compliance with legality and sustainability requirements. More broadly, by increasing supply chain transparency, traceability supports aspects of good governance such as accountability, effectiveness, efficiency, and transparency. For forest products, key global import markets have established requirements to manage the risk of sourcing illegal timber in supply chains; with the resulting increase in the demand of legally sourced forest products, traceability has become more important.

Traceability is an essential steppingstone to demonstrate legality. However, the ability to trace a product to its point of origin does not necessarily make the product legal or sustainable. Instead, by being able to trace the product to its point of origin, producers and buyers are better positioned to assess the risk of sourcing illegal products and are enabled to comply with the law.

Many governments that manage valuable forest resources have considered, or are already developing, traceability systems to better monitor legal compliance, facilitate exports to regulated markets, formalize the sector, or enhance forest resources management. However, forest products supply chains are diverse and complex with multiple actors involved at each stage of the supply chain. Inputs for primary processing originate from several forests or from nonforest timber sources. Inputs from secondary processing stem from multiple sites of primary processing, and additional trade and import of logs, other raw materials, and semifinished products can occur along the supply chain. Further, some products stem from coproducts occurring in primary processing. Thus, rather than a set of linear supply chains, forest products are the result of a supply network (Figure ES-1).

FIGURE ES-1 | Forest sector supply network



Source: Authors.

The supply network of the forest sector illustrates the physical material flows from forest to consumers. In its most comprehensive form, a traceability system could cover the entire network. In practice, the effective scope of traceability systems is smaller.

While interest in government-owned timber traceability systems is growing, there are many ways to design, implement, and maintain these systems. Each system should be designed to fit the objectives, needs, and capacities determined for a particular context. Well-designed and implemented traceability systems can provide legitimacy in international markets and demonstrate that products are compliant with quality standards required by buyers (Stäuble et al. 2022). It is important to provide guidance and support to governments developing traceability systems to make the appropriate decisions.

ABOUT THIS REPORT

This report seeks to provide practical technical guidance to decision-makers and designers of government-sponsored timber traceability systems so that they can better define their needs and design and implement traceability systems that respond to the specific needs and context of the country.

World Resources Institute (WRI) and the Food and Agriculture Organization of the United Nations (FAO) published a set of case studies summarizing the experiences of seven governments in Latin America developing and implementing 11 timber traceability systems (Stäuble et al. 2022). Building on the case studies, this report does the following:

- Introduces the general characteristics, core elements, and key definitions of traceability systems
- Synthetizes the state of knowledge on government-owned traceability systems
- Proposes a comprehensive analytical framework that system developers can use to assess the key issues as they design and implement government timber traceability systems

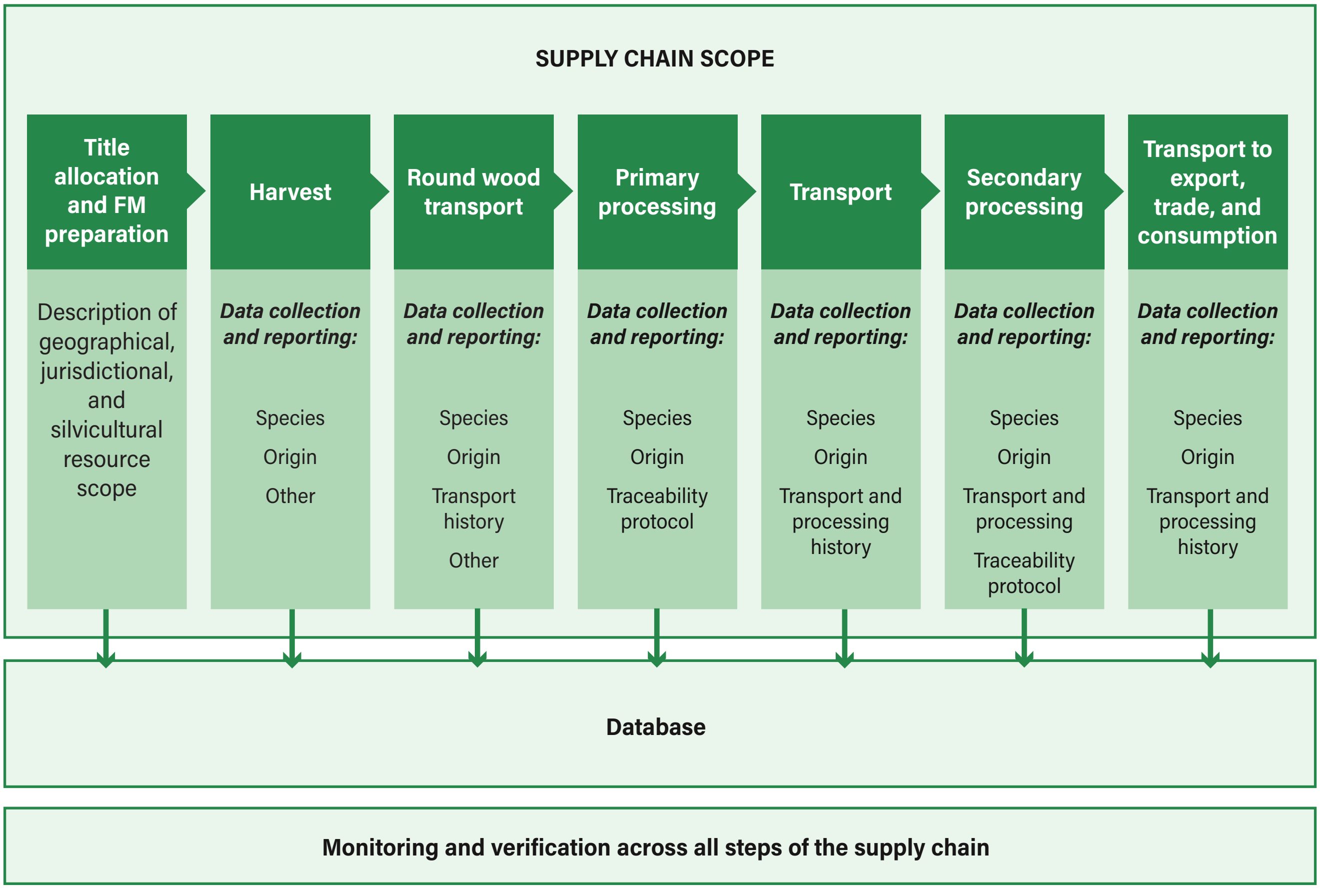
Thus, the first part of the report introduces the general characteristics and core elements of timber traceability systems. The section lays out some fundamental first steps in the development of a public timber traceability system, providing the basis for the second part: the traceability framework. The framework walks system designers through a series of guiding questions as they plan, design, implement, operate, and maintain a traceability system.

The focus is on government-owned traceability systems because these systems are mandatory and meant to be adopted by a variety of private sector stakeholders at a large geographic scale. The report focuses on the technical level while considering the micropolitical and governance levels, in a situation where there is already commitment to set up a traceability system and during its planning, implementation, and operation.

Features, core elements, and key definitions of government-led timber traceability systems

Seeking to standardize the lingo on the topic, the report presents key terms and definitions related to traceability systems, and the type of information that is captured in the different steps of the supply chain to help monitor and verify the claims about the flow of material (Figure ES-2). In addition, the section covers the fundamentals of government-led timber traceability systems. Some aspects covered in this section include how and where timber traceability systems fit into the natural resources management strategies; the geographic, product, and supply chain scopes of timber traceability systems; the two main traceability approaches (i.e, identity preserved and volume-based traceability); and the reporting procedures for different types of forest management. The section also touches briefly on the role of emerging data collection methodologies (e.g., remote sensing and timber identification tools) and data management infrastructure, and how they can be used in timber traceability systems.

FIGURE ES-2 | Generic supply chain and data collected to monitor material flow



Note: FM = Forest management.

Source: Authors.

THE TRACEABILITY FRAMEWORK

The traceability framework proposed in this report breaks down different aspects of the timber traceability system design, development, and implementation process in chunks, seeking to make it more manageable. Thus, the traceability framework is divided into three major phases: planning, implementation, and upkeep (See Table ES-1).

Throughout the report, the framework walks system designers through a series of guiding questions as they design, implement, and operate a traceability system (Table ES-2).

The technical framework is not meant to be prescriptive. It is flexible, and it can be adapted to local circumstances. It includes best practices and examples from governments that have gone through this process, highlighting factors that allowed them to create a system that fits their needs.

CONCLUSION AND RECOMMENDATIONS

To ensure that timber traceability systems meet the objectives they were set up to fulfill, system owners need to make the appropriate choices in system scope, data collection and reporting methods, and monitoring and verification methods, among others. The comprehensive approach to planning proposed in the framework seeks to

TABLE ES-1 | Traceability framework

PHASE	SUBPHASE	CONSIDERATIONS RELATED TO
Planning	Initial considerations	Generating the knowledge base
		Defining objectives, benefits, and indicators
		Financing
		Stakeholder and capacity mapping
		Legal requirements
	Scope	Geography and jurisdiction
		Forest resources
		Supply chain network
		System boundaries
	Design and development	Building a new system vs. adapting an existing system
		Ownership and data sovereignty
		Scope of information
		Data collection and reporting
		Data analysis
		Blocking processes
		Monitoring and verification
Implementation		Priorities for rollout
		Target forest resources for implementation
		Target supply chain priorities for implementation
		Priority functionalities for implementation
		Securing buy-in from private sector for implementation
		Alternative implementation strategies
Upkeep		Strategy review
		Performance tracking
		Alignment of allocated resources with goals
		Comprehensive internal audit
		External audits

Source: Authors.

support traceability system developers in designing well-thought-out systems with a feasible scope and to map out implementation phases that allow for early course correction and improvements when needed.

Since private sector buy-in is crucial for the success of the system, developers should think of means to incentivize system use; for example, via reduced royalties, speedier processes, and reduction of paperwork for early adopters, and by communicating clearly the different benefits expected from the system, as laid out in this publication.

It is neither feasible nor recommendable to roll out a comprehensive national traceability system all at once. System owners need to identify a region, individual forest areas, and entire or partial individual supply chains as a starting point for piloting the system. In each case, there will be different priorities and critical success factors to be considered.

Finally, while this report focuses on timber supply chains, the technical framework can also be applied to address traceability challenges in supply chains for other commodities.

TABLE ES-2 | Traceability framework: Key questions

PLANNING PHASE	
Subphase	**Key questions**
Initial considerations	Objectives and benefits: What will the system accomplish, and how can system owners, users, and other parties track progress?
	Financing: How will the development, implementation, and upkeep of the system be financed?
	Stakeholder and capacity mapping: Who will interact with the system, and how can system owners obtain user buy-in? What is the capacity of the intended users?
	Legal requirements: Are there any existing legal requirements in the forest sector of this geography for managing traceability requirements? Will any laws or regulations need to be drafted or amended for the system to be implemented?
Scope	Geography and jurisdiction: What are the geographical and jurisdictional boundaries of the system?
	Forest resources: Which resources should be covered by the system?
	Supply chain network: Which supply chains (or phases of the supply chains) should be covered, and can specific supply chains be excluded?
	System boundaries: How does the system capture wood entering or exiting the system from outside the scope? And for how long does the system monitor the asset?
Design and development	Building a new system vs. adapting an existing system: Are there existing systems in place that should be considered?
	Ownership and data sovereignty: Who owns the system and the data? How is access to information regulated?
	Scope of information: What information should the system capture?
	Data collection and reporting: How should data be collected and reported?
	Data analysis: How will the system manage and analyze reported data?
	Blocking processes: Where and when should the system block process?
	Monitoring and verification: What tools for monitoring and verification should be applied and how?
Implementation phase: Key questions	
Priorities for rollout: Where should the implementation start?	
Target forest resources for implementation: Which forest resources should be prioritized for implementation?	
Target supply chain priorities for implementation: Which supply chains should be targeted for implementation?	
Priority functionalities for implementation: Should all functionalities be implemented at once?	
Securing buy-in from private sector for the implementation: How can private sector buy-in be secured during the rollout?	
Alternative implementation strategies: Are there alternative strategies for implementation?	
Upkeep phase: Key questions	
Strategy review: Are the objectives and expected benefits of the system up-to-date and valid for its owners, stakeholders, and interested parties?	
Performance tracking: Have the goals defined for the last period been achieved? Are goals for the upcoming period set according to defined Key Performance Indicators?	
Alignment of allocated resources with goals: Are the allocated resources aligned with the goals?	
Comprehensive internal audit: Is an internal audit and review process in place that covers all relevant topics?	
External audits: Is there a need for an external audit?	

Source: Authors.

Introduction

Traceability is an essential steppingstone in achieving and demonstrating legality and sustainability. Producers and buyers are better positioned to assess the risk of sourcing illegal timber and enabled to comply with the law when they can show that the product can be traced back to its origin.

This guide introduces the general characteristics and core elements of government-owned traceability systems, as well as a framework to walk system designers through a series of guiding questions designed to help create a system that fits their needs and expectations.

WHAT IS TRACEABILITY?

A common definition of the term *traceability* is the "ability to trace the history, application or location of a product" (GS1 2017; ISO 2015). Traceability considerations can take an upstream or a downstream perspective from any given point in a supply chain, where the following hold true:

- Upstream traces the product from a given point in the supply chain toward the primary production and processing history.
- Downstream refers to further processing, distribution, use, recycling, or disposal of the product after delivery.

This publication focuses only on traceability for timber. When discussing traceability for timber products, the core questions are typically upstream:

- Which species does the product contain?
- Where did the trees that contributed material to this product come from?
- Were the trees harvested and processed in line with applicable legislation?
- Were the forests from where the trees come managed in a legal and/or sustainable manner?
- What is the pathway of the material through the supply chain network, and how are outputs referred to inputs at each node?

To be able to answer these questions, internal (e.g., tracing materials and products within an organization's processes) and external (e.g., tracing materials and products between organizations) traceability processes are needed.

WHY IS TIMBER TRACEABILITY IMPORTANT IN THE FOREST SECTOR?

Forests play an important role in biodiversity and water management, as carbon sinks, and as sources of food and raw material for local people and in global supply chains. Often timber and fiber are the most important commodities sourced from forests, and many governments seek to develop traceability systems as a tool to ensure that the timber and fiber material extracted from their forests comply with applicable legislation.

Major consumer markets have implemented laws and regulations prohibiting the trade of illegal timber and mandating due diligence to manage the risk of sourcing products made from illegal timber (ClientEarth 2018). With the resulting increase in the demand for legally sourced forest products, traceability has become more important in international markets. In many cases, risk assessment and mitigation in supply chains relies on the efficiency and efficacy of a traceability system. Traceability systems can play an important role in improving decision-making and management of forest resources, thereby reducing illegal logging and deforestation, and contributing to international climate targets. Further, regulated trade of endangered species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) also requires increased levels of traceability (Mundy and Sant 2015).

Traceability is not synonymous with legality or sustainability. However, traceability enables transparency and accountability in supply chains, so it is an essential steppingstone in achieving and demonstrating legality and sustainability. A traceable product is not necessarily legal or sustainable, but producers and buyers are better positioned to assess the risk of sourcing illegal timber and enabled to comply with the law when they can show that the product can be traced back to its origin.

