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PROJECT TECHNICAL

The Report on Pilot Operation of Blockchain-based Timber Traceability System

EXECUTING AGENCY:

Secretariat of the Global Green Supply Chains Initiative (GGSC)

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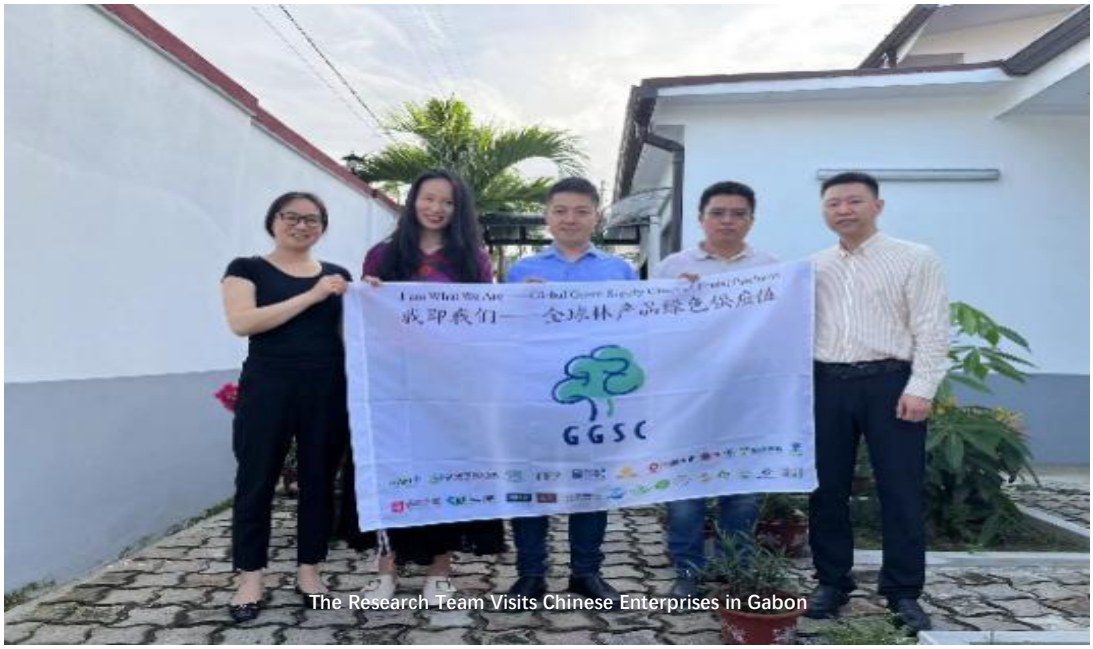
The Secretariat of the Global Green Supply Chains Initiative(GGSC)

21，November 2023 年

Gabonese Wood Processing Plant

The Research Team in the Gabon

The Research Team in the Republic of the Congo



The Research Team Visits Chinese Enterprises in Gabon

Photo of the Research Team and UFIAG

This report was written by the BC project team. Thanks for their effort and hard work.

Dr. Luo Xinjian,Project Coordinator.

Ms. Li Yinfeng,Wood Industry Expert.

Mr. Jin Ming,Blockchain Expert.

Dr. Meng Qian, Chief Writer /Industry and Trade Expert.

Ms. Gao Xuting, Director of Public Relations.

Mr. Luo Shiyu,Technical Assistants.

Ms. Zuo Ping,Technical Assistants.

Content

Abbreviation

AFD	The Agence Française de Développement
API	Application Program Interface
BFT	Byzantine Fault Tolerance
BTTS	Blockchain-based Timber Traceability System
CFAD	Concession Forestière sous Aménagement Durable
CITES	Convention on International Trade in Endangered Sp
FLEGT	Forest Law Enforcement, Governance and Trade
FSC	Forest Stewardship Council
GGSC	Global Green Supply Chains Initiative
GIS	Geographic Information System
GSNTBG	Gabon's National Timber Traceability System
IPIM	Trade and Investment Promotion Institute of Macao SAR, China
ITTO	International Tropical Timber Organization
PFA	Permit Forest Associated
PGG	Direct Agreement Permits
TRAFFIC	International Wildlife Trade Research Organization
VPA	Voluntary Partnership Agreement

The legal and sustainable supply of timber helps promote the sustainable forest management, and has influence on addressing climate change, serving the poor in communities, boosting employment, and promoting sustainable development. In recent years, many positive steps have been taken by the international community as well as individual countries towards regulating the supply chain of timber and its products. For example, the European Union, the United States, Australia, Indonesia, Japan have introduced relevant regulations and methods to ensure that the imported timber and its products are coming from legal sources. However, there are problems such as inconsistent certification standards, difficulty in traceability, and high costs. There is an urgent need to use the new technology to improve timber traceability and reduce the traceability costs. Blockchain technology, which is believed to has the advantages of decentralization, traceability, immutability, transparency, has been successfully applied in the fields of tracing food, virus, drugs and devices, and has great potential to solve the legality of timber traceability.

ITTO conducted a study of the blockchain-based international timber traceability system for building sustainable wood supply chain since 2020. During the implementation, the blockchain architecture applicable to the timber traceability system was initially established. In 2022, ITTO embarked on cooperation with the Macao Trade and Investment Promotion Institute (IPIM), for implementing the project "Supporting the Collaborative Trial Operations of the Blockchain-based Timber Traceability System (BTTS) for Building Legal and Sustainable Forest Products Supply Chain". The aim is to conduct the pilot operation of Blockchain-based timber traceability in producer and consumer, to verify the theoretical framework of BBTS and lay the foundation for the BTTS promotion and application. The project is executed by Secretariat of the Global Green Supply Chains Initiative (GGSC). This report is one of the research achievements of the project, focusing on summarizing the pilot operation of Blockchain-based timber traceability and the pilot findings.

1. Blockchain and its advantages in traceability

Blockchain is a distributed database system established by a number of nodes, and it is an open ledger system. It relies on technologies of distributed data storage in blocks, decentralized data transmission, and encryption algorithms, and links the blocks in a chain structure to form a distributed shared ledger. In this ledger, the consensus algorithm determines the bookkeeper, and the tamper-proof of the transactions in the ledger is ensured by the cryptographic signatures and hash algorithms; the traceability of the information of the blockchain is ensured by the

timestamps and hash functions: all these techniques provide a unique mechanism for credit creation. Applying blockchain technology in cross-border timber tracing has the following five advantages.

(1) Decentralization. Using blockchain technology in tracing origins of timber in a cross-border context enables each node to maintain and update the blockchain data and verify its effectiveness. This advantage is attributed to the distributed P2P network structure and equal right and obligation of each node at the same level. Because all node participants jointly maintain the data ledger, this effectively reduces the risks of overload to the server, single point of failure, and manager dereliction which happen frequently in traditional, centralized systems.

(2) Traceability. Now we explain how it works using blockchain technology for timber tracing. Firstly, at any node, new transaction information is generated and immediately distributed to other nodes through the P2P network. Then, each node uploads the information into the block, and stamped with a timestamp. A blockchain is formed by linking this block with the previous block according to the hash value of the previous block, and reverse modification is impossible for each blockchain. This whole process ensures the traceability of the data.

(3) Tamper-proof. Blockchain can be divided into public chain, consortium chain and private chain by the degree of openness. The consortium chain is suitable for cross-border timber tracing due to accessibility and permission control: that is, participants need approval before they can participate in the preservation, updating and maintenance of the ledger. At the present, most of consortium chain uses BFT consensus algorithms, which ensures that the transaction cannot easily be tampered. A single node can tamper only if its 51% or higher computing power is controlled, and the cost of computing is usually much greater than the benefit, which could effectively prevent hacker attacks.

(4) Privacy. The hash function and asymmetric encryption and other cryptographic methods of blockchain techniques can make data "available and invisible" and ensures the privacy of any data. At each node, the enterprise has a public and private key, based on which it converts the original data into a digital abstract by the hash algorithm, and then the digital abstract is encrypted and sent to any node with the private key; at any other nodes, the party who needs to verify traceability information can use the public key to decrypt and obtain the abstract value. In this process, the hash algorithm is again used to verify data authenticity. This entire tracing process does not retrieve any absolute data of the transaction information, and only verifies the

authenticity of the encrypted data, thereby ensuring the privacy for each participant.