A well-designed traceability system can provide legitimacy in international markets and can also demonstrate that products are compliant with quality standards required by buyers (Stäuble et al. 2022). Many governments that manage valuable forest resources have considered or are already developing traceability systems to better monitor legal compliance, facilitate exports to regulated markets, formalize the sector, or enhance forest resources management.

Box 1 gives an overview of typical benefits and challenges that could result from developing a national timber traceability system.

BOX 1 | List of benefits and challenges of developing a national timber traceability system

The bullets in the list below do not correspond, and they are independent from each other.

Benefits of government-owned traceability systems

- Improved management and monitoring of natural resource use because traceability systems allow compliance and analysis of production and supply chain information to inform resource management decisions
- Monitoring of supply for and demand of the forest industries sector
- Improved communication on the forest sector with domestic and international stakeholders
- Improved ability to collect royalties and taxes from the forest sector–associated industries
- More accurate trade and industry statistics
- Reduced informality by reducing barriers to formality and increased efficiency of regulatory processes
- Positioning of country forest resources as dependable and desirable for buyers interested in the sustainability and legality claims of the products
- Ability to use information systems and technologies to link products to production regions or units to benefit a broad range of supply chain actors, especially smallholders
- Improved governance of forest resources, reduced levels of illegal logging, and reduced deforestation rates

Challenges in the implementation and adoption of traceability systems by government agencies and the private sector

- Weak governance, corruption, and limited political will in some cases because forest resources might not be relevant in national gross domestic product (GDP) balances
- Legal frameworks that are inconsistent and/or require adaptation to enable, e.g., e-government
- Resistance to change from system users, system owners, and other stakeholders affected by the introduction of the system.
- Lack of stakeholder capacity to implement the system
- Inability to secure buy-in from all actors in the supply chain
- Lack of interinstitutional cooperation and implementing capacity and resources, and limited political will
- Lack of financial resources and commitment to continue to fund implementation, maintenance, and upkeep.
- Lack of incentives for good governance

Source: Authors.

Although these barriers and challenges should be considered, the development of a national timber traceability system has already helped achieve some of the benefits listed above. In Honduras, for example, although the traceability system—the Timber Traceability Information Technology System (in Spanish, Sistema Informático de Rastreabilidad de la Madera; SIRMA) is still under implementation, the Honduras forest authority can generate reports with up-to-date information about wood product flows in near real time in the country for selected phases of the supply chain. In Guatemala, where the system is also being implemented, the forest authority keeps track of business transactions through the Electronic Information System for Forest Enterprises (In Spanish, Sistema Electrónico de Información de Empresas Forestales; SEINEF), making it harder for informal or unregistered businesses to sell and transport their products (Stäuble et al. 2022).

OBJECTIVE

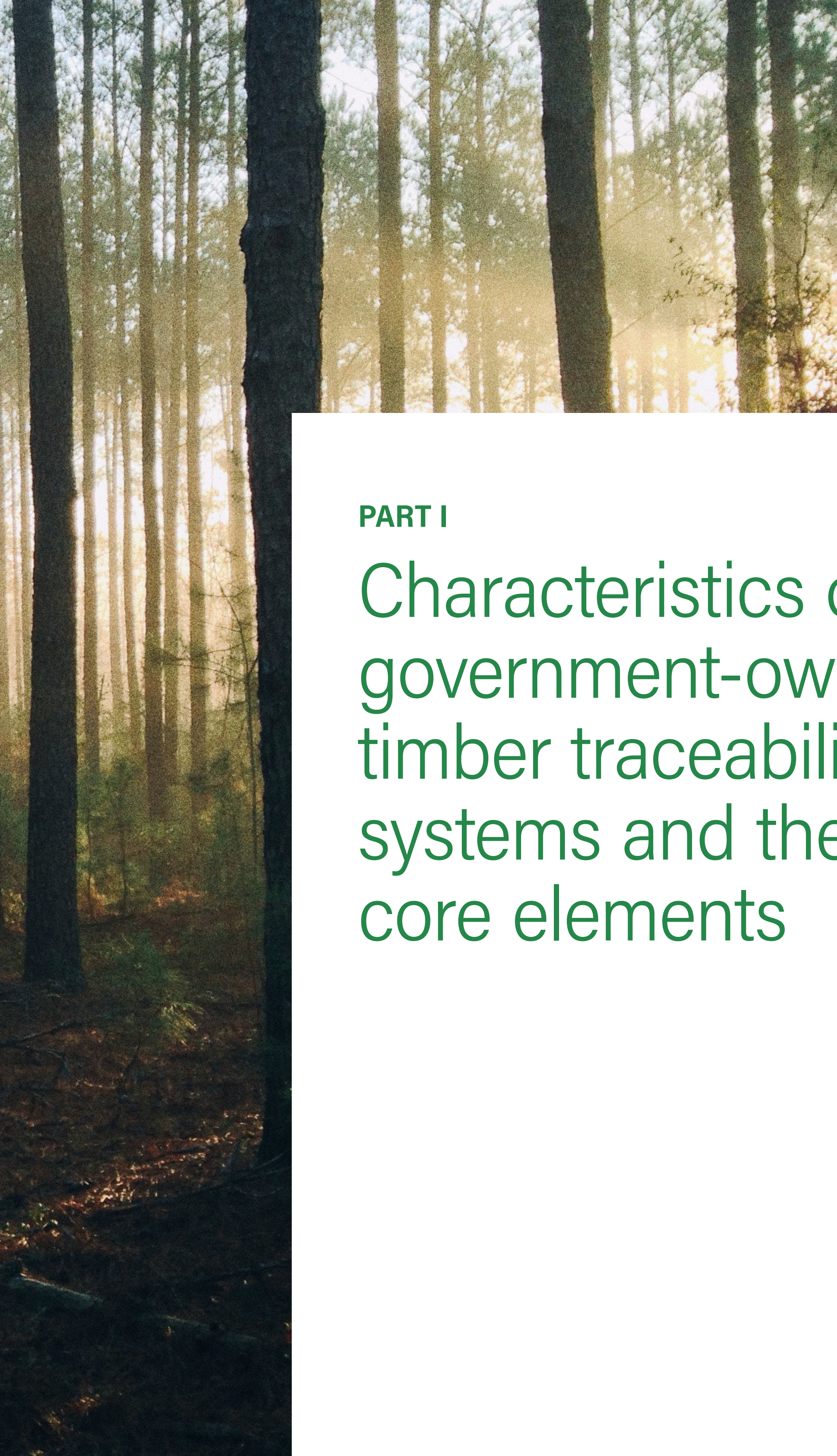
The objective of this publication is to provide practical technical guidance to decision-makers and designers of government-sponsored timber traceability systems so that they can better define their needs and design and implement traceability systems that respond to the specific needs and context of the country.

This guide aims to support governments in their efforts to develop traceability systems based on the lessons that have been learned from other experiences. This guide complements existing literature focused on the technical aspects of traceability systems; it also builds on analyses of the implementation of transnational processes such as bilaterally negotiated forest governance approaches involving traceability (e.g., the Forest Law Enforcement, Governance and Trade-Voluntary Partnership Agreements [FLEGT VPAs]) (Bartley 2014; Dykstra et al 2002; Overdevest and Zeitlin 2017; Seidel et al. 2012; Laporte and Vanderhaute 2016).

This guide focuses on government-owned traceability systems because these systems are mandatory and meant to be adopted by a variety of private sector stakeholders at a large geographic scale (national and subnational). The report does not analyze systems developed by third-party actors or companies themselves, and it does not address political or governance frameworks. The publication is complementary to another report published by the Food and Agriculture Organization of the United Nations (FAO) and World Resources Institute (WRI), which documents experiences with designing and implementing 11 timber traceability systems in seven countries in Latin America (Stäuble et al. 2022). While this publication draws on the findings from the case studies, it does not delve into the details of each country's experience since it aims to provide higher-level and more general guidance for policymakers. In addition to the case studies, this report is based on a review of existing publications on the topic, individual interviews with stakeholders, and results from expert workshops and consultations.

STRUCTURE OF THIS GUIDE

Following this introduction, Part I of this guide introduces the general characteristics and core elements of government-owned traceability systems. The section lays out some fundamental first steps in the development of a public timber traceability system, providing the basis for Part II, a Traceability framework. The framework walks system designers through a series of guiding questions as they design, implement, and operate a traceability system. The framework includes best practices and examples from governments that have gone through this process, highlighting factors that allowed them to create a system that fits their needs.



PART I

Characteristics of government-owned timber traceability systems and their core elements

This section covers the fundamentals of traceability as these relate to government-owned traceability systems, including how and where they fit into the natural resource governance approach and strategy, and their scope in terms of geographic product and supply chain coverage. The section also covers key terminology, common elements of traceability systems, two main approaches to traceability (identity preserved and volume-based traceability), and reporting procedures for different types of forest management. The section also touches briefly on the role of emerging data collection methodologies that can be used in timber traceability systems.

CHARACTERISTICS OF GOVERNMENT-OWNED TIMBER TRACEABILITY SYSTEMS

This publication is focused on the development of government timber traceability systems.

Government-owned timber traceability systems cover a defined supply chain scope under a specific jurisdiction (national or provincial/state-level), are mandatory, and are designed to meet the needs and unique context of the jurisdiction. Some other traits of government systems include the following:

- They are often part of a larger shift toward forest information and governance systems in which traceability covers production forests, transport of forest products, the processing sector, and trade, while other modules focus on land tenure, use rights, forest inventories, management of protected areas, forest fire management, trade promotion, and other topics.
- They operate a "central timber ledger," enabling the system to reconcile harvested volumes with output products across the forest sector.
- They are "business-to-authority" (B2A) systems, where the information fed into the system directly from private sector actors varies to some extent.

Government-owned traceability systems differ from other systems developed by private sector actors and civil society initiatives such as chain of custody certification. Unlike government traceability systems, commercial and civil society–driven traceability systems have the following characteristics:

- Are usually voluntary
- Their scope is more defined by markets and less by jurisdictions
- Are limited to the client/user supply chain; thus, they are unable to reconcile national or subnational data
- Do not carry direct legal consequences in cases of noncompliance

A traceability system is designed to collect, organize, and analyze supply chain information about a product (Sterling et al. 2015). The main elements of a traceability system are as follows:

- Scope of the system (e.g., geographic, product, supply chain stages, market, etc.)
- Definition of units, their identifiers, and applicable conversion factors
- Definition of traceability levels and reporting procedures
- Data management

- Procedures for monitoring and verification
- Procedures for auditing and continuous improvement of the system

SCOPE

A fundamental and vital consideration for a traceability system is to understand the supply chains of the products to be traced.

A simplified generic supply chain in the forest sector is typically composed of seven stages, as illustrated below (Figure 1).

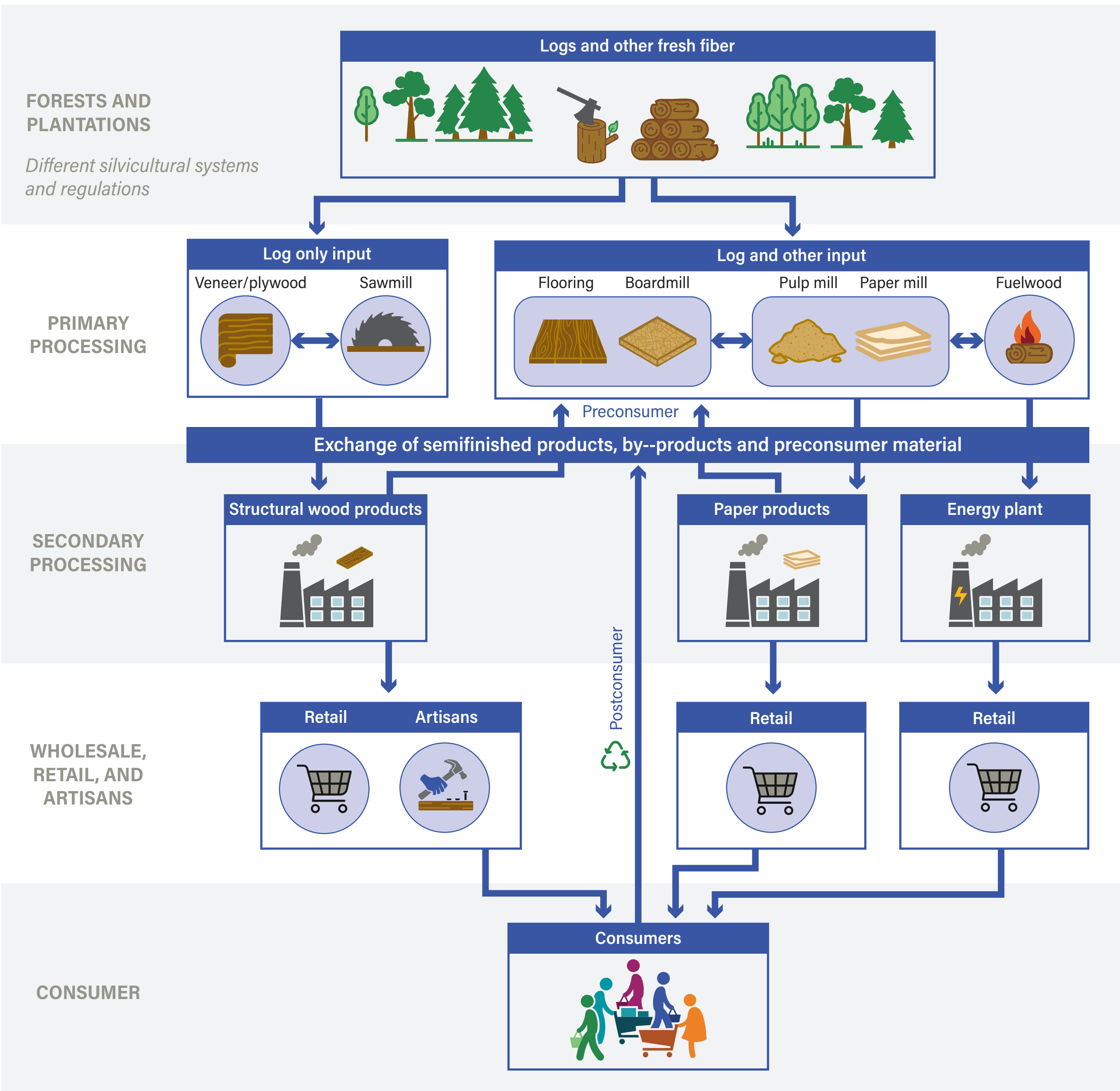
Multiple actors can be involved at each stage of the supply chain. Inputs for primary processing originate from several forest or non-forest timber sources; inputs for secondary processing stem from multiple sites of primary processing and additional trade and import of logs; other raw materials and semifinished products can occur along the chain.

FIGURE 1 | Generic forest sector supply chain

Source: Authors.

In addition, some products stem from coproducts occurring in primary processing. For example, the wood chips and sawdust generated in a sawmill are used to produce wood-based panels, paper, or wood pellets. Some forest products can also contain pre- and post-consumer recycled material. Thus, rather than from a set of linear supply chains, forest products are the result of a supply network (Figure 2). Public traceability systems for forest products need to be designed with the complexity of their supply network in mind.

FIGURE 2 | Forest sector supply network



Source: Authors.

The supply network of the forest sector illustrates the physical material flows from forest to consumers. In its most comprehensive form, a traceability system could cover the entire network. In practice, the effective scope of traceability systems is smaller. The boundaries are defined by the following:

- Geography and jurisdiction.
  A government-owned system will have predefined boundaries in terms of geography and jurisdiction.
- Timber sources covered.
  There may be reasons to limit the scope of the system to timber from certain types of forests and other sources.
- Products/species covered.
  There may also be reasons to focus on certain species and products and parts of the supply chain network and to exclude others.

UNITS, CONVERSION FACTORS, AND IDENTIFIERS

Much of the terminology used in traceability is widely used in other sectors, such as in the food industry. This section introduces some key terms that may be useful in navigating traceability systems. Through the supply chain, the materials take different forms that are quantified and managed in different units. To ensure consistency, a traceability system needs a defined set of measuring units, conversion factors, traceable resource units, and identifiers. Table 1 explains how each of these terms is used in this publication and how they are linked to each other (GS1 2017; Ringsberg 2014; Zhang and Bhatt 2014).

Defined measuring methods, even if applied correctly, have a permissible error, and the actual yield in processing always has a certain bandwidth. Therefore, traceability systems need to foresee a tolerance for volume discrepancies resulting from these conditions.

TABLE 1 | Elements of a traceability system

ELEMENT	DESCRIPTION
Measuring units	Forest products are measured in different units. They include mass, volume, and areal and linear units. The unit applied and the traceability approach (see the section "Levels of traceability" on the page below) in a specific situation is usually determined by the commercial customs at a specific point in a supply chain.
Traceable resource unit (TRU)	The smallest entity of material that is assigned an identifier in the system. Traceable resource units will change along the supply chain (e.g., a single log, a batch of sawn wood, pieces of furniture, etc.).
Identifier[a]	Each TRU needs a unique identifier as its representative in the traceability system.[b] Surrogate keys (e.g., sequential numbers) and mnemonic keys (e.g., a structured log code stating the owner, date, parcel, and tree number) can be applied. There are identifiers with internal data storage (RFID tags) and identifiers linking to external data storage (barcodes). Even the DNA profile of a tree can serve as an inherent identifier for timber (see Box 2 for more information).
Conversion factors	Conversion factors define how material is converted from one traceable resource unit to another. They are necessary when material is processed or when an actor prefers to convert material to a different measuring unit than the one used by his supplier.

Notes: RFID = Radio Frequency Identification; DNA = Deoxyribonucleic acid.

a. While the term *identifier* is generic, it is more precise than terms like *coding* or *labeling*, which can be more easily misinterpreted.

b. We use the term *traceable resource unit* (TRU) as a generic term that can include the materials (e.g., one dry metric ton of wood chips) or products (e.g., one chair) that are being traced. By using the term *traceable resource unit*, we seek to add clarity and precision to the discussion.

Source: Authors

Table 2 illustrates this concept of traceable resource units, measurement units, conversion factors, and identifiers in a simplified solid wood furniture supply chain.

TABLE 2 | Examples of traceable resource units, measurement units, and identifiers in a simplified solid wood furniture supply chain

	FOREST	SAWMILL INPUT	SAWMILL OUTPUT	FURNITURE FACTORY INPUT	FURNITURE FACTORY OUTPUT
Traceable resource unit	Log	Log	Bundle of sawn wood	Bundle of sawn wood	Pieces of furniture
Measurement unit	1 Cubic meter (m^3)	1 m^3	0.5 m^3 (Conversion factor 0.5)	0.5 m^3	2 Pieces (pcs) (Conversion factor: 4 pcs/ m^3 sawn wood)
Identifier	Spray-painted log code	Spray-painted log code	Barcode tag, stapled to the bundle	Barcode tag, stapled to the bundle	Sticker with serial number on each piece of furniture

Source: Authors.

LEVELS OF TRACEABILITY

The consideration of units, conversion factors, and identifiers will interact with the definition of traceability levels and reporting procedures. For any relevant event in the supply chain (processing, transport, or trade), the system will capture information on units, conversion factors, and identifiers, and this information will determine the level of traceability for the event. At each event, it is only possible to attain a traceability level that is equal to or lower than the traceability level of the input (Zhang and Bhatt 2014).

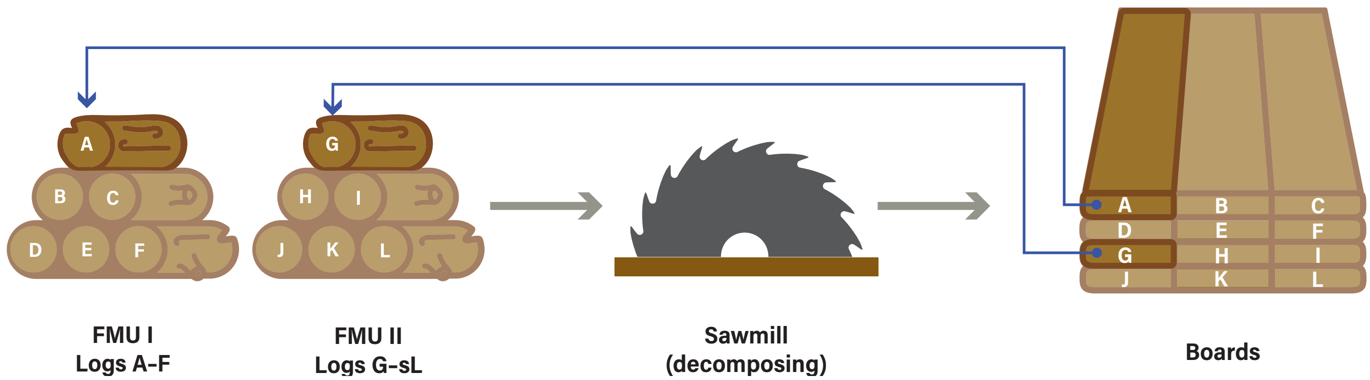
Depending on applicable input and output units, identifiers, and event characteristics, different traceability levels are attainable. The most common approaches in the forest sector are described below and illustrated for the process of sawing and wood planing.

Identity preserved

Identity preserved means that the information on a specific origin and even a specific harvesting event is maintained during each step and along the entire supply chain. Identity preserved products can be traced all the way back to their source of origin. For forest and timber products, this can mean tracing back to the forest management unit or even to the single tree and harvesting time, depending on which information was captured at the point of harvest.

For many forest products, identity preserved can be difficult to attain since raw material from different origins is mixed during processing in ways that can make traceability very costly. Even in the rather simple process of a sawmill, sawn wood from different logs is mixed in the resulting output bundles during sorting and grading. To attain identity preserved at the tree level, the traceable resource unit needs to be the single board and each board needs a unique identifier (Figure 3). An example where this has been implemented is the case of high-value tropical hardwood for musical instruments (Nogueron and Middleton 2013). Despite these challenges, some actors may consider identity preserved necessary in cases where widespread illegality is prevalent and in repeat incidents where the claims on origin of the timber are consistently inaccurate.

FIGURE 3 | Identity preserved in sawn wood production



Note: FMU = Forest management unit.

Source: Authors.

BOX 2 | Markers and identifiers for logs and processed products

Marking and identification technology is sometimes perceived as the centerpiece of traceability. It should be noted that it is only one element of the system.

Advanced marking and identification technology go beyond the traditional paper-based systems for documenting forest management planning, harvest, transport, and transformation to include digital components (such as barcodes and Radio Frequency Identification [RFID] tags) or other types of nonpaper-based tracers. The uptake of advanced marking and identification technology is still the exception rather than the standard in forest traceability systems, with irregular distribution across production systems, supply chains, and system owners. Uptake tends to be higher in collaborative or integrated supply chains, operations of large rather than small scale, and with higher mechanization levels. The benefits of advanced marking and reading technology like barcode labels and RFID tags are most widely applicable for the highly mechanized and efficiency-driven industries in the boreal and temperate zones and the plantation sector, typically as part of a private sector–owned Enterprise Resource Planning (ERP) system. Lower levels of mechanization and supply chain integration, as well as the diversity of actors and production systems, impede uptake in public and sector-wide systems. In these contexts, more advanced marking and reading technologies are often perceived as too costly. Problems also occur when system owners, such as a national government agency, prescribe the use of advanced marking but the users lack capacity to benefit from applying these marking methods; for example, when actors are obliged to use barcode labels to mark trees, logs, and wood products for the government´s control system, but they do not have the tools to read the codes for their own benefit.

Increased reading speed, reduced reading error, and unique identifiability of traceable resource units are direct benefits of implementing marking and reading technology that can increase profitability. Using tamper-proof identifiers and controlling their supply is further perceived as strengthening compliance. The log identifier becomes a "proof of legality" under the assumption that only legal actors can apply it. In contexts susceptible to corruption, this approach inhibits the risk that the identifiers become a tradeable good, as reported for "official transport documents" from several countries (Greenpeace 2015; Urrunaga et al. 2012). They can then be misused to launder illegal wood, especially when field data collection and reporting are not sufficiently advanced to keep up with the application of identifiers. The cost of hardware for log-marking and identification technology is decreasing, while awareness of these tools in the sector is growing. Although there is no silver bullet for log-marking, it is likely that context-specific solutions will be increasingly implemented along with evolving traceability systems (Laporte and Vandenhaute 2016; Seidel et al. 2012; Bendaoud et al. 2012; Ringsberg 2014).

Source: Authors.

Volume tracking

Volume tracking, also known as mass balance, is used to monitor supply chain networks or parts of supply chains in which identity preserved cannot be implemented or is not deemed necessary. The objective is to ensure that the total of network outputs corresponds to the total of inputs, considering conversion factors; therefore, input and output volumes are reported for each event and process. Inputs and outputs are reconciled to have a plausibility check that no uncontrolled material has entered the supply chain. Thus, it is not a traceability approach in a narrower sense, but the concept is often applied in traceability systems or parts of them (Figure 4).

In this approach, the management of conversion factors plays a critical role.

Differences between the conversion factor that has been defined for a mill or other production point and the conversion factor achieved by the actual process generally result in one of the following scenarios:

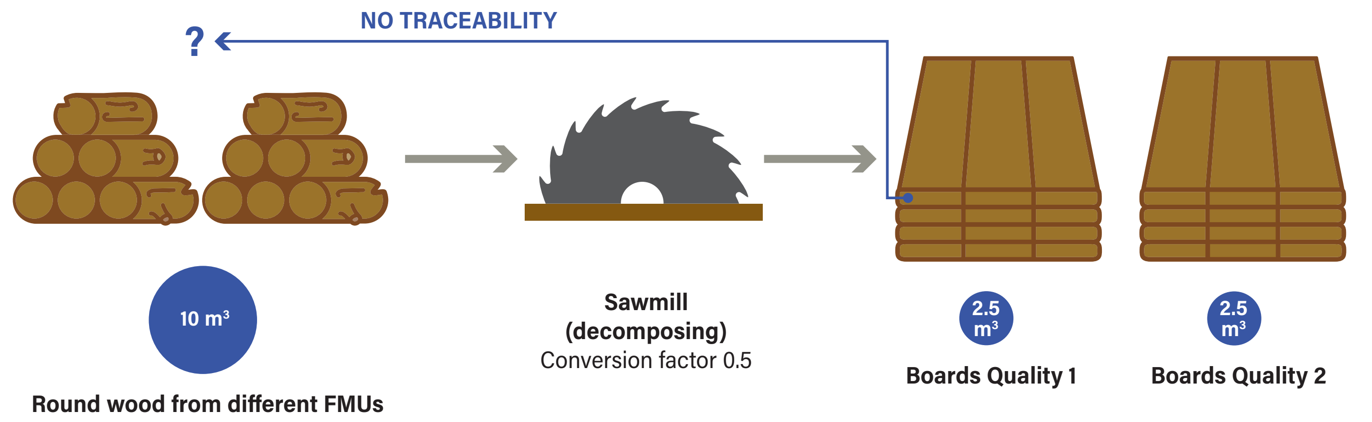
- When the conversion factor defined for a particular process or event is higher than the actual conversion factor achieved in a process, the actual input volume exceeds the reported input volume. This can create loopholes for unreported inputs to enter the supply chain.
- When the conversion factor defined for a particular process or event is lower than the conversion factor achieved by the actual process, the output volume exceeds the possible output that the defined conversion factor foresees for the process.

For example, if the conversion factor for a sawmill is 0.5 (1 cubic meter [m^3] roundwood yields 0.5 m^3 of sawn wood) in the system and the mill cuts 150 m^3 of roundwood (equaling 75 m^3 of sawn wood) per day, deviations from this factor can have the following effects:

- If the real conversion factor is 0.4, the mill needs 187.5 m^3 of roundwood to produce 75 m^3 of sawn wood.
- If the real conversion factor is 0.6, the mill will yield 90 m^3 of sawn wood instead of 75 m^3 as "foreseen" by the system.

Setting the tolerance of the conversion factor at a level wide enough to consider the industry's typical variation, yet close enough to impede timber laundering, remains a challenge for system designers. This is an area where the systems can start a continuous improvement process after initial rollout, learning from the reported information and the results of mill inspections.

FIGURE 4 | Volume tracking in a sawmill



Notes: m^3 = cubic meters; FMU = Forest management unit.

Source: Authors.