(5) Low cost for each node. Compared to any traditional centralized information system, the biggest cost of the blockchain-based cross-border timber tracing system is system development and tailor-made chips. The increase in participating nodes does not affect the capacity. For example, if a new timber enterprise is added, the only addition would be to connect the dock of the enterprise to the current system. Even if the enterprise does not have an information system in place, the IT party can remotely deploy and build a corresponding system for it. In other words, each node operates independently in the blockchain-based tracing system, and any malfunction of one node does not affect the operation of the whole system. This guarantees the reliability of the tracing system. In contrast, the extra cost is substantial for higher requirements for hardware equipment in the cases of nodes increase under the traditional centralized traceability information system. This is not the case in the blockchain traceability system.

At present, the timer traceability mainly relies on the traditional IT technology, that is, establishing the centralized traceability information system, and there are two major difficulties in information infrastructure construction and model promotion:

The first one is that cross-border timber tracing involves a large amount of unstructured data (information that either does not have a pre-defined data model or is not organized in a pre-defined manner including pictures, videos, raw signaling data, etc.). Even if the centralized IT infrastructure uses cloud-based virtualization technology, the efficiency of data interaction such as calculation and query will encounter technical bottlenecks when the number of virtual nodes (the number of participants) passes a certain level. In this case, it would be difficult to break through and the cost would increase dramatically with the growth of nodes.

Secondly, the traditional traceability system is based on the completion of the data interaction amongst interfaces of the information systems of all participants. This process has an obvious disadvantage in the lack of protection to data ownership and privacy, leading to the unwillingness and even resistance to provide accurate and complete data by the stakeholders. In addition, the cost persists high in supply chain management and trust maintenance, which would hinder the popularization of cross-border timber traceability systems.

Compared to the traditional centralized traceability technology, blockchain technology with the advantages of openness, tamper-proof, anonymity, traceability, etc. can effectively solve the

above-mentioned problems, and plays a better role in facilitating comprehensive system of timber tracing and in empowering the entire industrial chain of timber products.

2. The collaborative operations mechanism of blockchain-based timber traceability

The timber supply chain involves many sub-industries, long chains, and diverse participants. The main objectives of the blockchain-based timber traceability system(BTTS) are to trace the forest from which the timber originated, verify that the timber traded comes from sustainably managed forests, and meet the legal and sustainable requirements of importing and exporting countries. Therefore, a collaborative operation mechanism that is compatible with incentives for all stakeholders is the key to the successful operation of BTTS. In general, the BTTS collaborative operation mechanism includes the construction, of Consortium Blockchain, the role and function of participants, the collaborative traceability process and the system architecture, aiming to solve the problem of coordination between the stakeholders along the supply chain, enable all stakeholders to jointly complete the upload and maintenance of timber traceability information, and strengthen the supervision of wood traceability through regulatory authorities and third-party certification bodies to promote legal and sustainable timber trade.

2.1 The establishment of Consortium Blockchain

According to the degree of openness, blockchain can be divided into Public chain, Consortium chain and Private chain. The Public chain has no access requirements and is a completely decentralized blockchain that is not controlled by any institution. The Consortium chain is a multi-center structure, which is only open to its members, and participants need to be reviewed and authorized in advance. A private chain is similar to a centralized system, where a single institution is generally responsible for managing the entire blockchain and has control over issues such as user access, consensus rules, and updating ledgers. Timber traceability usually adopts the Consortium chain, which has the characteristics of access mechanism and permission control. Participants need to be reviewed and authorized in advance to participate in saving, updating and maintaining public ledger.

In practice, the basis of collaborative operations mechanism of blockchain-based timber traceability is to establish the Consortium chain. Namely, the timber stakeholders of timber industry (including forest owner, sawn mills, importers and exporters, processing enterprises, forestry authorities, customs, third-party certification bodies, IT Platform operators, etc.) first

form an alliance to form a consensus mechanism, and set up an access mechanism and authority control that can jointly participate in the BTTS. Through the technical rigid constraints of the Consortium chain, all participants have built a cross-border timber traceability ecosystem with mutual trust, controllable risks, and circulation based on credit value.

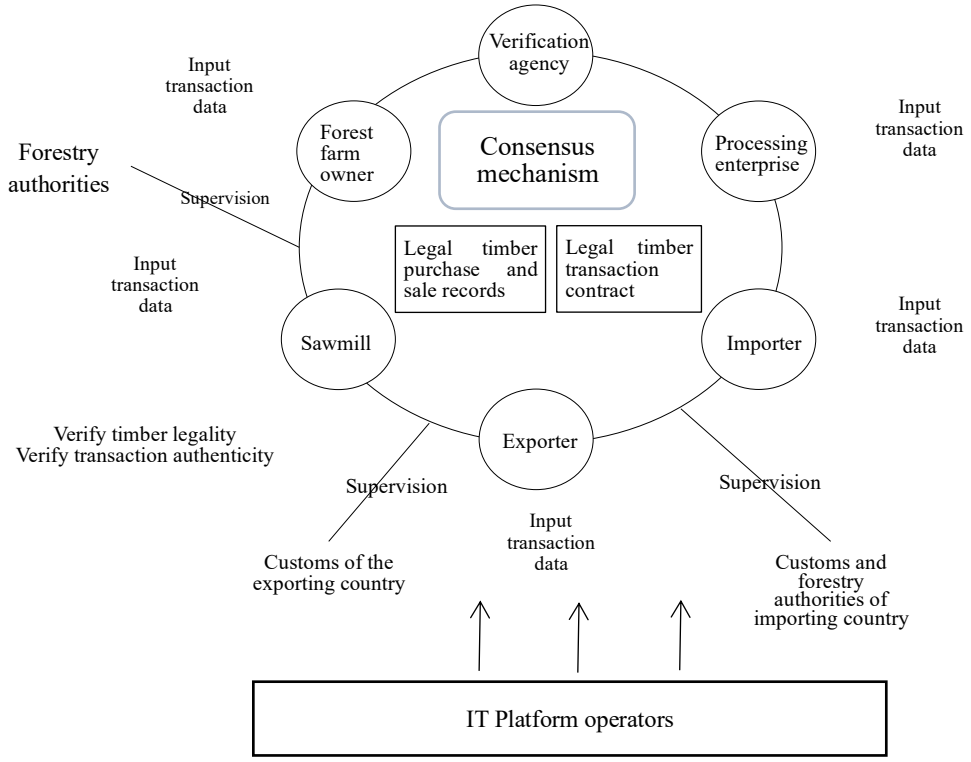


Figure 1: The Consortium Blockchain of the blockchain-based timber traceability system (BTTS)

2.2 The participants and their role of BTTS

In the Consortium Blockchain of the blockchain-based timber traceability system (BTTS), the core participants can be divided into five categories:

(1)The participants involved in timber production and operation, such as forest owner, sawmill, importer and exporter, and wood (wood products) processing enterprise. They are data providers, important users, and the main stakeholders of the timber traceability system, who are responsible for uploading the information needed for the trade transactions.

(2) The government departments that supervise timber legality, including forestry authorities, customs, etc., are important supervision authorities to ensure the effectiveness of cross-border timber traceability. Once illegal timber or unauthenticated/inauthentic data are identified, the regulatory authorities can locate the responsible unit through the blockchain traceability system

in a timely manner, and reduce adverse impacts, impose penalties according to law.

(3) The third-party verification agencies that review and verify the reported data by the timber enterprises, are mainly responsible for auditing and verifying the authenticity and validity of the certificates of legal origins of timber provided by forest farm owners, sawmills and other enterprises in accordance with relevant laws and regulations, and in the end issuing corresponding certification documents. The third-party verification agencies are important service providers for blockchain-based cross-border timber traceability.

(4) The IT Platform operator, who develops and operates the BTTS, is the provider of the IT infrastructure (including software, hardware, and services) required for timber traceability, and is responsible for ensuring the normal operation, update and maintenance of the BTTS. For example, operators need to consider embedding GIS geographic information, wood-related laws and regulations of various countries, CITES tree species information, etc. into BTTS smart contracts, compiling them into computer programs, which all participants must strictly abide by, so as to improve the standardization and standardization of timber transactions.

(5) The consumers of timber and timber products is an important node for promoting the legal and sustainable management of timber through consumption behavior. Consumers can scan the timber traceability code (QR code or barcode) through mobile phones, tablets and other apps to obtain the source information of the whole life cycle of timber. By doing this, the legal and sustainable practices will be strengthened through consumers' behavior.

2.3 The collaborative traceability process of BTTS participants

The traceability process of the blockchain-based timber traceability system (BTTS) is that all participants upload the timber production and circulation information in turn, and the corresponding information is digitized in the blockchain system (including the identity and parameter information), and the participants maintain/update the timber flow information. In addition, timber traceability information can be recorded in quantum cloud code by the "one-object-one-code" carrier-tracing technology. Due to the complexity of timber supply chain, there are a number of branches in the transaction process. In this paper, we focus on the key operation procedures as shown in Figure 2.

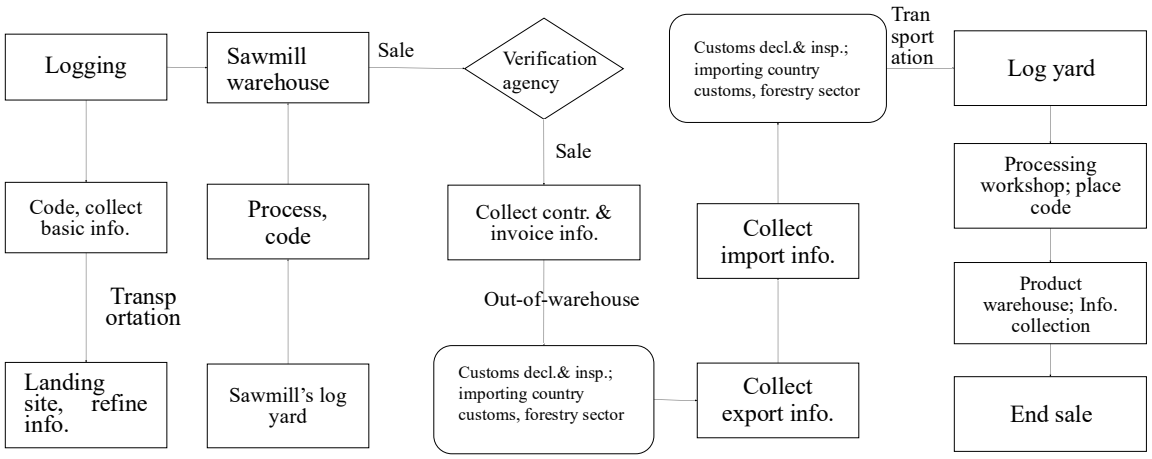


Figure 2: The collaborative traceability process of BTTS

Logging: The main entity in this stage is the forest farm owner. Monitoring and video surveillance equipment can be installed on the forestland to collect real-time data on timber growth and the environment, in order to document the wood information. Each piece of timber is marked with a quantum cloud code (namely, "data fingerprint") after harvesting. In the cases where local network is bad, a location chip can be embedded in the quantum cloud code to record and store the real-time displacement change of the timber. Considering the forestland conditions, the following basic information can be entered after logging – i.e., tree species, harvester, and harvesting time. Next, the information such as timber production, and licenses of sustainable forest management and harvesting permit can be added after transporting to the wood landing site. If the timber is sold from forest farm owners to sawmills, the sales information should be uploaded to the blockchain, by means of electronic scanning on the contracts, invoices and other documents. This process reduces human intervention and improves operational efficiency. All the on-chain data are immediately time stamped once entered the blockchain traceability system. When the timber is sold to the next stage, the forest farm owner makes a transaction request, encrypts the digital abstract using the private key and sends it to the sawmill, followed by the real-time updates of the timber transaction.

Sawing: The main entity in this stage is the sawmill. Transported from the wood landing site to a sawmill, the logs are usually piled in the stockyard, and then cut into sawn timber with standard length. In this process, the quantum cloud code attached to the log could be damaged, and it is necessary to attach a new label to the minimum unit of sawn timber manually and record the segment data once the log becomes several sawn timbers. In order to prevent fraud

in this process, the following two approaches could be applied: The first is to install video surveillance equipment in the sawmill to monitor the whole process of log stacking, sawing, and selling. The second is to apply a cap for the total amount of output sawn timber based on the volume and other relevant data of the harvested logs, with the aim of avoiding excessive processing.

Verification: The main entity of this stage is the third-party verification agency. In the exporting country, the authoritative organizations with experience in forest management and timber certification are selected, who will verify the timber data of the forest farms and sawmills to ensure the legality of timber and the authenticity of transactions. The third-party verification agency needs to have a relatively complete database and connect to the cross-border timber traceability system, and to verify the legality of timber without retrieving private data. In the cases of abnormality, on-site verification will be conducted by the blockchain administrator.

Trade: The main entities in this stage are importers and exporters, while customs and forestry authorities can join to strengthen the supervision of timber trade. The import and export traders upload the data of the enterprise, the purchase, the inbound and outbound details, the port details of the import and the export. These data is uploaded by means of electronic scanning to the cross-border timber traceability system via the quantum cloud code. The customs and forestry authorities of both the importing and exporting countries can build their own management system and connect to the cross-border timber traceability system, so as to access data on timber harvesting, processing, certification and amount value. They can certify the legality of timber trade by signing with their private key, which effectively speeds up the customs clearance.

Processing: The main entity in this stage is the wood or wood product processing and manufacturing plant. Timber can be purchased through the domestic importer or from the wood market, or, the processing plant can directly import timber from other countries. The quantum cloud code carried by timber records any status change in the past. In a processing plant, timber could experience several key nodes including the log stockyards, processing workshops, finished product warehouses, and sales sites. Take the processing workshop, sawn timber may be processed into boards or furniture products, involving complex timber status changes. Once the original quantum cloud code is damaged, a new label needs to be attached. The control method in this process is consistent with that in the stage of sawn timber, where the “video surveillance + cap control” method is adopted to reduce the risk of any intervention in the

traceability process. The processing plant retrieves the information in the cross-border traceability system, attaches a new quantum cloud code to the smallest unit of wood products, and sells it to consumers.

Sales: The main entity in this stage is the consumer of wood or wood products. Consumers do not need to upload any data but can scan the code and obtain the traceability information for their consumption rights. Generally, the consumer rights are limited to the basic information such as the origin, logistic information and tree species. In the cases of re-exporting the wood product to another country who requires the verification of legality, related rights of authorization can be given to the customs of the importing country.

2.4 System structure of BTTS

According to the business scope of cross-border timber trade, the system model for BTTS is constructed according to the level of the blockchain (see Figure 3), which mainly includes three parts: the low-level blockchain layer, the middleware service layer, and application scenario service layer. Based on the blockchain platform, it provides credible and secure data sharing across countries.