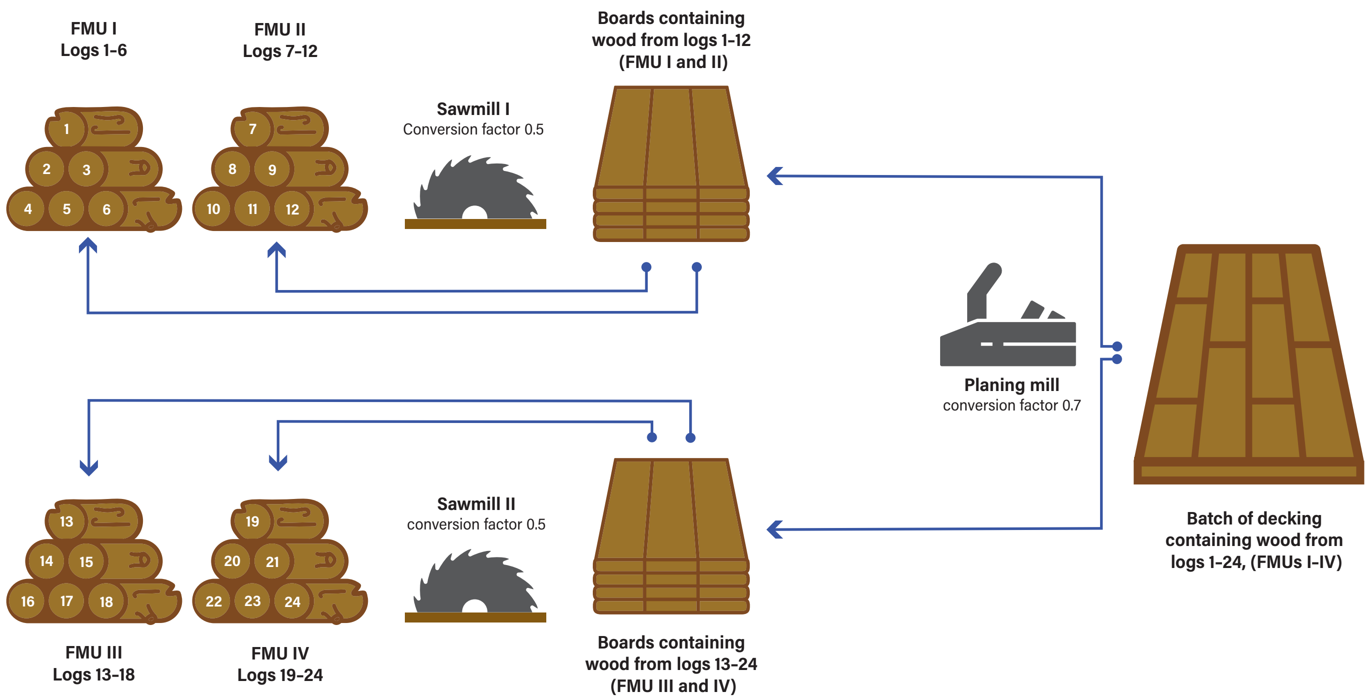
Even if the conversion factor correctly estimates the actual output, a consistent input/output balance of a site (such as a sawmill) in a volume tracking system is not a guarantee that the site complies with all regulations, because the input/output balance gives no evidence of whether all inputs and outputs are correctly reported.

Adding traceability to volume tracking—source mapping

Keeping records on which inputs have been processed in a defined period at a processing facility allows the traceability system to compile information that maps out all possible origins. For example, a mill can keep records on all roundwood origins that could possibly contribute to a batch of sawn wood. Recordkeeping does not allow every single board to be traced back to the log of origin, but it does allow for the identification of all possible logs contributing to a batch of sawn wood. Downstream actors can thereby determine a range of possible inputs and origins of the product. This level of traceability could be enough for certain products that are low-risk or low-value in markets and do not require full traceability.

This method complements the volume tracking approach in narrowing down possible forest origins of a processed product, even across several steps in a supply chain (Figure 5).

FIGURE 5 | Volume tracking with source mapping



Note: FMU = Forest management unit.
Source: Authors.

REPORTING PROCEDURES FOR DIFFERENT TYPES OF FOREST MANAGEMENT

The traceability approaches and reporting procedures for a traceability system should be chosen based on the silvicultural production system used in the forest areas covered. The type of forest, forest management, and silvicultural production system all help determine what information needs to be captured by the system and how it can be collected.

Silvicultural production and harvesting systems vary across forest types and complexity of interventions, from large-scale interventions in more homogeneous types of forests with lower species diversity (such as plantations and some boreal or temperate forest types) to more complex interventions in more diverse types of forest (such as lowland tropical forests). From a traceability system perspective, these production systems can be characterized in the three categories described below. In practice many different forms of documenting roundwood species and origin exist across all kinds of production systems.

In single tree selection systems in natural forests, the exact location, species, and dimensions of each tree to be harvested are determined during harvest planning. The harvest plan usually requires approval from the forest authority, including the list of individual trees to be harvested. Thus, very detailed information on each tree is captured during forest management planning and tree harvest.

In rotational clear-cut and patch-cut systems, which are more typical for temperate forests, each saw log may get an individual number during harvest, but the information on origin is only managed on the level of forest management unit or harvest area and does not specify coordinates in the forest of each tree.

In industrial roundwood production systems in boreal and temperate forests, pine forests in some tropical countries, or in wood sourced from planted forests managed with shorter rotations, roundwood as a traceable resource unit is identified at the wood pile level and/or cutting area and can contain a mix of species.

Where species information is not relevant for primary processing because it does not determine the product quality and is not required by applicable regulation, it usually is not captured at the log level. Instead, the typical species composition from a given origin will be known and the overall volume per species and per cut is documented. For example, this can be the case for the inputs of a paper mill in the temperate zone.

In addition to the information on species and origin, it is useful to capture further information at the point of harvest and along the supply chain to validate the information on species and origin, or to support other claims that may be important for some market segments. For example, the system can opt to document whether raw material originates from certified forests or from small and community producers. Information on when and by whom activities were carried out and which equipment was used (e.g., machinery and transport vehicles) is helpful for data analysis (see "Data management" below).

How information is captured and reported is just as important as which information is captured. Data collection and reporting is one of the areas where the use of emerging technology has a remarkably high impact on the quality of a traceability system. Examples include the use of the Global Positioning System (GPS) and mobile applications to create georeferenced census and harvest reports, use of GPS to track transport and reporting material receipt at mills, and digital applications to measure the volume of trees and logs.

The use of advanced field data collection and reporting is growing quickly in timber traceability systems. In the highly mechanized operations in the boreal and temperate forests, harvesting machinery is increasingly equipped with sensors that can collect a wide range of information for traceability and process management. In less mechanized contexts such as single tree selection systems in tropical forests, mobile technology—such as laptop computers, tablets, and smartphones—are increasingly integrated into data collection and reporting processes (Box 3).

BOX 3 | Technology for data collection and reporting

The growing availability and decreasing cost of mobile hardware and software for field data collection are driving higher uptake of these tools in forest operations. The combination of a digital clock, a Global Positioning System (GPS) module, a gyroscope, a digital camera, a storage unit, a processing unit, and connectivity to the Internet in one or several devices facilitates collection of the relevant data elements in forestry. Most notably, the growing popularity of smartphones and their integration in everyday life is facilitating their use in traceability systems. Weak connectivity levels still cause challenges for data reporting. Often, devices will be offline while collecting the field data and will only be uploaded to the data management platform once they are connected to the Internet. Satellite Internet is becoming increasingly affordable and facilitates connectivity in the most remote areas; yet, the cost of this technology is significant in many operations. Imperfect connectivity levels in the field impede the benefit realization of advanced field data collection and reporting, mainly by slowing down reporting dynamics. However, even if reporting cannot happen in near real time, there is still an improvement to systems based on manual data collection and reporting on paper.

Technical sensors can complement or substitute human senses and collect data faster, more reliably, with less human error, and in a format ready for further processing and verification. Benefits of advanced field data collection and reporting are direct and obvious for business process management. Fast, accurate, and comprehensive data collection is a cornerstone of the concept of "precision forestry," an umbrella term for business management–driven initiatives, exploring the use of advanced technology in forestry. The benefits for government-owned traceability systems with legality assurance objectives are rather indirect, but, nonetheless, potentially high. It is a common saying that "people are smarter than systems." In forestry, large parts of the front line in this battle between system designers and actors with an incentive to circumvent them run across the field of data collection. Data in traceability systems are most vulnerable at the beginning of the supply chain, where the reference data (trees eligible for harvest and their volume) for all subsequent monitoring and analysis are fed into the system. Advanced field data collection and reporting can help to solve the "bad data in, bad data out" problem if it changes the cost-risk-benefit ratio for feeding the system with false or fraudulent information. With advanced data collection and reporting protocols, false data reporting is impeded in several ways:

- Data are captured with technical sensors and via a standardized methodology, results are reproducible, the human factor is reduced.
- Secondary data and metadata are captured along with key data elements, manipulation effort is increased (e.g., if a tree is reported as harvested via the user interface of a mobile application, the device will capture when this event takes place, where it takes place, which registered user did it, and the app may even ask to take a picture of the felled tree as additional evidence. All this can be done in less time than documenting these events on paper. At the same time, the barrier to falsifying the information of this event is much higher than for falsifying it in paper-based reporting.)
- Some data elements such as GPS coordinates are remotely verifiable, and when reporting dynamics are sufficient, inconsistencies can be flagged and addressed on short notice.

From a technical point of view, the benefits of advanced field data collection and reporting are mainly impeded by connectivity levels. The rough field conditions in forestry have also been quoted as a limiting factor, and technology may lack the requisite robustness for use in forestry. Further technical limitations exist for different key data elements. For example, volume measurement for standing and harvested trees is still a challenge, and there is a lack of tools for integrating this key data element in advanced data collection and reporting. Also, field technology for species identification is still in a very early stage of development and far from being integrated in traceability systems.

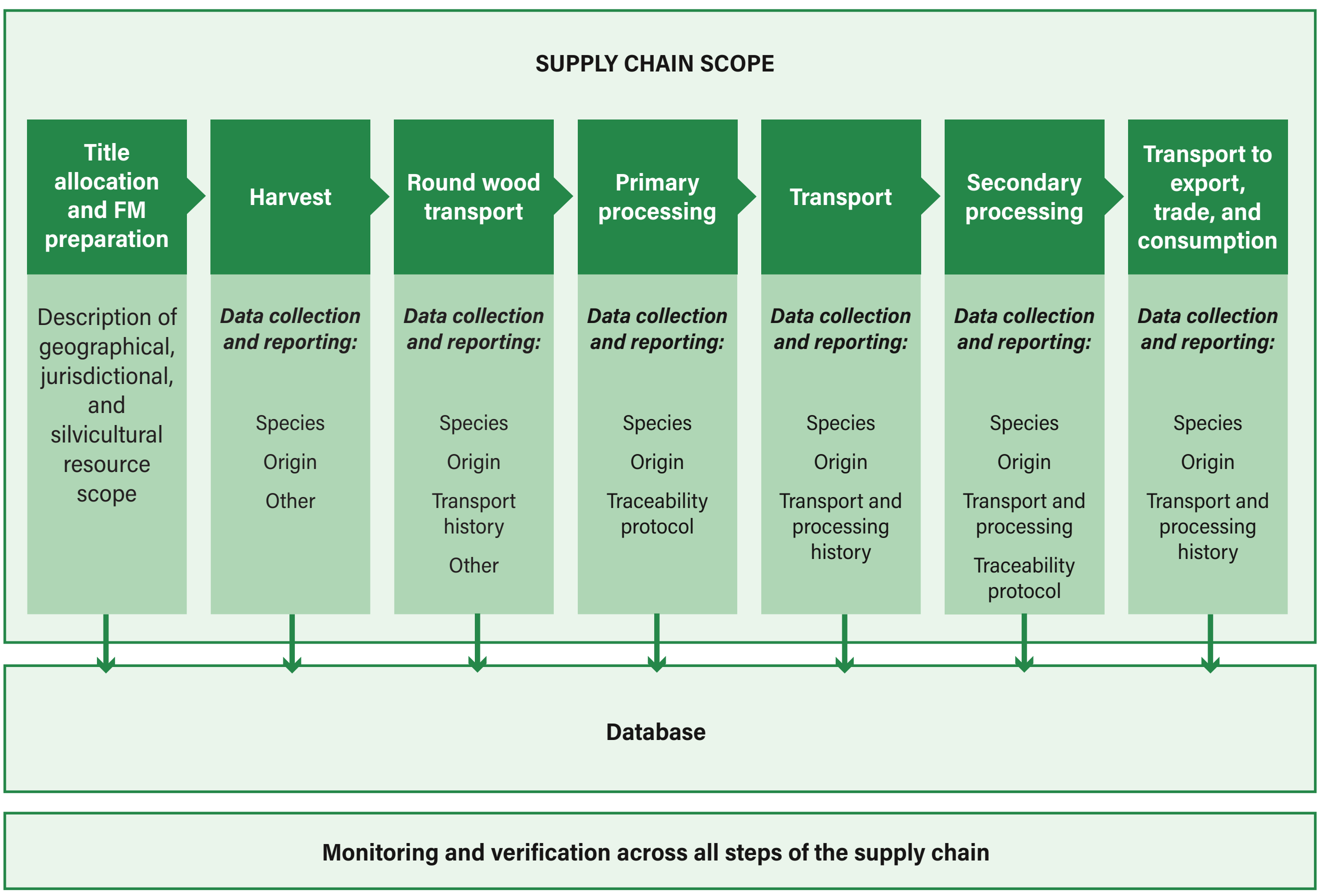
Source: Authors.

DATA MANAGEMENT

A database forms the backbone of most government-owned traceability systems in the forest sector. Without digitizing and centralizing data collected along the supply chain, the benefits of a traceability system cannot be realized. This is commonly accepted as the main weakness of purely paper-based traceability systems (Dykstra et al. 2002; Seidel et al. 2012). Database technology is omnipresent nowadays, and the barrier to entry is accordingly low. The biggest challenges to utilizing the full potential of this technology are confidentiality and data-tampering issues, transparency issues, lack of capacity, and a poor understanding of the potential of these tools. The problem also exists when the authority that owns the system does not share data with other relevant actors. For example, when regional authorities, operating a volume tracking platform, refuse to pass on information to the national authority, which is responsible for verifying harvest, this severely impedes the latter's work (Urrunaga et al. 2012).

Figure 6 shows the type of information that can be reported to a central database in a generic traceability system to support monitoring and verification of claims about the flow of material.

FIGURE 6 | Generic supply chain and data collected to monitor material flow



Note: FM = Forest management.

Source: Authors.

An information platform alone is no guarantee for reliable information and may even be counterproductive if downstream supply chain actors trust the system outputs without verifying the quality of the information. If upstream supply chain actors and system owners have incentives and opportunities to feed unreliable or falsified data into the platform, these unreliable data can be passed along the supply chain undetected. In such cases, an information platform can fail to meet key objectives for a traceability system, such as the prevention of illegal logging and wood laundering. Examples of such cases include title allocation without completed application process, accepting falsified harvest plans with inflated tree numbers and volumes, manipulating approved harvest volumes for permits, and creating ghost accounts for nonexistent actors (title holders or sawmills) (Greenpeace 2013, 2015; Kleinschmidt et al. 2016; Urrunaga et al. 2012).

These experiences show that improved data management and information platforms alone cannot overcome weak governance and corruption. These limitations can partly be addressed by improvements in data collection, reporting and verification, and building a system in which the back end (relational databases storing the information) is designed to pick up data inconsistencies and anomalies easily and flag issues for field verification. On the other hand, the "bad data in, bad data out" problem should also be addressed by providing incentive structures and generating buy-in from system users. In a well-designed system for traceability and legality assurance, compliance is the rational choice because the cost of noncompliance is higher than the cost of compliance.

Nongovernmental organization (NGO) analysis of public system data shows that actors committed to using existing supply chain data already reported to government information platforms can achieve considerable improvements (BV Rio 2016; EIA 2014; Greenpeace 2015). If NGOs and other third parties can expose inconsistencies within a government-owned traceability and reporting system by analyzing publicly accessible data, system owners should be able to conduct similar analyses or consider integrating algorithms to flag these inconsistencies automatically. For these types of external analyses, at least part of the data collected in a system needs to be publicly accessible. Increasing data transparency also helps to build confidence in the integrity of the system among users and external stakeholders, such as civil society and timber buyers.