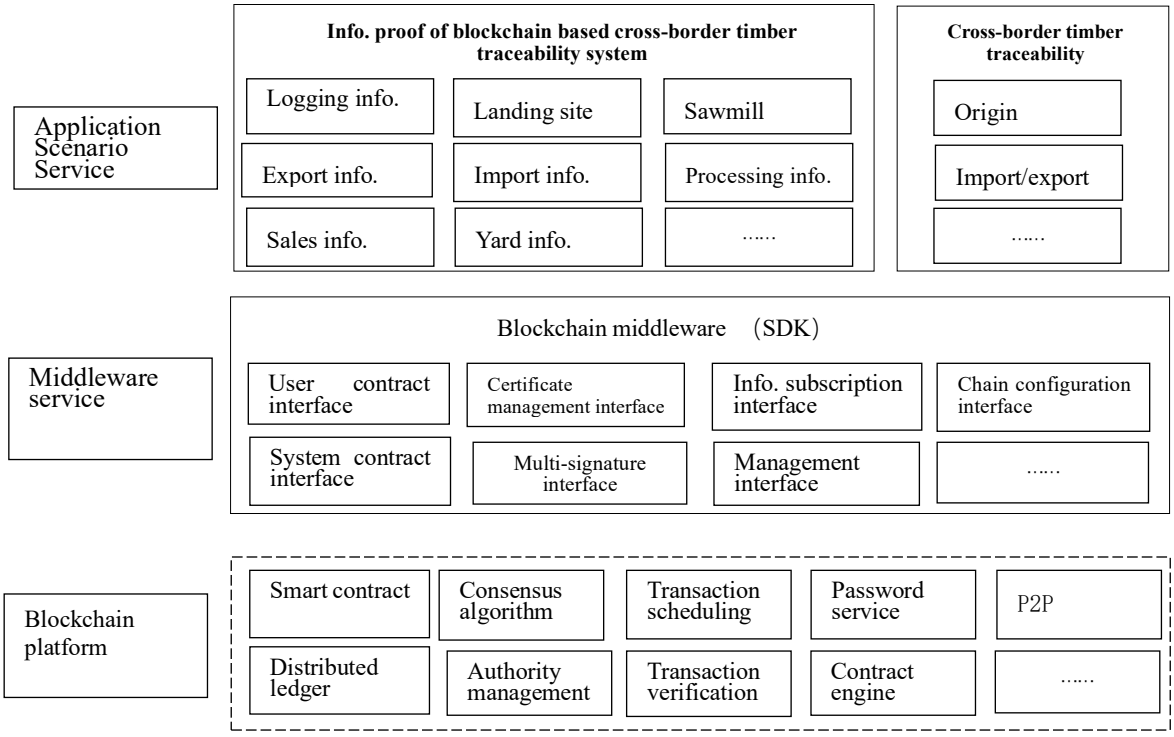


Figure 3: The system structure of BTTS

(1) The base technology platform provides basic functional modules such as consensus algorithms, smart contracts, transaction scheduling, cryptographic services, multi-chain ledger storage, and contract engines. The overall objective for this platform is to provide a universal technical support for the upper business applications. The most important functions are smart contracts and consensus algorithms. The smart contract incorporates relevant laws and regulations, policies, standards, and action plans from both the import and the export countries into the blockchain and compiles them into computer programs. All the nodes are obliged to abide by them, which not only improves the standardization of timber transactions, but also reduces intervention and ensures the verification of legal timber. Meanwhile, the smart contract stipulates that, in case the status of timber changes in any stage of the supply chain, logging, production, transportation, trading, processing, and selling, the digital signature of each participant can be used for judgement and to ensure the coherence and integrity of the timber supply chain. The traceability platform adopts BFT consensus algorithm, and this can ensure that the ledgers of honest nodes remain consistent unless the number of malicious nodes exceeds one-third. The platform also avoids excessive energy consumption by "proof-of-work" (PoW) protocol and Po* algorithms due to the use of token incentives.

(2) Blockchain middleware encapsulates the capabilities of the low-level blockchain into different forms of application programming interfaces (API) such as Go and Java, for fetching and interacting with upper application systems. Throughout the middleware layer, the system can be docked with the interface among timber companies, regulatory authorities, third-party verification agencies and international organizations. Information can be retrieved for verification, while the privacy of the participant can be well protected.

(3) The application service layer provides core services to node users of the traceability system. It stores documents and certificates related to timber logging, piling, import and export, processing, and selling, and also provides service support including information inquiry and verification, with trackable information to the origins. In addition, each batch or each piece of timber can be marked with a quantum cloud code, and users can scan the code and quickly access the timber traceability information.

3. Findings of DRC-China log traceability pilot

To verify the role and effectiveness of the BTTS collaborative operation mechanism and identify the difficulties and challenges in blockchain-based timber traceability practices, the

project executing organization selected two supply chains for traceability pilots: one for logs and the other for sawn timber, that is, the case “DRC-China Supply Chain” for log pilot, and the case “Gabon-China Supply Chain” for sawn timber pilot. The findings of the pilots will be respectively elaborated in this section and Section 4.

3.1 Basic information of log exporting country - DRC

3.1.1 Forestry information

DRC is located in central Africa, with an area of 2.3454 million square kilometers and a forest coverage rate of 53%. The forest area is approximately 1.23 million square kilometers, accounting for 47% of the forest area in the entire equatorial zone of Africa and 6.5% of the world's tropical forest area. There are hundreds of tree species, among which some precious ones include ebony, iroko, afromosia, sapelli, wenge, and kevazingo.

3.1.2 Main forestry laws, regulations and policies

The "Forest Law" issued in 2002 is the main forestry law currently in effect in the DRC. It clearly stipulates that all forests belong to the state, and local residents and forest concession holders only have various rights to utilize forests. For example, local residents can collect forest products and can also engage in rotation of crops in forests over $2hm^2$ with the permission of the provincial government. Communities and municipalities have traditional rights to utilize forests within their jurisdiction and become long-term franchise operators of such forests. The law also makes clear provisions on forest conservation ways, forest use rights, forest logging and transfer, and punishment regulations.

In order to protect forest resources, the DRC government has formulated policies to encourage the export of processed timber products and restrict the export of logs and bulk timber. The government stipulates that log export companies must have timber processing plants in normal operation and implements quota management on the annual export volume of logs for each company. DRC has the highest export tax on logs, followed by sawn timber, rotary veneer, and plywood. For products with more added values, lower export tax is imposed. In addition to levying business tax and commodity inspection tax, the export of logs also requires the following procedures: 1) the "Foundation Account for Restoration of Forest Resources" issued by the Ministry of Environment, which is locally referred to as the "Account A"; 2) Logging

permit; 3) Export license; 4) Export quota; 5) Provide timber invoices; 6) Bank guarantee; 7) Inspection certificate from the Commodity Inspection Bureau.

3.1.3 Requirements for legality management of timber

Currently, the management of timber legality information records in the DRC is primarily carried out through paper-based documentation and manual verification. Different registration records and supporting documents are required at each stage. For example, a logging permit issued by the Ministry of Environment and Sustainable Development is required for logging. After timber cutting, the end of the log needs to be marked with the abbreviations of the tree species, logging permit number, log number (equivalent to the identification number of the timber), traceability marks such as the harvesting enterprise info (as shown in Figure 4). The export requires documents such as a logging permit issued by the Ministry of Environment and Sustainable Development, log volume table, sales certificate, purchase certificate, and export quota. The log volume table is an important material for log traceability, which includes information such as tree species name, logging permit number, log number, volume, logging time, forest land, company, etc.

Figure 4: Log Labeling in DRC

3.1.4 Digital timber traceability information system

The DRC has been actively developing a digital timber traceability system in recent years. According to the website of the Ministry of Commerce of China, as early as July 2014, the Ministry of Environment and the Ministry of Trade of DRC stated at the meeting of Wood Protection Emergency Working Committee that it is necessary to study and develop a

traceability strategy for timber as soon as possible to improve the regulation of timber trading and combat illegal harvesting. According to the "Overview of Timber Traceability in Congo Basin Countries" released by TRAFFIC in March 2023, since the start of VPA-FLEGT negotiations with the EU in 2010, the DRC government has started the development of computerized timber traceability system. Between 2013 and 2015, state-owned forest monitoring and traceability systems were developed, namely the Computerized Forest Management Information System (SIGEF) and the Timber Traceability and Legality Management Platform (TRABOIS). However, due to the incomplete coverage of the physical trade chain and the refusal of the private sector to bear the direct costs of implementing the system, the application of these systems has come to a deadlock. Information obtained during the project team's research visit to the DRC in May this year reveals that currently, the DRC has not yet promoted or applied any digital timber legality traceability system.

3.2 Process of the DRC - China log supply chain

The supply chain for logs from DRC to China involves several key links such as logging, storage yard, transportation, export, import, distribution, retail, and processing, as shown in Figure 5.