While transparency is important, confidentiality remains an important concern for businesses providing data. An effective traceability system will necessarily contain sensitive and confidential business information. The scope of this information and management of data protection and access will likely remain a complex issue that will need to be resolved on a case-by-case basis. Some actors have suggested that blockchain technology offers a potential solution, but few pilots to apply blockchain to forest supply chains have been completed or have shared their experiences to date (Castka et al. 2020; Figorilli et al. 2018). The principle underlying blockchain is perceived to work well for transactions with a virtual currency but faces new challenges when applied in tracking physical transactions involving transformation, commingling, and disintegration of wood products.

Comprehensive data collection and systematic data analysis are the basis of robust monitoring and verification.

MONITORING AND VERIFICATION

In government-owned traceability systems for forest supply chains, monitoring includes all activities that support the effective implementation of the system and approaches to identify and address issues in the functioning of the system.

Verification refers to the activities undertaken to validate the information captured by the traceability system, including verifying that legal requirements for logging and associated trade are met at different points in the supply chain. Verification activities can be done by government agencies or by third parties. Due to their cost and time requirements, verification activities are often based on samples. In some cases, the system is designed to register transactions between buyers and sellers (a data handshake), and in case of irregularities the system raises a flag for further investigation.

It is important to design, implement, and communicate about all the verification activities in a traceability system. For example, legislation on forest management often includes a requirement for a field inspection prior to harvest. The information on these activities needs to be compiled and managed centrally to avoid scattered and isolated data in different silos. As discussed in Box 3, there are now different advanced field data collection and reporting methods available when monitoring activities are conducted through field verification.

This publication highlights examples from two types of advanced data collection and reporting: monitoring and verification based on remote sensing, and product testing to verify claims about species and origin of a wood sample.

Data collection and reporting in monitoring and verification

There is increasing uptake of advanced field data collection and reporting not just in the data collection process for traceability systems but also in the monitoring and verification process. These advanced data collection and reporting processes can prevent fraud and data errors, including in cases where fraudulent forest management plans have been approved or false harvest reporting was verified by government officials (Global Witness 2015; Greenpeace 2013; Urrunaga et al. 2012).

One problem related to field verification is the high cost involved in sending a qualified person of integrity or an interagency group of officers to a remote forest area with the task to confirm information previously reported by another supply chain actor. Reducing the salary for verification staff will make them more vulnerable to corruption, but paying them well, which does not guarantee integrity, indirectly contributes to the increased margin on illegal timber products. Institutions and individuals tasked with verifying data may also lack capacity to fulfill their tasks with due care and may face pressure to collaborate with or provide cover for illegal practices (Bennet and van Hensbergen 2011; Brown et al. 2008; Global Witness 2015; Greenpeace 2013; Kleinschmidt et al. 2016; PROFOR 2015).

There are, therefore, two potential benefits related to applying advanced field data collection and reporting in verification. First, applying these advanced practices can increase the efficiency and reliability of the verification activity itself. Second, applying these advanced practices in a traceability system can reduce the need for field verification. When reported information becomes more reliable and trustworthy, and the system can pick up anomalies (e.g., sudden changes in recovery rates or discrepancies between inventory and harvested tree diameters), the need for field visits may be reduced, sample rates for field visits can be lowered, and target verification can take place. However, since human users can outsmart systems and because some verification activities will continue to require the presence of experts in person, field-based monitoring and verification activities will continue to play an important role in traceability systems.

Remote sensing

Uptake of remote sensing (use of satellite and aircraft-based sensors) is growing. Systems and platforms providing users with satellite-based data on land cover and land cover change are now available for global and in some cases national and subnational areas. High-resolution data are increasingly available, and costs for these images are decreasing.

The specific application of remote sensing to verification activities depends on the silvicultural management systems described above. For patch-cut and rotational clear-cut systems, remote sensing verification can be applied to determine whether there are trees present in the designated harvest area before and after the harvest activities. For single tree selection systems, remote sensing verification entails confirming if a single tree was harvested within an area that still has a closed tree cover. In some forest concessions in Brazil, remote sensing–based verification of selective logging has been piloted. While this approach is currently still in a test phase, there is a high degree of interest in applying remote sensing to verify activities such as logging of individual trees (selective logging) in tropical forests (Stäuble et al. 2022). Access to high-resolution imagery can still be costly, but some providers can enter into agreements with governments and third-party actors to make these data available for free in certain cases. For example, the Norwegian government and Planet announced a partnership that makes available 5-meter-resolution imagery for more than 64 tropical countries (O'Shea 2020).

In some cases, the regulatory framework does not include a specific allowance for applying remote sensing to monitoring and verification activities, which can present obstacles to the expansion of these tools in traceability systems that include an objective of legality assurance for timber. Other emerging tools and approaches such as drones also need to be validated and officially acknowledged in regulation or standard operating procedures before they can serve as verification tools and support investigations (Perú, Ministerio Público 2020).

The use of remote sensing technology can help reduce cost and increase the efficiency of verification activities, especially as high-resolution imagery becomes more accessible and satellite-based monitoring systems like Global Forest Watch (GFW) make the information more widely available. The successful application of remote verification to single tree selection production systems would represent a quantum leap for verification activities. The scale of monitoring activities could be radically increased with the resources currently dedicated to costly field-based verification and could lead to significantly increased efficiency. For example, the current forest law in Peru requires that between four and six people visit the site of a CITES-listed tree species for a fully compliant harvest (Perú, Congreso de la República 2015), including the following officials:

- The forest engineer who identifies the tree to be harvested and includes it in the harvest plan.
- An official of the National Service for Forests and Forest Wildlife (in Spanish, Servicio Nacional Forestal y de Fauna Silvestre; SERFOR), the management authority for CITES, to verify the existence of the tree.
- The forest operator who cuts the tree, and his colleagues.
- An official of the Organization for the Supervision of Forest and Forest Wildlife Resources (in Spanish, Organismo de Supervisión de los Recursos Forestales y de Fauna Silvestre; OSINFOR), the authority responsible for verifying the harvest.
- A forest management auditor if the forest is certified.
- In some cases, an official from the local authority responsible for the non-CITES-listed tree species.

This example illustrates the high cost of field verification, which could be reduced with the systematic integration of remote sensing into verification activities. While harvests of single trees are still difficult to detect with remote sensing, basic information about harvest activities within a designated concession can still be analyzed before undertaking a field mission, for instance, whether harvest activities took place in the right location (Nogueron and Kaldjian 2015). Another possible benefit of using remote sensing in verification is the potential to mitigate corruption by physically separating government enforcement agents from supply chain actors in the field, who could exert pressure or offer bribes to these agents (Brown et al. 2008). Ground truthing of remote sensing data will still be necessary, but missions can be targeted more effectively if remote sensing images are routinely integrated into control processes. Together with advanced field data collection and reporting, remote sensing can prevent inputs of poor quality or falsified data into a traceability system; remote sensing creates an opportunity to increase comprehensiveness, the level of detail, and the reliability of information on forest management at acceptable cost to supply chain actors and government oversight agencies.

The most significant limitation in the use of remote sensing for verification purposes is that some elements of compliance are not likely to be verifiable through remote sensing—for example, verification of species or quality of the harvesting and forest management practices and post-harvesting activities, including replanting or assisted natural regeneration. Other limitations in the use of satellite imagery include high cloud cover in tropical countries and the need for a certain level of technical knowledge and computer capabilities. However, through platforms like Global Forest Watch, the Radar for Detecting Deforestation (RADD) alerts, and emerging artificial intelligence algorithms to detect logging (see, e.g., Hethcoat et al. 2020), users can have increasing access to forest monitoring products in user-friendly formats.

While mitigating the potential for single incidents of fraud and corruption in the field, centralizing and scaling up verification through remote sensing can create new risks of higher-level corruption if the integrity of the responsible body is affected. However, with more publicly available remote sensing data, this tool can even expose these cases via civil society monitoring and independent forest monitors (Vallee et al. 2022).

Product testing

The lack of comprehensive (or identity preserved, to use the earlier term) traceability systems for fragmented and international supply chains is driving a growing demand for scientific product testing in regulated consumer markets. Scientific product testing uses a range of analytical methods to verify the species or the geographic origin of a wood sample, and in some cases, to verify both.

A significant limitation to wide-scale application of product testing is the lack of comprehensive reference libraries for commercially traded timber species covering the main harvest countries. There are several projects underway to collect samples and build reference data, but the existing databases still need to be expanded. The up-front investment needed to create reference data for the most reliable methods is still high. The cost of applying these methods in supply chains is decreasing but, depending on the method used, can still be out of reach for many actors.

Despite these challenges, scientific product testing is an important screening and verification tool for raw material, and for semifinished and finished products. The main advantage of these methods is that they deliver empirical results, deduced from inherent product properties. Therefore, testing can be very useful not only for assessing single product samples but also for assessing the reliability of claims from different traceability systems. Product testing faces limitations in different product types (the higher the degree of processing, the less applicable most testing methods are) and in resolution (the level of spatial resolution depends on the density of sampling efforts, but so far it is not clear that the methods can distinguish materials from two sides of a geographic demarcation line). Table 3 gives an overview of scientific product testing for identifying species and origin of forest products. It is important to note that different methods are currently available in different countries and that more work is needed to create the right enabling conditions for wide-scale application of wood identification. While analyses are becoming cheaper, some tests still require further time and financial resources for timber verification.

TABLE 3 | Scientific product testing for identification of species and origin of forest products

METHOD	IDENTIFICATION OF INDIVIDUALS	IDENTIFICATION OF SPECIES	IDENTIFICATION OF GEOGRAPHIC SOURCE	APPLICABILITY	STATE OF IMPLEMENTATION
DNA[a]	DNA fingerprinting	DNA barcoding	Application of geographically informative loci	Solid wood	Applied in labs
Stable isotope analysis[b]	No	No	Yes	Solid wood	Applied in labs
Direct Analysis in Real Time-Mass Spectrometry (DART-MS)[c]	No	Yes	Potentially[d]	Solid wood	Applied in labs
Microscopic fiber analysis[e]	No	Genus only	No	Pulp and paper	Applied in labs
Wood anatomy	No	Yes	No	Solid and composite wood	Applied in labs; Xylotron under development for identification in the field[f]

Notes: DNA = Deoxyribonucleic acid.

a. Finch et al. 2020.

b. Watkinson et al. 2021.

c. Musah et al. 2015.

d. Finch et al. 2017.

e. Helmling et al. 2018.

f. Ravindran et al. 2019.

Source: Authors.

The application of all three of the approaches to monitoring and verification described here (advanced data collection and management, remote sensing, and product testing to verify claims on species and origin) is likely to continue to increase. Similarly, supply chain actors are increasingly recognizing the importance of monitoring and verification components as a central building block of traceability systems for forest supply chains (Laporte and Vandenhaute 2016). Advanced data collection and reporting methods are therefore poised to gain importance in comprehensive traceability systems, while remote sensing and product testing are well-positioned to become commonly used methods for screening, monitoring, and verification. The costs associated with implementing these methodologies are fluctuating, but costs are expected to go down as technology evolves and becomes more widely used.


PART II

Traceability Framework

This section provides a more detailed look at the various steps involved in planning, designing, and implementing, as well as maintaining, a government-owned timber traceability system (Table 4).

TABLE 4 | Traceability framework

PHASE	SUBPHASE	CONSIDERATIONS RELATED TO
Planning	Initial considerations	Generating the knowledge base
		Defining objectives, benefits, and indicators
		Financing
		Stakeholder and capacity mapping
		Legal requirements
	Scope	Geography and jurisdiction
		Forest resources
		Supply chain network
		System boundaries
	Design and development	Building a new system vs. adapting an existing system
		Ownership and data sovereignty
		Scope of information
		Data collection and reporting
		Data analysis
		Blocking processes
		Monitoring and verification
Implementation		Priorities for rollout
		Target forest resources for implementation
		Target supply chain priorities for implementation
		Priority functionalities for implementation
		Securing buy-in from private sector for implementation
		Alternative implementation strategies
Upkeep		Strategy review
		Performance tracking
		Alignment of allocated resources with goals
		Comprehensive internal audit
		External audits

Source: Authors.

In addition, this section provides a series of guiding questions (Table 5) that can be used by government agencies that are considering the development of a traceability system for the forest sector, as a generic road map for planning the development and implementation processes, and for the upkeep and maintenance of a traceability system. The framework is not meant to be prescriptive, and it can be adapted to local circumstances. It includes best practices and examples from governments that have gone through this process, highlighting factors that allowed them to create a system that fits their needs.

TABLE 5 | Traceability framework: Key questions

PLANNING PHASE	
Subphase	**Key questions**
Initial considerations	Objectives and benefits: What will the system accomplish, and how can system owners, users, and other parties track progress?
	Financing: How will the development, implementation, and upkeep of the system be financed?
	Stakeholder and capacity mapping: Who will interact with the system, and how can system owners obtain user buy-in? What is the capacity of the intended users?
	Legal requirements: Are there any existing legal requirements in the forest sector of this geography for managing traceability requirements? Will any laws or regulations need to be drafted or amended for the system to be implemented?
Scope	Geography and jurisdiction: What are the geographical and jurisdictional boundaries of the system?
	Forest resources: Which resources should be covered by the system?
	Supply chain network: Which supply chains (or phases of the supply chains) should be covered, and can specific supply chains be excluded?
	System boundaries: How does the system capture wood entering or exiting the system from outside the scope? And for how long does the system monitor the asset?
Design and development	Building a new system vs. adapting an existing system: Are there existing systems in place that should be considered?
	Ownership and data sovereignty: Who owns the system and the data? How is access to information regulated?
	Scope of information: What information should the system capture?
	Data collection and reporting: How should data be collected and reported?
	Data analysis: How will the system manage and analyze reported data?
	Blocking processes: Where and when should the system block process?
	Monitoring and verification: What tools for monitoring and verification should be applied and how?
Implementation phase: Key questions	
Priorities for rollout: Where should the implementation start?	
Target forest resources for implementation: Which forest resources should be prioritized for implementation?	
Target supply chain priorities for implementation: Which supply chains should be targeted for implementation?	
Priority functionalities for implementation: Should all functionalities be implemented at once?	
Securing buy-in from the private sector for implementation: How can private sector buy-in be secured during the rollout?	
Alternative implementation strategies: Are there alternative strategies for implementation?	
Upkeep phase: Key questions	
Strategy review: Are the objectives and expected benefits of the system up-to-date and valid for its owners, stakeholders, and interested parties?	
Performance tracking: Have the goals defined for the last period been achieved? Are goals for the upcoming period set according to defined Key Performance Indicators?	
Alignment of allocated resources with goals: Are the allocated resources aligned with the goals?	
Comprehensive internal audit: Is an internal audit and review process in place that covers all relevant topics?	
External audits: Is there a need for an external audit?	

Source: Authors.

PHASE 1: PLANNING

1.1 Generate knowledge base

From the start, it is important to collect and compile relevant information about the forest sector to establish the knowledge base to inform the overall process and identify gaps. Information collected could include facts about the forest sector and key actors and stakeholders, details about timber flows and markets, patterns and risk of illegality, capacity of the users, assessment of the legal framework, etc.

1.2 Initial considerations

Before making any decisions about the development process, including the scope and type of traceability system, system designers need to identify the needs, assets, challenges, and opportunities for the desired system. This section covers the aspects that need to be considered in planning a traceability system:

- **Defining objectives, benefits, and indicators of effectiveness**: What will the system accomplish, and how can system owners, users, and other parties track progress?
- **Financing**: How will the development, implementation, and upkeep of the system be financed? How will government agencies operating the system develop a sustainable financing mechanism?
- **Stakeholder and capacity mapping**: Who will interact with the system, and how can system owners obtain user buy-in? What is the capacity of the intended users?
- **Legal requirements**: Are there any existing legal requirements in the forest sector of this geography for managing traceability requirements? Will any laws or regulations need to be drafted or amended for the system to be implemented?

Addressing these four aspects will be critical for ensuring that the system can function and is embraced by users. Neglecting these topics could result in a system that does not deliver the intended benefits.

Defining objectives, benefits, and indicators

Before the development process begins, it is important to define the benefits that are expected from the system and the indicators that will be used to track those benefits. Table 6 provides some examples of potential benefits and performance indicators.

TABLE 6 | What benefits can be expected from introducing a traceability system? And how can the benefits be measured?

BENEFIT	INDICATOR
▪ Demonstrates compliance with national policies, international agreements, and legality requirements ▪ Positions national natural resources as dependable and desirable for buyers	Improved forest compliance statistics (numbers of infringements, sanctions over time) Improved access to regulated markets Recognition of the system in consumer country import regulation and due diligence guidance for importers Improved access to premium domestic markets
Improves natural resource use management and monitoring	Achievement of targets for reducing deforestation and forest degradation
▪ Monitors supply for and demand of the forest sector ▪ Results in more accurate trade and industry statistics	Industry demand for forest-based raw material is covered from legal harvest Increased investment in the forest sector Well-defined government strategy to address weaknesses and strengths of the forest sector industry informed by data collected and generated by the system and in the development process
Reduces informality	Reported supply and demand aligns with supply and demand estimated from other sources (empirical studies, anecdotal evidence, etc.)
Improves ability to collect royalties and taxes from the forest sector	Higher royalties as informality is reduced. Registered actors pay for the full volume they harvest/process. Previously unregistered actors are registered and pay taxes and royalties

Source: Authors.

Identifying the expected benefits and performance indicators will ensure that there are clear goals for the process and that the system adds value to the forest sector at the scale needed.

If a traceability system already exists at the national or subnational level, the lessons learned in the implementation of such a system should be documented at this stage and incorporated into the decision-making in the system's development process.

Financing

A plan for funding the development, implementation, and upkeep of a system is critical to success. An initial investment is required to plan and develop a traceability system. For example, in Panama, the government started with a small budget of approximately $50,000 to design and implement a system for one of the regions in the country (Stäuble et al. 2022). In many cases, systems have been financially supported by international donors (Stäuble et al. 2022). Some systems are mostly developed in-house by the responsible authority; others are mostly outsourced to service providers (Box 4).

BOX 4 | "Make or buy" considerations

There are examples of government in-house and outsourced system development. Some countries build the development capacity within the authority and only contract small tasks to external service providers, others outsource large parts to external services. Sometimes, the system is owned by the forest authority; sometimes other government institutions such as the tax authority or Ministries of Trade and Industry are involved. While it can be perfectly justified and efficient to outsource development services for traceability systems, it is obvious that the ownership and a deep understanding of the purpose and functionality of the system need to stay with the responsible authority. Therefore, the capacity to develop, manage, and benefit from a system needs to exist in-house, ideally prior to taking any outsourcing decisions.

There may even be a correlation between internal vs. external motivation and financing and development and implementation success. There are indications that systems, driven by intrinsic government motivation and lower shares of external funding and outsourcing have been developed and implemented at lower cost and with greater success than externally driven and funded systems, where larger parts of the development were done by service providers (Stäuble et al. 2022).

Source: Authors.

Financing also needs to be secured for upkeep and continuous improvement of the system. Some systems can generate direct income for their own maintenance through stumpage fees or fees for waybills. In some cases, a share of penalties issued to actors for failing to use the traceability system flows back into its financing. Other systems are financed less directly through diversion of public funds or allocation of funding from international donor agencies.

So far, there have been few efforts to analyze the planned and real budgets for government-owned traceability systems, in part because some of the costs of planning and operating a system are managed in different agency budgets, or not publicly accessible. In a panel held at the 2017 Forest Legality Week hosted by WRI, representatives from different government-owned traceability systems shared cost estimates for development and implementation ranging between $300,000 and several million US dollars over varying project timelines (Stäuble 2017).

Considerations related to costs for running a traceability system include the following:

WHAT ARE THE IMPLICATIONS OF DIFFERENT INITIAL FUNDING SCENARIOS FOR A TRACEABILITY SYSTEM?

Systems that are funded only with donor money may face an increased risk of escalating development cost and/or an underestimation of the running cost. Such externally funded systems may also face a higher risk that the process focuses too much on export-oriented supply chains or donors´ requirements, and neglects domestic needs.

It is likely that a certain degree of public funding from the government of the target country or region will increase the intrinsic motivation of system owners to be successful.

WHAT POSSIBILITIES EXIST TO COVER THE RUNNING COST AND FURTHER DEVELOPMENT OF THE SYSTEM, AND WHAT ARE THE IMPLICATIONS OF DIFFERENT FUNDING STRATEGIES?

It is critical to design financing mechanisms that avoid creating unintentional negative incentives for system owners and system users.

The system should not depend entirely on one source of income, whether system-generated income, donor funding, or public funding. A mix of these three main sources can mitigate the risks resulting from using only one of them:

- **System-generated income**: It should not incentivize circumvention of the system by its users nor misuse of the system by the authority. This means that cost of compliance, royalties collected via the system, penalties issued for noncompliance, and the perceived risk of conviction need to be designed in a way that leads to compliance as a rational choice for all actors. There is anecdotal evidence that systems have been misused by authorities to issue unjustified or disproportionate penalties (INTERPOL 2016). Poor design of reporting, data analysis, and monitoring and verification procedures can incentivize private sector actors to circumvent royalty payment through false reporting or by not reporting to the system.

- **Donor funding**: This type of funding is usually spent on initial system development or larger modification projects but not for covering operational costs. Where systems have a strong focus on exports and compliance with consumer country import regulation, some operational costs might be covered from consumer country funds. This inhibits the risk that the system does not generate the same level of uptake and enforcement in the domestic market compared with export-oriented supply chains—which can lead to objectives for forest management not to be achieved.
- **Public funding**: Public funding should stem from an agency not positioned to benefit from compliance or noncompliance with the system, to minimize the risks associated with self-generated income, mentioned above. The downside to public funding sources is that they generally do not incentivize performance of system owners and users. Finally, public funding can be cut for reasons beyond the control of the system operators and users, such as a financial crisis or changing markets for wood products that affect funding for natural resource management and oversight.

HOW WILL FUNDING BE INFLUENCED BY OVERALL ECONOMIC CONDITIONS?

System owners should analyze the viability of the financing mechanism for different economic projections for the forest sector and the overall economy to ensure alternative funding mechanisms can be identified as fallback options.

For example, if the system relies too strongly on self-generated funds, it may face a funding shortfall if the forest sector faces a downturn.

System owners also need to be aware that a traceability system is never "finished" at the point when the budget is planned. Instead, a stepwise approach in development and implementation is recommended. Even once the system is up and running at its full intended scope, learning from the data collected will drive continuous improvement, and adaptation to changing conditions in the sector will be required. These factors should be considered in the funding plan.

Stakeholder and capacity mapping

It is important to identify all stakeholder groups that will be involved with a government-owned traceability system. Table 7 outlines the groups it may be important to consider in a mapping exercise.

The expectations and concerns of each group of stakeholders should be identified and addressed. Initial support for or resistance against the traceability system can provide an important first indication about critical areas and actors that may need additional incentives or support to successfully implement the traceability system. Planning should be accompanied by stakeholder engagement and tailored communications and consultations to identify the needs and expectations of all stakeholders and ensure the system responds to their needs and expectations.

During this phase, a first analysis of the forest sector supply chain network (see also Figure 2) should be carried out to ensure the system builds on a comprehensive understanding of the material flows throughout the sector.

TABLE 7 | Stakeholders for government-owned traceability systems

GOVERNMENTS	PRIVATE SECTOR	CIVIL SOCIETY AND OTHER
1. National forest authority including law enforcement 2. Subnational forest authorities including law enforcement 3. Transportation, processing, and trade authority 4. Law enforcement 5. Tax and revenue authority 6. Protected areas authority 7. CITES authority 8. Customs authority	1. Title holders 2. Forest management unit operators 3. Loggers 4. Primary processors 5. Transporters 6. Secondary processors 7. Importers and exporters 8. Trade associations and clusters (forestry, export, import, or trade) 9. Forest management specialists 10. Technical service providers 11. Industry associations 12. Traders and managers of storage and reloading points (e.g., ports) 13. Chain of custody certification bodies 14. Consumers/Retailers	1. Civil society organizations (national and international) 2. Forest management and chain of custody certification schemes 3. Academia 4. Donor organizations 5. Consumers 6. Media

Notes: CITES = The Convention on International Trade in Endangered Species of Wild Fauna and Flora.
Source: Authors.

Mapping out the capacity of actors is another important activity in this phase. A traceability system is a system that collects and processes information from a supply chain network, which means that the system output cannot be of higher quality than the system input. Therefore, varying capacity in data collection and reporting across the sector needs to be assessed to identify critical gaps at an early stage and to plan for outreach and capacity-building measures to address these gaps. The main considerations are summarized below.

HOW DOES HUMAN AND TECHNICAL CAPACITY VARY ACROSS THE FOREST SECTOR SUPPLY CHAIN NETWORK?

Connectivity levels and technical capacity are often lowest at the first critical steps of the supply chain (at the forest level) and typically increase further downstream in the supply chain. Forest management activities often take place in remote areas with low network coverage. Primary and secondary processing industries are usually in areas with better connectivity and better infrastructure.

Small and medium and/or community-owned enterprises may face more challenges in providing the resources and capacity to meet reporting requirements than larger businesses, and the greatest need for capacity building and technical and operational support as well as support to access credit and finance (Global Timber Forum 2020).

HOW SHOULD SYSTEM DEVELOPERS DEAL WITH CAPACITY GAPS?

Failure to address capacity gaps can lead to the following:

- Stakeholders (sometimes out of necessity) report false information to the system and compromise the quality of the data.
- Data quality is variable across the system, and it is impossible to distinguish good data from bad data, thus lowering the overall reliability of the information.
- Discrimination by single actors and undesirable fractioning of the system and the sector into "good data supply chains" and "bad data supply chains."

System developers should tackle such capacity gaps in two ways:

First, it is important that the system does not create barriers to entry for forest operators and smallholders. Also, data collection and reporting should be designed to be achievable by all actors. For instance, in Colombia stakeholders submit data through a single-window system; in Guatemala and Peru, the data collection forms are Excel-based and in similar format to the tools used by the industry, making them easier to use (Stäuble et al. 2022).

However, high-quality data collection and reporting are essential for the system to achieve the objectives. Therefore, a capacity-building plan and budget for outreach, engagement, and training need to be in place for all points in the supply chain network, where a lack of capacity constitutes a risk to the integrity of the system.

Legal requirements

A clear legal framework is a necessary enabling condition for a successful traceability system. Before a system can be designed, it is important to identify inconsistencies in the legal framework (e.g., if a law allows farmers to convert forests while the forest law prevents conversion), and to determine whether laws will need to be changed, amended, or newly enacted to support the system.

While the specific legislative changes may only become clear at a later stage, a structured approach to any regulatory changes should be included in initial planning activities. It is also important to consider the time frame needed for the regulatory changes to be drafted, approved, and communicated in traceability system planning. If the legal framework is repeatedly changed for the sake of the traceability system, or if the system is implemented and it turns out that system requirements do not reflect the legal framework, acceptance of the system may drop irreversibly. Questions to consider include the following:

HOW SHOULD FOREST SECTOR-SPECIFIC REGULATIONS INCORPORATE THE TRACEABILITY SYSTEM?

The objectives and related indicators should be incorporated in the applicable legislation. The mandatory use of the system needs to be defined for all relevant actors, and sanctions for nonuse or misuse need to be specified.

Rules for using the system need to entail specific regulations:

- All obligations of all system users on what and how to report to the system
- All rights of the authority to access, use, process, and verify the information in the system
- All responsibilities of the authority to protect all the information in the system
- All responsibilities of the authority to share and publish all information

WHICH ASPECTS OF THE REGULATORY FRAMEWORK NEED TO BE CONSIDERED WHEN DEVELOPING THE SYSTEM?

The following regulatory aspects will affect the development of the system and should be considered at an early stage:

- Privacy: All data collection and reporting procedures need to be in line with applicable regulations to protect individual privacy.
- Business confidentiality: An effective traceability system will contain information that might be classified as confidential. This needs to be considered from the start to avoid resistance to report to the system.
- International trade regulations: If it is an objective of the system to comply with international trade regulations or country-specific import regulations, these requirements need to be considered.

- Transparency and access: The system needs to comply with applicable transparency and data privacy regulations in the country, while allowing the maximum possible access for stakeholders, to provide accountability and enhance credibility of the system.

1.3 Defining the scope of the traceability system

The scope of the system should consider, at minimum, the geography and jurisdictions, the type of forest resources and other wood sources, and the type of supply chains or supply chain network. Issues to consider in defining the scope of the traceability system include the following:

WHAT ARE THE GEOGRAPHICAL AND JURISDICTIONAL BOUNDARIES OF THE SYSTEM?

The geographical scope of the traceability system must coincide with the jurisdictional scope of the competent authority in charge of managing the system: a provincial forest authority cannot manage a national-level traceability system. However, the scope of the system should be as comprehensive as possible and consider all entry points of potential inputs into the supply chain network from external sources. The assessment of the scope of the system also needs to map the entry and exit points where wood resources are entering and leaving the geographical and jurisdictional scope targeted by the traceability system on their way from harvest points or to markets.

To avoid the risk of double counting (e.g., actors reporting the same amount of input material twice to two different systems), reporting should be designed to avoid the possibility of one actor reporting information into two separate nonintegrated systems (e.g., a national and a subnational system) (BV Rio 2016).

WHICH SOURCES SHOULD BE COVERED BY THE SYSTEM?

The scope of the timber traceability system includes the categories of forest sources covered, including types of forests (managed natural forests and plantations). Wood from non-forest sources, imported roundwood, and derived products should be considered, where relevant.