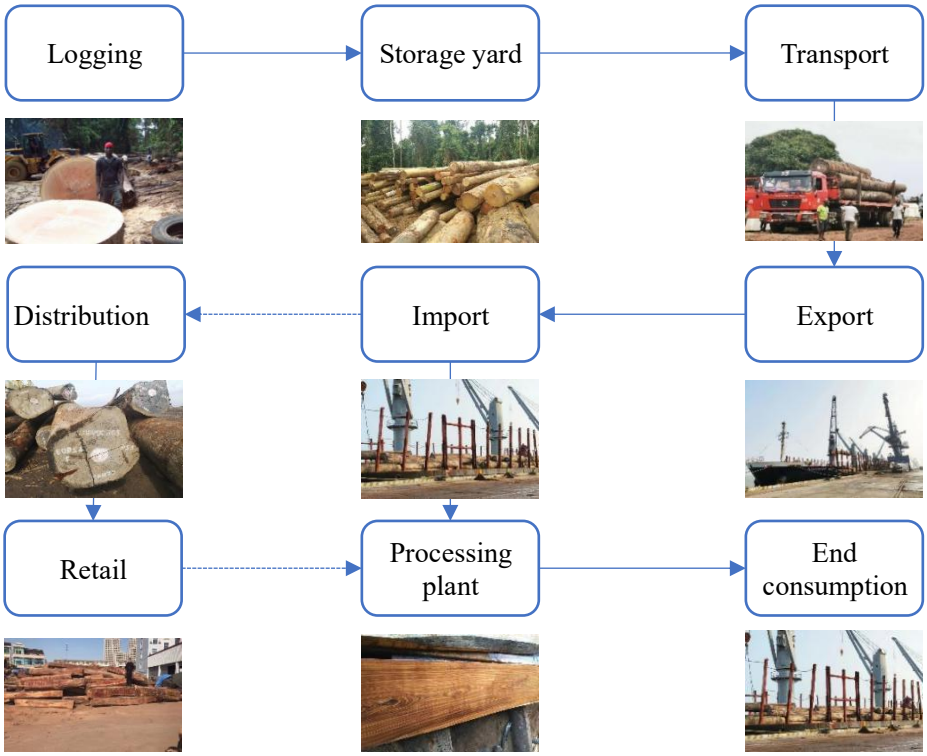


Figure 5: DRC - China Log Supply Chain Display

3.3 Data information collected for log traceability

The primary goal of the blockchain-based timber traceability is to ensure that the timber originates from legally and sustainably managed forests and complies with the laws and regulations of the respective countries at various stages such as logging, processing, and import/export. With this goal in mind and centering on blockchain-based timber traceability, the project team has summarized the document requirements to ensure the legality of timber at each link, thus providing data information for timber traceability throughout the supply chain. It is important to note that this data information serves as evidence to demonstrate the legality and sustainability of timber at each link and does not imply that companies need to upload all the data information to the BTTS.

3.3.1 Harvesting link

According to the policy and legal requirements of the DRC, the exploitation of any forest product requires a pre-prepared list of forest resources and a forest remediation plan. Prior to logging, a logging permit issued by the Ministry of Environment and Sustainable Development is required, along with tax clearance certificates (e.g., harvesting tax).

Table 1: Key Information on the Harvesting Link

Category	Information filled	Required documents	Data collection method
Franchised forest land management enterprise	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Forest information	Location, coordinates and related business documents of forest land	List of forest resources, contract for licensed forest land, forest remediation plan, etc.	Manual entry (one-time entry, forming a basic database)
Harvesting information	Tree species, diameter, length, harvesting time, quantity, log number, harvesting unit, responsible person, etc.	Logging permit, tax clearance certificate (e.g., licensed forest land's area tax and harvesting tax)	Manual entry

The pilot units have provided feedback stating that the basic information of companies and the forest land information is relatively unchanged, and it's recommended to allow companies to

write this kind of information into the system beforehand, so that during timber traceability, the information can be directly accessed to avoid duplicate entries. Currently, there is usually no network coverage in the forest land of the DRC, making it difficult to upload data to the system in a timely manner. One suggestion is to mark the harvesting information on the logs in the forest and submit/upload it to the system when the network is available.

To verify the authenticity of the forest land information and harvesting information, on one hand, GIS information system may be developed in the BTTS to monitor the forest resources and land information of the DRC, through which the information submitted by companies may go through comparison and verification. On the other hand, integrating the BTTS system with the forest management system of the DRC government departments may be considered, that is, traceability information in BTTS submitted by companies may be shared with the government departments through an API interface, thus verifying the authenticity and accuracy of the information provided by the companies.

3.3.2 Storage yard link

The storage yard is a temporary storage location for timber, and is also the first node of displacement after timber harvesting. According to the laws and regulations of the DRC, it is necessary to complete a log volume registration form at this node, recording information such as tree species name, logging permit number, log number, volume, logging time, forest land, company, etc.

Table 2: Key Information on the Storage Yard Link

Category	Information filled	Required documents	Data collection method
Yard information	Storage yard name, location, tree species name, logging permit number, log number, volume, logging time, forest land, company, etc.	Log Volume Registration Form	Manual entry

The pilot units suggested that the information of the storage yard may be pre-filled, and when it needs to be filled out in relevant links later, it can be directly selected. Due to the storage yard is located in the forest, there is usually no network coverage, and data cannot be uploaded in a timely manner. It can be filled out together with the log volume registration form, and then

uploaded and submitted when the network is available.

3.3.3 Transport link

The transport link is an important part of timber transport from forest land to sales point. According to the laws and regulations of the DRC, timber transport requires a transport license before transportation. In the actual transport process, it is also necessary to bring with the logging permit, log volume registration form and other documents that can prove legal harvesting. In order to ensure the clarity of transport quantity and route, the following information needs to be collected in this link: transport unit information, information about means of transport, transport personnel information, tree species, quantity, log number, etc.

Table 3: Key Information on the Log Transport Link

Category	Information filled	Required documents	Data collection method
Transport unit	Country/region, unit name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Log transport	Transport vehicle/vessel, responsible person, departure point, destination, transport time, tree species, quantity, log number, etc.	Transport license and transport form	Manual entry, selection of harvesting and storage yard information from the previous step

According to feedback from the pilot units, information on transport units, means of transport, and transport personnel in this link can be entered in advance based on daily situations and selected when needed. Information such as transport time, tree species, quantity, and log number may be filled out in conjunction with the transport form or contract.

3.3.4 Export link

According to the requirements for the export of logs from the DRC, in addition to traceability information, the information that needs to be recorded in this link mainly includes export enterprise information, export supporting documents required by customs, etc.

Table 4: Key Information on the Log Export Link

Category	Information filled	Required documents	Data collection method
Export enterprises	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Customs declaration unit	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Export information	Export port, export date, declaration date, shipping unit, commodity name (including timber name and Latin), log number, quantity, specification, volume, unit price, total price, destination country, destination port, domestic source of supply, contract/agreement number, packing list number, etc.	Log volume table, logging permit, contract, invoice, certificate of origin, plant quarantine certificate, customs declaration form, bank documents, taxes, etc. For CITES species, a CITES certificate must be provided	Manual entry or import of customs declaration data

The pilot companies provided feedback that the above-mentioned documents and certificates are stored in their own information management systems. Through API interfaces, the relevant documents and files may be accessed and viewed in BTTS, so as to verify the authenticity of traceability information. At the same time, with API interfaces, the relevant documents and files can be shared with customs and other government departments to verify the information against the government's records, imposing supervision over authenticity, validity, and legality of the on-chain data of the companies.

3.3.5 Import link

In addition to the traceability information, the information to be recorded in this link mainly includes the import enterprise information, customs clearance supporting documents required by the customs, such as the certificate of origin, plant quarantine certificate, fumigation certificate, weight note, packing list, commercial invoice, trade contract, and ocean bill of lading. To import rosewood, a species import license is also required, while for endangered timber, an endangered species certificate is required. In addition, if customs inspection reveals new varieties or discrepancies in the documents and goods, it is required to provide timber

legality documents and species testing certificates.

Table 5: Key Information on the Log Import Link

Category	Information filled	Required documents	Data collection method
Import enterprises	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Import information	Import port, import date, arrival date of goods, shipping unit, commodity name (timber name), quantity, specification, unit price, total price, country of origin, contract/agreement number, packing list number, log number, etc.	Certificate of origin, plant quarantine certificate, fumigation certificate, weight note, packing list, invoice, trade contract, ocean bill of lading, quantity and quality inspection certificate, import license, etc. For CITES species, a CITES certificate is required	Manual entry or import of customs declaration data

Similar to the export link, the above-mentioned documents and certificates are stored in companies' own information management systems. Through API interfaces, the relevant documents and files may be accessed and viewed in BTTS, so as to verify the authenticity of traceability information. At the same time, with API interfaces, the relevant documents and files can be shared with customs and other government departments to verify the information against the government's records, imposing supervision over authenticity, validity, and legality of the on-chain data of the companies.

3.3.6 Sales link

Logs imported to China enter the sales or processing link via importers. Some timber importers have their own processing factories, where they directly process the timber after importing the logs, making the timber traceability process simpler. Some other timber importers resell the timber to wholesalers, who then sell it to retailers or timber processing factories, making the supply chain more complex and the traceability more difficult.

Table 6: Key Information on the Timber Sales Link

Category	Information filled	Required documents	Data collection method
Enterprise information	Name, legal person, address, telephone number and place of production of the enterprise	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Sales information	Order number, tree species, specification, quantity, volume, log number, shipper, purchaser, sales time, etc.	Purchase order and contract	Scan documents to assist with manual verification and data entry

According to feedback from the pilot enterprises, China's timber processing industry is developed with good infrastructure and network facilities. Most enterprises have their own internal business management systems. When using blockchain technology for traceability, they can rely more on their existing business management systems to achieve data extraction and conversion, and can also use Internet of Things (IoT) technology to achieve real-time monitoring of timber processing, storage and transport processes.

4. Findings of Gabon-China sawn timber traceability pilot

4.1 Basic information on sawn timber exporting country - Gabon

4.1.1 Forestry information

Located in central and western Africa, with the equator crossing the central part of the country, Gabon covers an area of 268,000 km^2 with rich natural resources, enjoying the reputation of being a "resources repository" and a "country of green gold", and is a major producer of oil, manganese ore, and timber in Africa. Gabon's forest coverage rate is as high as 85%, and the productive area is about 60% of the national territory. Its log reserve is approximately 400 million m^3, ranking third in Africa. There are more than 400 types of trees in the country, mainly including Okoum and Otsego, among which Okoum has a storage capacity of 130 million m^3, ranking first worldwide.

In 2021, Gabon's log production was 2.528 million m^3, a year-on-year increase of 25.7%. The production of timber products was 1.578 million m^3, a year-on-year increase of 34.5%, including 872,000 m^3 sawn timber; 625,000 m^3 veneer; plywood increased by 62.6% year-on-

year to 81,000 m^3, and the production of secondary and tertiary processed products of logs increased significantly. Gabon has banned logs export since May 2010, only export of processed timber was allowed (mainly including sawn timber, veneer, and plywood). Calculated at current prices, Gabon's timber exports reached 1.098 million m^3, a year-on-year increase of 34.4%, with an export value of 491.2 billion Central African CFA francs (approximately 810 million US dollars). Among them, the Gabon Special Economic Zone NKOK accounted for 723,000 m^3 of timber production, approximately 50% of the total production.

4.1.2 Main forestry laws, regulations and policies

The revised "Forest Law" (2012) is the main current forestry law in Gabon, providing relevant regulations and requirements for forest governance, legal harvesting rights, taxes and fees, timber harvesting activities, third-party rights, trade and transport, etc., and stipulates that harvesting enterprises must implement planned logging of forest land to ensure sustainable production of forest land. Most industrial harvesting is registered timber production forests. Individuals or enterprises shall obtain a permit from the forestry authorities when conducting industrial timber harvesting. The harvesting certificates issued by the government are mainly divided into three categories: 1) Long-term harvesting certificate (CFAD - Concession Forestière sous Aménagement Durable). A single CFAD grants a harvesting area of 50,000 to 200,000 hm^2. Applicants shall sign a temporary agreement with the Ministry of Forests, Oceans, Environment and Climate Change first, then make forest land planning within 3 years. During this period, one thirtieth of the total area of forest land can be harvested each year. A single harvesting company can obtain multiple CFADs, but the total area must not exceed 600,000 hm^2. The CFAD award contains two stages. In the first stage, the enterprise signs a temporary agreement with the government for a period of 3 years. In the second stage, if the business plan and industrialization plan are approved, the licensed CFAD will be issued to the enterprise in the form of an Order of Prime Minister; 2) PFA - Permis Forestier Associé. This permit is only issued to Gabonese residents and can be included in the CFAD unified planning, with an area not exceeding 15,000 hm^2; if it is planned for self-operation, it can reach 50,000 hm^2; 3) The harvesting permit (PGG-Permis de Gré à Gré) recognized by both parties. It is the original family logging permit, only issued to Gabonese residents, with a harvesting volume of less than 50 trees.

The annual harvesting volume of high-value tree species in the forest management plan shall

be determined with 20-30 years harvesting cycle, and cutting cycle not less than 20 years. The total harvesting volume in each forest management unit shall not exceed by 15% of the total volume determined in the forest management plan. All natural or legal persons applying for timber processing and forest harvesting must obtain a harvesting permit in accordance with relevant regulations. Restriction measures have been implemented on the diameter class of harvested timber, 60cm for softwood and 50cm for hardwood, and destruction is prohibited. In addition, the new "Forest Law" has also restored the family harvesting permit system, allowing limited harvesting at the edges of residential and industrial areas. All processing and manufacturing companies must have corresponding licenses and permits for timber processing, and also need to develop an industrialization plan approved by forestry organizations. The input and output of the plant must be recorded in the quarterly report of the received logs, and forestry companies engaged in logging and timber processing must keep quarterly and annual records for forest management purposes.

The Gabonese government issued a presidential decree in September 2018, requiring all enterprises engaged in forest management in Gabon to pass FSC certification by 2022, otherwise their forest franchise rights will be revoked. FSC forest certification is originally a voluntary certification, and forest management enterprises can choose whether to complete it or not. The promulgation and implementation of this policy means that FSC forest certification will become a mandatory requirement in Gabon. Currently, the deadline for compliance with this regulation has been extended to 2025, but the Gabonese government has introduced incentive policies for companies that obtain FSC certification. In February 2021, the Gabonese government adjusted the forest area tax. For enterprises without FSC certification, the area tax will increase from 400 XAF/ha to 800 XAF/ha, while for enterprises with FSC certification, the area tax will be reduced to 300 XAF/ha.

4.1.3 Requirements for legality management of timber

Gabon has always attached great importance to the legality of timber. To prove the legitimacy of the source, there are well-established requirements for traceability records and labeling in each timber link in Gabon. For example, before timber harvesting, a detailed forest survey plan needs to be formed for the forest land. In the plan, each tree to be logged is given a number, which is equivalent to the identity information of the timber and serves as the unique code for tracing in subsequent stages. After timber harvesting, it is necessary to mark the logging time,

number, forest land, forest owner, diameter, length, and other information on the tree stumps and timber heads (as shown in Figure 6) for subsequent inspection. After the timber is transported to the storage yard, the above information needs to be marked on each section of timber during the section making process (as shown in Figure 7), registered and recorded, and reported after being inspected and signed by the management personnel of the Ministry of Forests, Oceans, Environment and Climate Change. During the transport, the log transport forms must be completed before leaving the storage yard, and these documents must be properly kept during the transport process. In the production and processing process, it is also necessary to mark and register information during the processes of section making, sawing, wet board packaging, dry board packaging, etc. (as shown in Figure 8 and Figure 9).

In the above-mentioned traceability processes, the documents involved in Gabon's timber traceability can be mainly divided into three categories:

The first category is company-related documents, including professional certification, forest tax payment receipt, industrial plan compliance certificate and industrial development plan compliance certificate;

The second category is forest management-related documents, including business authorization, temporary development, operation, renovation agreements, management plans, five-year management plans, annual operation plans, wildlife protection plans, environmental impact assessments, and payment receipts for monitoring fees;

The third category is regulatory certification documents, including on-site notebooks, harvesting and export tax payment receipts, waybills, packing lists, and export licenses (CITES licenses).

Currently, the timber legality traceability in Gabon also primarily relies on a combination of paper-based records and manual verification. However, the country has developed a national timber traceability system to transition towards digitization and informatization.