The following questions can help determine whether the scope of resources to be covered in the traceability system can be limited to certain supply chains or resources, or if material from specific sources can be excluded from the scope:

- Are objectives and benefits limited to a single forest type, such as plantations or managed natural forests?
- Are the products derived from these forests exclusively sourced from this forest type (consider legal and illegal possibilities)?

Sometimes, the main reasons for creating a traceability system include concerns about one or more specific types of forests. However, it is often difficult to exclude other forest types from the supply chain. Therefore, providing a conclusive answer to the second question is difficult without a functional traceability system. In many products and supply chains, material from different sources is mixed. Limiting the scope of the traceability system to single sources or species will inevitably create opportunities for leakage and unreported entries into the supply chain, compromising the data quality in the system.

Two of the most common ways to launder illegally logged wood are either by obtaining a permit for plantation production of wood for mills and funneling illegally logged timber through the plantation permit, or by laundering illegally cut wood by mixing it with legally produced plantation wood (Nellemann 2012). Thus, the scope of resources covered by a traceability system should be as comprehensive as possible. At the same time, data collection and reporting requirements should consider existing practices in different forest types. For example, requiring reporting based on single logs in a plantation sector where roundwood is usually reported on by truckload level will not increase the acceptance of the system.

WHICH SUPPLY CHAINS SHOULD BE COVERED, AND CAN SPECIFIC SUPPLY CHAINS BE EXCLUDED?

The considerations described above on determining the scope for types of resources covered by a traceability system apply also to determining the scope of which supply chains to include in a traceability system. The guiding questions include the following:

- Are objectives and benefits limited to specific subsectors, supply chains, or products, for example, the solid wood products industry, the paper industry, or the fuel wood sector?
- Is it possible to segregate the material from these subsectors from the overall material flow?

To answer these questions, system designers should draw on the findings from the sector mapping and material flow analysis carried out during stakeholder and capacity mapping.

As with the geographic scope, the supply chain scope should be made as comprehensive as possible, but reporting requirements and the required level of detail should consider common practices of different industries as will be described in the section on design and development.

HOW DOES THE SYSTEM CAPTURE WOOD ENTERING OR EXITING THE SYSTEM FROM OUTSIDE THE SCOPE?

Once the system scope for geography, jurisdiction, forest type, and supply chain is defined, system planners need to identify and analyze all entry and exit points of relevant material from outside the scope of the system. These can be understood as "system imports and exports."

The relevance of imports should be determined by analyzing the quantity entering the system and the risk of illegal harvest or trade associated with these imports.

For imports from perceived high-risk sources, it is important to integrate risk mitigation requirements. For low-risk imports stemming from a recognized control system or determined to be at low risk of illegality, the system could allow entry without additional risk mitigation requirements.

To define such risk mitigation requirements, due diligence requirements such as the 2010 European Union (EU) Timber Regulation and currently proposed EU Deforestation Regulation, the 2008 Lacey Act, or the 2012 Illegal Logging Prohibition Act of Australia can serve as benchmarks.

The above consumer country regulations should also inform the analysis of export market requirements (e.g., regulated international markets, connected subnational systems, or others) to ensure that the system can deliver materials with the necessary specifications for the markets targeted.

In this phase, the analysis should also include the prevalence of CITES-listed species in the geographical and supply chain scope (whether from domestic resources or imports) and their related requirements. The analysis should also clarify if information on certification status should be captured by the system or if legal conversion timber shall be identified as a separate category of origin (CITES n.d.).

1.4 Design and development

Because of the challenges related to system scope and integrity, as discussed in the previous section, comprehensiveness is a key success factor for a traceability system. The analysis of basic frame conditions for a traceability system during the planning stage will highlight sources and supply chains that will be more difficult to cover in the system than others. Implementing a comprehensive system all at once is impossible. System owners should therefore plan a stepwise approach to implementation. Conducting a thorough analysis that covers the questions identified in the previous sections will give planners an initial indication about options for rolling out the system in phases. More importantly, this analysis can highlight the limitations of a noncomprehensive traceability system. In the next phases (design, rollout, and upkeep), system owners should be aware of these limitations and allow them to guide their decisions. Aspects to consider include the following:

ARE THERE EXISTING SYSTEMS IN PLACE THAT SHOULD BE CONSIDERED?

Where possible, a traceability system should build on existing information management systems, processes that contribute to traceability, or private systems used by individual companies. Building on existing systems or processes can flatten the learning curve for all actors. Existing systems can also inform planning through previous experiences and challenges. Obtaining input from companies that have already integrated traceability into their operations can help create buy-in, facilitate consistent data sharing, and avoid duplication of efforts or the creation of parallel systems. However, system designers need to ensure that a traceability system does not cater to certain companies or sectors.

Even if a new system is built from scratch, there may be data available that, after thorough validation, can be imported into the new system; for example, registries of forest titles or processing facilities.

The recent development of the National System for the Control of the Origin of Forest Products (in Portuguese, Sistema Nacional de Controle da Origem dos Produtos Florestais; SINAFLOR) in Brazil aims to integrate existing state-level systems into a national umbrella system rather than developing a new system (Stäuble et al. 2022).

WHO OWNS THE SYSTEM AND WHO OWNS THE DATA? HOW IS ACCESS TO INFORMATION REGULATED?

Traceability systems are usually owned and operated by the forest authority. Based on analysis of the existing legal and institutional framework as well as stakeholder mapping (Figure 5), system designers need to map out which other public or private institutions may provide inputs to the system, could benefit from the information in the system, or both.

Detailed operational rules can only emerge at a later stage of the design process, but designers should set a basic framework for governing transparency at an early stage.

Figure 7 gives an example about how to categorize different levels of transparency for different user groups.

WHAT INFORMATION SHOULD THE SYSTEM CAPTURE?

Once the design team has defined the scope of the system, they can establish a process map that covers all relevant events in the supply chain network (processing, transport, or trade) where traceability data need to be captured. For each event, they need to define the data elements required.

During this process, the design team defines the units, conversion factors, tolerance, and the identifiers for each event, which will determine the attainable traceability levels for individual processes and whole supply chains.

Securing buy-in from private sector actors at this stage is critical. Designers should analyze existing business practices for each process and for different business sizes and build on them where appropriate.

FIGURE 7 | Transparency matrix for traceability systems

LEVEL OF ACCESS TO INFORMATION

Direct system access	**Public Interface/ Dashboard**	**Interauthority cooperation**	**Academia, CSOs, private sector**	**Full disclosure**
Information provided on demand	n/a	Interauthority cooperation	Academia, CSOs, private sector	Investigations
Published reports	Low transparencys	n/a	Academia, CSOs, private sector	n/a
	Aggregated, anonymized information	Aggregated information with user identification	Detailed anonymized information	Detailed information with user identification

LEVEL OF DETAIL OF INFORMATION DISCLOSED

Note: CSOs = Civil society organizations.
n/a = Not applicable.

Source: Authors.

In practice, system developers and operators face several challenges in developing comprehensive and functional frameworks, resulting from the following realities of the forest sector:

- Different supply chain actors use different methodologies for measuring the same unit. For example, there are at least three different basic approaches for measuring the volume of a single log and numerous differences in converting actual volume to commercial volume (bark deduction; consideration of bow, twist, and other defects). Most roundwood measuring is done by hand with basic tools. Thus, there can be significant volume discrepancies when different actors measure the same log. System designers should aim to standardize measurement and define necessary tolerance at each node of the supply chain network.
- Different supply chain actors apply different units to the same material. For example, while sawmills count the wood chips (by-products of the main process) in bulk cubic meters, the pulp industry often converts this volume into metric tons of absolute dry material, measuring the mass and humidity of incoming material. These differences between products must be accounted for in the system.
- Different actors will have different conversion factors for the same process. For example, the yield conversion from roundwood to sawn wood varies between sawmills and over time within one sawmill. The conversion factor depends on criteria like the cut species, the installed technology, the skill of the saw operator, roundwood quality and dimension, and product quality and dimension. A fixed conversion factor from roundwood to sawn wood may be valid as an overall, long-term average, but for a traceability system a fixed conversion factor can lack accuracy.

Because of these realities, traceability systems will require tolerance for data discrepancies resulting from the above-mentioned challenges. The system shall flag deviations so that system owners can analyze them. Thus, the system can also learn from the historic data and further refine conversion factors and tolerance levels.

HOW SHOULD TRACEABILITY DATA BE COLLECTED AND REPORTED?

In parallel with the above process, the design team can discuss with stakeholders how traceability data should be collected and reported.

System designers need to define which data elements the system captures for each relevant event, and how data will be collected and reported for each step. The potential benefits of new applications and tools for data collection and reporting were discussed in Box 3 in Part I of this publication. When applying these principles in the design process, the following questions should be kept in mind and discussed with the relevant stakeholders:

- How can unintentional error be minimized?
- How can incentives and opportunities to intentionally report false data be minimized?
- How can cost of data collection and reporting be minimized?
- How can barriers to entry to complying with data collection and reporting requirements be avoided or mitigated?

Because public traceability systems are business-to-authority reporting systems, continuously involving system users is crucial in this phase of developing data collection and reporting procedures.

Private sector users play key roles in the system by collecting and reporting data, so their willingness to participate is critical in ensuring the successful implementation of the system. Different actors will have different needs, capacity, and cost of data collection and reporting. These issues need to be addressed in this design phase. Field testing of different data collection, reporting, and marking technologies needs to be carried out with a representative group of future users.

HOW WILL THE SYSTEM MANAGE AND ANALYZE REPORTED DATA?

Once the system owners have determined which data are collected by the system and how they are reported, designers can start to define how the system processes and analyzes the data.

The traceability system collects information on the material flow and associated economic transactions from forest to finished products. Inputs, stock volumes, and outputs should correspond to each event as well as to entire corresponding supply chains. Even with highly standardized data collection and reporting procedures, there will be mismatches and inconsistencies between data reported from different actors at different stages. System designers need to decide how to deal with such mismatches. This includes the definition of tolerance for variance, and acceptable and unacceptable errors. Unacceptable errors should be flagged and catalyze further investigations. For example, if a processing facility reports an unusually high yield, there can be valid reasons (good roundwood quality, cutting of yield-optimized products, modern technology), but it could also indicate that the site is processing unreported inputs. On the other hand, if a company has a good track record with limited red flags, field inspections can be minimized.

WHERE AND WHEN SHOULD THE SYSTEM BLOCK PROCESSES?

Many systems require reporting of the full workflow and exclude the contingency of skipping single steps in the process chain. Even if in some situations reporting can only happen ex post (e.g., due to low connectivity at the time and place of an event), at least the full process history is recorded with this approach.

It is essential for designers to find ways to automatically cross-check or reconcile data and consider the following:

- Is the harvest data consistent with inventory data?
- Can the system be linked to customs data to validate reported imports or exports?
- Are transport vehicles registered in the system also registered in the vehicle registration office?
- Is the reported stock volume of a forest management unit realistic when compared with existing inventories?

During this phase, system designers can further map out the rules for transparency and access rights, as mentioned and sketched out in Figure 7.

WHAT TOOLS FOR MONITORING AND OVERSIGHT SHOULD BE APPLIED? AND WHAT TOOLS FOR VERIFICATION SHOULD BE APPLIED?

A systematic and technology-supported approach to reporting (data collection, reporting into the system, and data analysis), as described in the previous sections, will contribute to the reliability and integrity of information in the system and collect information that can then be made available to different stakeholders.

Yet, additional safeguards are needed to verify self-reported private sector data, as described in Part I of this report, under "Monitoring and verification." The concept for monitoring and verification activities should follow a risk-based approach. The main risk to address is the risk of undetected reporting of false data.

Criteria of likelihood include incentives and opportunities to intentionally report false data on the one hand, and unintentional false reporting on the other. The risk of unintentional false reporting will be higher for processes in which material flows are complex and internal traceability approaches are demanding (e.g., paper production with a mix of inputs consisting of industrial roundwood, sawmill by-products, market pulp, and recycled paper).

Thus, the monitoring and verification approach not only detects fraud and false reporting but also aims to identify steps to improve data collection and reporting procedures. Both objectives are equally important.

Figure 8 illustrates typical risks of fraud or false reporting, critical control points, and possible approaches to address these risks along the supply chain. The figure can serve

FIGURE 8 | Risk matrix for guiding monitoring and verification

	Title allocation and FM preparation	Harvest	Round wood transport	Primary processing	Transport	Secondary processing
Likelihood	High economic incentive to submit fraudulent managment plans Incentives for bribery and collusion Low risk of unintentional error	Medium to high incentive to report falsely Medium risk of unintentional errors Incentives for bribery and collusion	Medium to high incentive to report falsely Medium risk of unintentional errors Incentives for bribery and collusion	High incentive to not report illicit inputs and launder them via an overstated conversion factor Medium risk of unintentional errors	Medium incentive to report falsely Medium risk of unintentional errors	Low to medium, most material will be sourced officially. Potential incentive to not report primary processed products from informal suppliers. Medium risk of unintentional errors
Severity	High, creation of large fake volumes to launder illegal wood	High, creation of large fake volumes to launder illegal wood	Medium to high, creation of smaller fake volumes per transaction	High, systematic wood laundering as major entry point of unreported material	Medium, creation of smaller fake volumes per transaction	Low to medium, potential to launder additional volumes smaller than for primary processing
Resulting risk	**High**	**High**	**Medium to high**	**High**	**Medium**	**Low to medium**
Monitoring and verification	Field Verification Remote Sensing Use of independent third parties	Field Verification Remote Sensing Use of independent third parties	Road checks GPS tracking	Mill inspections Temporary mill gate surveillance	Road checks GPS tracking	Mill inspections Temporary mill gate surveillance
Critical control point	**Yes**	**Yes**		**Yes**		

Notes: FM = Forest management; GPS = Global Positioning System.

Source: Authors.

as a starting point for planners to design and incorporate monitoring and verification activities in the system. The risk-based, deliberate sampling for monitoring and verification activities needs to be complemented by random sampling.

Severity criteria should consider economic (does false reporting lead to loss of royalties?), ecological (does false reporting affect vulnerable or protected species/areas?), and social (does false reporting affect minorities or smallholders?) aspects. Severity should generally be considered higher further upstream in supply chains than downstream because the upstream information serves as reference for all subsequent downstream reporting.

It is also important to consider who is mandated to undertake verification activities. As some reported instances of fraud and failures of traceability systems involved bribery and collusion of public officials (Brancalion et al. 2018; INTERPOL 2016; Urrunaga et al. 2012). Having independent third parties undertake part of monitoring and verification activities would be an important step to achieving credibility for the system. Furthermore, the system should be designed to track users and activities throughout the supply chain and the verification process (e.g., which officer inspected and approved a certain batch) to support verification activities.

Finally, it is important to consider the quality of data, not only for system inputs but also for data collected as part of monitoring and verification activities. These records must maintain a standard of quality that is equal to or higher than the reported traceability data in terms of comprehensiveness and should result from advanced field data collection and reporting.

PHASE 2: IMPLEMENTATION

During the design and development phase, the design team will test individual elements of the traceability system, such as reporting of different events, identifiers for roundwood or processed wood, remote verification tools, and elements of the database itself. The scope of these tests should grow toward more comprehensive field tests during the design phase. These tests, together with results from initial considerations and scope definition phases will give useful inputs for developing an implementation strategy.