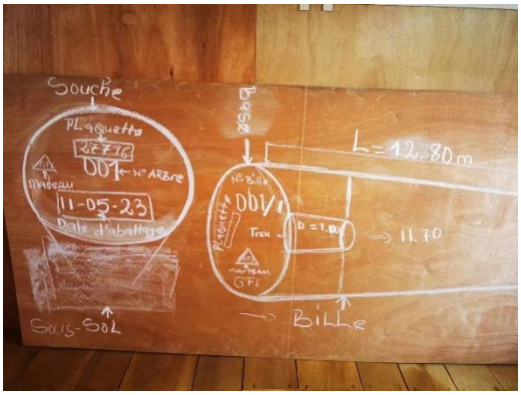


Figure 6: Labeling Information after Timber Cutting in Gabon

Figure 7: Labeling of Section Making of a Timber Storage Yard in Gabon

Figure 8: Timber Processing and Section Making of a Timber Processing Plant in Gabon

Figure 9: Labeling of Sawn Timber Packaging at a Timber Processing Plant in Gabon

4.1.4 Digital timber traceability information system

Gabon has always been exploring the use of new technologies for timber traceability in recent years. According to Gabon's "Direct Consultation" report in March 2021, the Gabonese Ministry of Forests, Oceans, Environment and Climate Change launched the pilot testing stage of the first module of the national timber traceability system on March 29, 2021. The first stage of the pilot testing was conducted by the Owendo Forest Products Control Bureau in the storage yards of the Benes Timber Company and the National Timber Company in Gabon, with the participation of the Regional Customs Administration. At the same time, a two-month training session was conducted for forestry administrative and preparatory finance personnel. This system enables departments such as forestry, customs, and taxation to obtain real-time data on timber products from forests to their destination (export ports or processing plants)., thereby detailed information about the timber at each stage is extracted through labels and bar codes by using high-performance mobile information technologies.

The Gabonese National Timber Traceability System (GSNTBG) was developed with the collaboration of the Ministry of Finance, the Ministry of Forests, Oceans, Environment and Climate Change, and the Ministry of Customs. Its objective is to digitize the timber supply chain and forest management, and to utilize GIS geographic information technology for more efficient real-time forest management and planning to ensure taxation. The Ministry of Forests, Oceans, Environment and Climate Change has established a dedicated technical committee to promote the system. On May 1, 2023, the Gabonese government signed a contract with CSM Technologies Pvt. Ltd., an IT company from India, which thereby assists in the promotion of the Gabonese National Timber Traceability System. The comprehensive promotion and

operation of the system has been implemented since May 2023.

According to the requirements of the Gabonese National Timber Traceability System (GSNTBG), the Gabon Track system, Tracer system, and the traceability systems developed by enterprises themselves can be integrated with the GSNTBG system, so as to upload traceability data to GSNTBG. The Gabon Track system was funded and developed by Agence Française de Développement (AFD), and was promoted and applied in some enterprises in Gabon from November 2020. The Tracer system is a tropical timber traceability system developed by FRM Ingenierie, currently being promoted and applied in the Gabon Special Economic Zone NKOK.

4.2 Gabon-China sawn timber supply chain process

The Gabon-China sawn timber supply chain refers to the process in which logs are harvested from Gabonese forests, go through stages such as storage yard, transportation and sawn timber processing in Gabon, then are imported by China, and go through stages such as transportation, distribution, and further processing, as shown in the following figure.

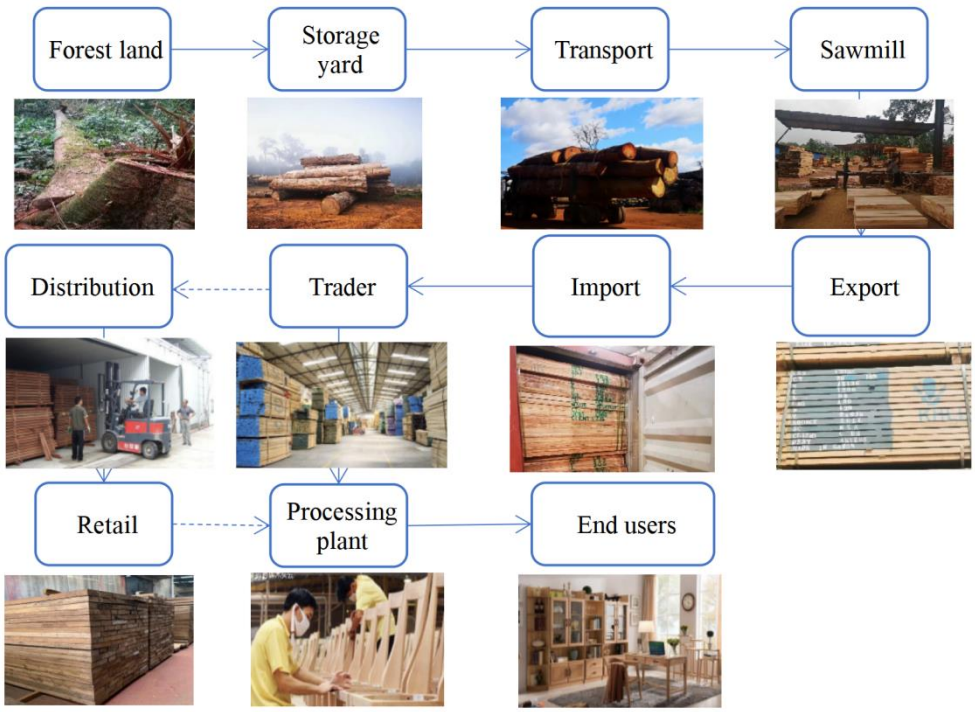


Figure 10: Gabon-China Sawn Timber Supply Chain Display

4.3 Data information collected for sawn timber traceability

Through the pilot of the Gabon-China sawn timber supply chain, the project team centers on

blockchain-based sawn timber traceability and summarizes the document requirements for legality at each link, thus providing data information for sawn timber traceability throughout the supply chain. It is important to note that this data information serves as evidence to demonstrate the legality and sustainability of timber at each link and does not imply that companies need to upload all the data information to the BTTS.

4.3.1 Harvesting link

According to Gabon's policies and legal requirements, as well as pilot operations situation, the key traceability information on the harvesting link includes forest land information, harvesting information, etc. The specific details are as follows:

Table 7: Key Information on Traceability of Gabonese Timber Harvesting Link

Category	Information filled	Required documents	Data collection method
Franchised forest land management enterprise	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Forest information	Location and forest land conditions	Forest survey planning, etc.	Manual entry (one-time input of forest land information, forming a basic database)
Harvesting information	Tree species, diameter class, harvesting time, quantity, number, harvester, etc.	Forest logging concession granting certificate, harvesting planning, logging permit, etc.	Manual entry (one-time input of forest land information, forming a basic database)

Currently, some companies in Gabon have utilized GIS technology for forest management and planning. Similar to the situation in the DRC, feedback from pilot units indicates that there is usually no network coverage in Gabon's forests, making it difficult to upload data to the system in a timely manner. One approach is to mark the harvesting information on the logs in the forest and upload it to the system when there is network connectivity. To verify the authenticity of forest and harvesting information, it is suggested to integrate the BTTS system with the Gabonese National Timber Traceability System, sharing the traceability information in BTTS submitted by companies with government departments through API interfaces, thereby verifying the authenticity and accuracy of the information submitted by the companies.

4.3.2 Storage yard link

After harvesting, the logs are dragged to the storage yard for section making registration (the maximum length of log transport cannot exceed 13m). The information of section making,such as time, quantity, number, volume, personnel, etc,,must be registered, and log waybills must be generated, signed by the monitoring personnel of the local forestry authorities and the responsible person of the enterprise, and then submitted to the Ministry of Forests, Oceans, Environment and Climate Change. The key information that needs to be traced at this node includes storage yard name, location, inventory, harvesting permit number, forest land inventory, tree species, log number, volume, length, etc., as shown in the table below:

Table 8: Key Information on Traceability in Log Storage Yard Link

Category	Information filled	Required documents	Data collection method
Yard information	Yard name, location, harvesting license number, forest inventory, tree species, log number, segment information, volume and length	Log waybills	Manual entry

According to the pilot survey, the storage yard is usually located in the forest, without network coverage, which means that data cannot be uploaded to the traceability system in a timely manner. To address this, the traceability information may be marked and registered along with on-site section making registration (log waybills), and could be uploaded and submitted to the system when the network is available. Additionally, the registration information of the section making is still filled out using paper materials, which can easily cause errors. In the future, this work may be combined with the blockchain-based timber traceability system to achieve electronic registration.

4.3.3 Transport link

The transport link is an important part of the timber transport from forest land to plants, which requires the clear transport quantities and routes. At this node, the key information that needs to be traced includes transport unit information, transport vehicle information, transport personnel information, departure point, destination, transport time, tree species, quantity, log number, shipping unit, etc., as shown in the table below:

Table 9: Key Information on Log Transport Traceability

Category	Information filled	Required documents	Data collection method
Transport unit	Country/region, unit name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Log transport	Transport vehicle, driver, departure point, destination, shipping unit, transport time, tree species, quantity, log number, etc.	Transport form, transport contract and sales contract	Manual entry, requiring forest land information, harvesting information, etc. in the transport process

According to the suggestions from the pilot unit, information on transport unit, means of transport, and transport personnel in this link can be entered in advance based on daily situations and selected when needed. Information such as transport time, tree species, quantity, and log number may be filled out in conjunction with the transport form or contract.