It is neither feasible nor recommendable to roll out a comprehensive national traceability system all at once. System owners need to identify a region, individual forest areas, and individual entire or partial supply chains as a starting point for piloting the system. In each case, there will be different priorities and critical success factors to be considered.

It is likely that technical problems will occur during the rollout, and that further modifications will be required. Therefore, it is recommended to roll out the system in a context in which system owners can focus on technical issues and work quickly to resolve them. This means starting with actors among whom high acceptance of the system is likely. This will also ensure that results of the initial pilots will be less biased because of potential lack of acceptance. However, the initial scope should not only cover the "low hanging fruits" but represent different supply chain actors facing different challenges in using the system.

System developers can formulate their guiding questions along the scope definition to frame the development of an implementation strategy:

WHERE SHOULD THE IMPLEMENTATION START?

The legal framework needs to be established and clear for the target region of implementation because any legal ambiguities will interrupt the process and can lead to a loss of system acceptance.

Geography should be considered in terms of access to all parties involved since the early implementation phase can require frequent travel to support system users.

WHICH FOREST RESOURCES SHOULD BE PRIORITIZED FOR IMPLEMENTATION?

If different reporting requirements exist for different silvicultural systems, all variations should be considered during initial rollout, unless there is a clear priority for specific forest types.

Again, access to the forest management units and private sector buy-in should be considered in choosing the resources to be used for initial pilots.

WHICH SUPPLY CHAINS SHOULD BE COVERED IN INITIAL IMPLEMENTATION?

In general, the rollout should evolve downstream along the supply chain starting at the forest so that the supply chain scope of the initial implementation will be determined mostly by the chosen forest area and type.

System developers can choose to limit the scope to the entry gate of secondary processing for an initial phase and include secondary processing, subsequent trade, and consumption later.

For validation of system functionality during initial rollout, it is helpful to identify a short, linear, and clearly delineated supply chain; for example, for sawn wood or decking as opposed to wood-based panels or paper production, where delineation is very challenging.

SHOULD ALL FUNCTIONALITIES BE IMPLEMENTED AT ONCE?

Some elements and functionalities of the system should be prioritized in implementation to target resources and focus attention. Because a comprehensive database is the backbone of a traceability system, developers need to focus on implementing this element as a first step. Low barriers to entry and acceptance by users are more important than detailed data collection and reporting requirements at this stage, because if goodwill from users is lost early, it will be hard to recover from this problem later.

It is better to collect less data at an early stage of implementation but manage and analyze it comprehensively than to collect a lot of data from the start but not be able to process it. At the same time, it is important to clearly communicate to actors that more data will be collected at a later stage of implementation to avoid misunderstandings of the system scope among system users.

HOW CAN PRIVATE SECTOR BUY-IN BE SECURED DURING ROLLOUT?

Since private sector buy-in is crucial for the success of the system, developers should think of means to incentivize system use; for example, via reduced royalties, speedier processes, and reduction of paperwork for early adopters and by communicating clearly the different benefits expected from the system, as laid out in this publication.

Rollout should also be accompanied by stakeholder engagement and training based on the needs identified at previous stages and use tailored communications and consultations to help identify the needs and expectations of all stakeholders and ensure their expectations and concerns are addressed in the development of the system.

Increasing the intensity of monitoring and verification early on can be beneficial to ensure the reliability of information in the system in its early phase. But this enhanced monitoring and verification activity should be carried out without issuing sanctions for false reporting, to not threaten user acceptance at an early stage.

ARE THERE ALTERNATIVE STRATEGIES FOR IMPLEMENTATION?

A strategy to rollout a national timber traceability system in phases is to identify the most complex and critical supply chains in the scope of the system and start with these; if the system works for the most complex supply chain, it will work equally well for the remainder of the sector. However, this could be a high-risk approach.

System owners should take the time to learn important lessons from an early rollout with a limited geographical, timber resource, supply chain, and data scope before they expand along these dimensions.

PHASE 3: UPKEEP

It may take several years until the system reaches the initially planned scope and functionality, which means that implementation and upkeep will always overlap. Eventually, traceability systems stay under continuous development. The recommended approach is therefore to establish a management cycle for the traceability system that includes an annual review of the following five elements:

STRATEGY REVIEW: ARE THE OBJECTIVES AND EXPECTED BENEFITS OF THE SYSTEM UP-TO-DATE AND VALID FOR ITS OWNERS, STAKEHOLDERS, AND INTERESTED PARTIES?

Policy conditions may change over time and have an impact on the objectives of the system. New objectives in natural resource management may have an impact on the traceability system. New target markets or changes in export market regulation may affect the system. Information needs of civil society regarding forest-based products can change over time, as well. These are just a few examples to illustrate why a periodic review of a traceability system from a strategic perspective is recommended.

PERFORMANCE TRACKING: HAVE THE GOALS DEFINED FOR THE LAST PERIOD BEEN ACHIEVED? ARE GOALS FOR THE UPCOMING PERIOD SET ACCORDING TO THE DEFINED KEY PERFORMANCE INDICATORS (KPIS)?

System owners should set targets for the indicators (See Table 7) defined during the initial planning phase. Further KPIs could focus on data quality and user-friendliness. For example, an analysis of investigation results, triggered by automatic system alerts as well as results of randomly conducted monitoring and verification activities, can yield information on how data quality and system integrity change over time.

ARE THE ALLOCATED RESOURCES ALIGNED WITH THE SET GOALS?

System owners should review budgeting from the past period and define needs for financial, technical, and human resources for the next period.

IS AN INTERNAL AUDIT AND REVIEW PROCESS IN PLACE THAT COVERS ALL RELEVANT TOPICS?

System owners should conduct an internal audit and review of all relevant processes, procedures, and requirements, and evaluate possibilities for improvement.

The process should include the following:

- An assessment of whether the system is functional at all stages
- An analysis of whether there are new events/processes in the scope that need to be reflected in the system
- A check to confirm whether data collection and reporting procedures are still state of the art
- Consideration of relevant feedback from users and of further stakeholder inputs

EXTERNAL AUDIT: IS THERE A NEED FOR AN EXTERNAL AUDIT?

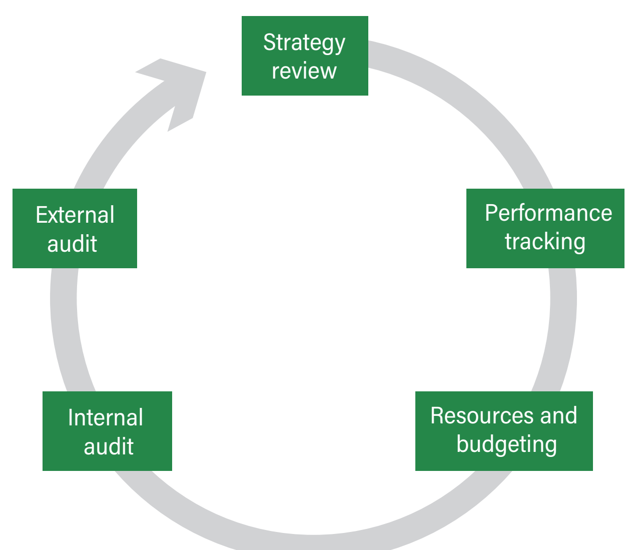
Because timber traceability systems operate in a context that is at risk for bribery and petty and grand corruption, it is highly recommended to plan for an impartial third-party audit process to ensure the continued credibility and legitimacy of the system.

Possible third parties with the necessary expertise to carry out such audits include the following:

- Authorities other than the one responsible for the system
- National and international research organizations and academia
- International consultancies, experts, or accredited certification bodies

Audit teams should be composed of members from the groups stated above to compensate for any potential conflict of interest. Figure 9 illustrates the management cycle for the upkeep of a traceability system.

FIGURE 9 | Management cycle for a traceability system



Source: Authors.

Conclusions

Drawing from existing literature, 11 case studies in seven countries in Latin America (Stäuble et al. 2022), stakeholder communication, and results from meetings and workshops, this report synthetizes the state of knowledge on government-owned traceability systems as an instrument of national and international forest governance.

In Part I, the guide establishes a generic definition of government-owned traceability systems and defines and describes their core elements: scope; units, conversion factors, and identifiers; levels of traceability; reporting procedures; data management; and monitoring and verification.

By defining and aligning these key terms and concepts with the existing knowledge base, Part I creates the base for Part II of this guide, the traceability framework. The framework lays out a generic road map with questions guiding the development, implementation, and upkeep of a government-owned traceability system.

Decision-makers, system designers, and other interested parties can use this guide to build basic knowledge about traceability systems, for project planning for new systems, and to assess existing systems.

This publication facilitates the development of consistent and comparable approaches in the overall discussion on traceability systems, in understanding what objectives are feasible when developing new systems, and in measuring what has been achieved with existing systems.

In doing so, this guide supports the meaningful and beneficial development of traceability systems as a valuable contribution to forest governance. The insights from this project can also be used for the development of supply chain governance tools for other supply chains beyond timber that impact forestry; for example, agricultural commodities that can lead to forest conversion.

In addition to applying this publication for decision-making, and system design and analysis of existing systems, the country case studies cited in this work should be considered as useful further readings. The Latin America case studies (Stäuble et al. 2022) provide more detail on specific systems and describe traceability systems from a practical perspective.

Since private sector buy-in is crucial for the success of the system, developers should think of means to incentivize system use; for example, via reduced royalties, speedier processes, and reduction of paperwork for early adopters and by communicating clearly the different benefits expected from the system, as laid out in this publication.

It is neither feasible nor recommendable to roll out a comprehensive national traceability system all at once. System owners need to identify a region, individual forest areas, and individual entire or partial supply chains as a starting point for piloting the system. In each case, there will be different priorities and critical success factors to be considered.

Finally, while this report focuses on timber supply chains, the technical framework can also be applied to address traceability challenges in supply chains for other commodities.

LIST OF ABBREVIATIONS

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
FLEGT-VPA	Forest Law Enforcement, Governance and Trade-Voluntary Partnership Agreement
OSINFOR	Organismo de Supervisión de los Recursos Forestales y de Fauna Silvestre (Body for the Supervision of Forest and Forest Wildlife Resources)
SEINEF	Sistema Electrónico de Información de Empresas Forestales (Electronic Information System for Forest Enterprises)
SERFOR	Servicio Nacional Forestal y de Fauna Silvestre (National Service for Forests and Forest Wildlife)
SINAFLOR	Sistema Nacional de Controle da Origem dos Produtos Florestais (National System for the Control of the Origin of Forest Products)
SIRMA	Sistema Informático de Rastreabilidad de la Madera (Timber Traceability Information Technology System)

GLOSSARY OF TERMS AND CONCEPTS

Blockchain technology
A blockchain is a decentralized and distributed ledger that keeps records of digital transactions in a way that makes them accessible and visible to multiple participants in a network, while keeping them secure without the need for a centralized organism or database. Blockchain technology was key to the emergence of cryptocurrencies as it creates the possibility of a distributed ledger and eliminates the need for a central ledger (Figorilli et al. 2018). The use of blockchain technology for traceability systems is currently being discussed and tested by several actors.

Business-to-authority (B2A) system
A system that is owned and used by an authority, where most of the information in the system is collected and reported directly by private sector actors, as opposed to a system where all information is gathered and reported by public officials.

Central ledger
A digital file as part of a traceability system to record traceability data, such as inputs and outputs of each participating organization in a centralized manner.

Chain of custody
Originally a term that refers to documenting the history of evidence from the point it is obtained until it is presented at court in the legal context. The term was adopted by forest certification schemes for certifying that labeled products contain only eligible inputs.

Chain of custody certification defines minimum requirements for internal and external traceability of forest-based products. In general, chain of custody does not entail full traceability.

GLOSSARY OF TERMS AND CONCEPTS (CONT.)

Conversion factors

Conversion factors define how material is converted from one traceable resource unit to another. They are necessary when material is processed or when an operator prefers to convert material to a different measuring unit than the one used by his supplier.

Downstream traceability

Refers to further processing, distribution, use, recycling, or disposal of material and products from any given point in the supply chain toward the end consumer.

External traceability

Refers to tracing material and products as they are traded between organizations.

Identifier

Each traceable resource unit (TRU, see below) needs a unique identifier as its representative in the traceability system. Surrogate keys (e.g., sequential numbers) and mnemonic keys (e.g., a structured log code, stating the owner, date, parcel, and tree number) can be applied. There are identifiers with internal data storage (Radio Frequency Identification [RFID] tags) and identifiers linking to external data storage (barcodes). Even the deoxyribonucleic acid (DNA) profile of a tree can serve as an inherent identifier for timber. (See Box 3 for more information.)

Identity preserved

A level of traceability in which the information about a specific origin is maintained during each step and along the entire supply chain. An identity preserved product can be traced all the way back to its original source.

Internal traceability

Traceability within an organization's processes.

Measuring units

Forest products are measured in different units. They include mass, volume, and areal and linear units. The unit applied in a specific situation is usually determined by customs at a specific point in a supply chain.

Planing

Processing sawn wood into planed wood with a smooth surface.

Pre- and post-consumer recycled material

Preconsumer recycled material is waste material that was created during the manufacturing process and can be used as input for another production process.

Postconsumer recycled material is material that was created from goods after they had been used by a consumer and can be used as input for another production process.

GLOSSARY OF TERMS AND CONCEPTS (CONT.)

Rotational clear-cut and patch-cut systems
Silvicultural production and harvesting systems where all trees of a defined area are cut in a planned harvest event.

Sawing
Processing roundwood into timber (sawn wood, boards, beams, etc.).

Single tree selection systems
Silvicultural production and harvesting systems that manage a forest area for harvest of individual trees throughout a forest stand, as opposed to patch-cut or clear-cut systems, where all trees of a defined area are cut in a planned harvest.

Stumpage fees
The price paid for the right to harvest timber, paid by the forest enterprise to the landowner. The applied unit is typically the amount/volume. Where traceability systems are applied to monitor private concessions on public lands, the calculation of stumpage is usually part of the system.

Traceable resource unit (TRU)
The smallest entity of material that is assigned an identifier in the system. Traceable resource units will change along the supply chain (e.g., a single log, a batch of sawn wood, pieces of furniture, etc.).

Traceability
Traceability has been defined as the ability to trace the history, application, and location of a product, including the origin of its materials and parts, its processing history, and its distribution and location after delivery (ISO 2015).

Upstream traceability
Refers to the processing history of material and products from any given point in the supply chain toward the point of origin.

Volume tracking
Volume tracking, also known as **mass balance**, is a concept for monitoring supply chain networks or parts of supply chains in which an identity preserved approach cannot be implemented. The focus is to ensure that the total of network outputs corresponds to the total of inputs; therefore, input and output volumes are reported for each event and process.

Waybills
Umbrella term for mandatory transport documents for forest products as required by applicable regulation.

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World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

OUR CHALLENGE

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

OUR VISION

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

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