4.3.4 Processing link

According to Gabon's forestry laws and regulations, log export is prohibited and logs must be processed before export. The processing requires detailed records of log warehousing (transport waybills, supply and sales contracts, forest land related documents, log batches), log outbound delivery (batch entry), sawn timber processing (including section making, wet board and dry board packaging), and other detailed information. The specific information and required documents are shown in the table below:

Table 10: Key Information on Traceability in Sawn Timber Processing Link

Category	Information filled	Required documents	Data collection method
Processing enterprises	Country/region, unit name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Log warehousing	Tree species, quantity, log number, length, volume, supplier, storage time, responsible person, log batch number, etc.	Transport waybills, supply and sales contracts, forest land related documents,	Import of internal management system

		and log batch table	
Log outbound delivery	Tree species, quantity, log number, length, volume, supplier, outbound time, responsible person, and log batch number	Outbound note and log batch table	Import of internal management system
Sawn timber processing	Section making information: tree species, quantity, log number, section number, length, volume, and batch number; Dry board information: tree species, specification (length, thickness, height), volume, quantity, and log batch number; Dry board information: tree species, specification (length, thickness, height), volume, quantity, and log batch number	Section making registration form, wet board registration form, and dry board registration form	Import of internal management system

According to the feedback from pilot units, the traceability-related information at this stage has already been uploaded to the enterprise's own business management system. To avoid duplicate data entries, the BTTS system may provide an API interface to connect with enterprise business management systems of different types and modes.

4.3.5 Export link

During the export of sawn timber from Gabon, it is necessary to complete loading under the joint supervision of the Ministry of Forests, Oceans, Environment and Climate Change and the customs management personnel. Only after the issuance of the travel permit and the loading supervision documentation can the sawn timber be exported. The submitted documents include original travel permit and loading supervision documentation, weight note, invoice, trade contract, certificate of origin, customs declaration, loading list, etc.

Table 11: Key Information on Traceability in Sawn Timber Export Link

Category	Information filled	Required documents	Data collection method
Export enterprises	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)

Customs declaration unit	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Export information	Export port, export date, declaration date, shipping unit, commodity name (timber name), quantity, specification, log batch number, unit price, total price, destination country, destination port, domestic source of supply, contract number, loading list number, etc.	Original travel permit and loading supervision documentation, weight note, loading list, invoice, trade contract, certificate of origin, customs declaration, delivery note, bill of lading, etc. For CITES species, CITES certificate shall be provided	Manual entry or import of customs declaration data

The pilot enterprises stated that the aforementioned documents and certificates are recorded in their internal information management systems. Users of the BTTS may access relevant documents and files through the API interface, so as to verify the authenticity of traceability information. Some companies can export a portion of their data and information from their own systems in Excel format and then import it into the BTTS.

4.3.6 Import link

When sawn timber is exported from Gabon to China, in addition to the traceability information, the information recorded in this link is required to include the certificate of origin, plant quarantine certificate, fumigation certificate, weight note, packing list, commercial invoice, trade contract, and ocean bill of lading, according to the requirements of Chinese customs. When importing rosewood, a species import license is also required, while for endangered timber, a CITES certificate is required. The specific details are as follows:

Table 12: Key Information on Traceability in Sawn Timber Import Link

Category	Information filled	Required documents	Data collection method
Import enterprises	Country/region, enterprise name, contact person, address, telephone number and organization code	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Import information	Import port, import date, arrival date of goods, shipping unit, commodity	Certificate of origin, plant quarantine certificate, fumigation certificate,	Manual entry or import of customs declaration data

	name, tree species, quantity, specification, unit price, total price, country of origin, contract agreement number, packing list number, log batch number, etc.	weight note, packing list, commercial invoice, trade contract, ocean bill of lading, quality and quality inspection certificate, import license, etc. For CITES species, a CITES certificate is required	

The pilot enterprises stated that the aforementioned data, documents, and certificates need to be provided during customs clearance. However, most companies currently have their own information management systems. The BTTS users can use the API interface to directly retrieve and view the relevant documents and files from the enterprise's information management system.

4.3.7 Sales link

After the sawn timber enters China from Gabon, it enters the sales or processing link, with most being sold to retailers or processing enterprises in the fields of furniture, flooring, etc. Traceability information includes enterprise information and sales information of both buyers and sellers, as follows:

Table 13: Key Information on Traceability in Sawn Timber Sales Link

Category	Information filled	Required documents	Data collection method
Enterprise information	Name, legal person, address, telephone number and place of production of the enterprise	Industrial and commercial registration certificate, employment license, etc.	Manual entry (one-time entry, forming a basic database)
Sales information	Order number, tree species, specification, quantity, shipper, purchaser, sales time, log batch number, etc.	Purchase order and contract	Scan documents to assist in manual verification and entry

China's timber processing industry has good infrastructure and network facilities, and most of its enterprises have their own internal business management systems. When using blockchain technology for traceability, they can achieve data extraction and conversion by relying on the existing business management systems, and using Internet of Things (IoT) technology, so as to

achieve real-time monitoring of timber processing, storage and transport processes.

5. Summary

This study has constructed a collaborative operating mechanism for the Blockchain-based Timber Traceability System (BTTS) and conducted pilot operations with "DRC-China Log Supply Chain" and "Gabon-China Sawn timber Supply Chain" as the cases, uncovering challenges and difficulties in the practical implementation of blockchain-based timber traceability. Specifically, for the construction of a blockchain-based timber traceability system, the following aspects need to be considered:

- **The collaborative operation mechanism of BTTS can effectively enhance the authenticity and reliability of blockchain-based timber traceability.** The participating entities in the BTTS system include platform operators, business organizations, regulatory bodies, third-party certification bodies, etc., each with different objectives, functions and roles in timber traceability. Therefore, an incentive and compatible collaborative operation mechanism for all stakeholders is crucial for the successful run of BTTS. This study suggests the establishment of a consortium chain involving timber companies, importers and exporters, third-party verification agencies, government departments, platform operators, etc. Under the constraints of consensus mechanisms and admission criteria, each stakeholder fulfills their respective functions, such as uploading traceability data, supervising and managing, and providing platform services, to ensure the authenticity and effectiveness of traceability information and build a trustworthy, transparent, and convenient timber traceability ecosystem.

- **Blockchain-based timber traceability requires enhanced cooperation with government departments.** Cross-border timber traceability involves the integration of data, standards, and policies from different countries, requiring deep international cooperation within the forestry community (including governments, enterprises, associations, certification bodies, etc.), with a particular emphasis on government-level cooperation. Among the three pilot countries involved in this study, Gabon is actively promoting the application of the Gabonese National Timber Traceability

System (GSNTBG). The DRC has previously conducted research and development on the computerized forest management information system as well as the timber traceability and legality management platform with the support of the World Bank. China Forest Certification Council (CFCC) is also actively developing and promoting the QR code-based system for timber legality traceability. Therefore, when constructing the BTTS, considerations should be given to the organic connection with local government traceability systems to effectively promote the implementation of blockchain-based timber traceability system, and improve the efficiency of cross-border trade of legal and sustainable timber.

- **The combination of blockchain-based traceability and other technologies (e.g., internet of things) has great potential in improving the reliability and efficiency of timber traceability.** At present, the record of legality traceability information in the pilot countries is primarily done through manual collection and paper-based documents. The intervention of human factors increases the uncertainty of traceability information and requires substantial manpower and material resources. BTTS can promote the construction of digitalization and informatization for enterprises. Additionally, its integration with advanced technologies such as IoT, satellite positioning systems, and remote sensing systems can enable more accurate and efficient monitoring and positioning of forest resources. The integration of BTTS with these technologies may be considered, so that forest resource information obtained through remote sensing, traceability information submitted by enterprises, and information collected by regulatory authorities can be cross-verified to better validate the accuracy of timber traceability information and improve traceability efficiency.