TECHONEY

Development of a **blockchain-based ecosystem** that allows an **improved positioning of small producers of honey** on local and international markets

DELIVERABLE

D4.1.2 Traceability in IoT and blockchain-based short agri-food supply chain

DUE DATE OF DELIVERABLE	31.October.2023 (M18)
START DATE OF PROJECT	01.May.2022
DURATION	36 months
LEAD PARTNER FOR DELIVERABLE	LIGM
DISSEMINATION LEVEL	PU (Public)

The TECHONEY project is part of the **PRIMA** programme (Project ID: *1711*, Call: *2021*, Topic ID: *2.3.1*) with support from the European Union's Horizon 2020 research and innovation programme and the national research and innovation funding agencies of Spain (AEI, *PCI2022-132917*), France (ANR), Algeria (DGRSDT), Luxembourg (FNR, *16735444*), Tunisia (MESRS), Morocco (MHESRI-M), Italy (MUR), and Turkiye (TÜBİTAK).

DOCUMENT CHARTER

TITLE BLOCK

PROJECT	PROJECT FULL TITLE	DEVELOPMENT OF A BLOCKCHAIN-BASED ECOSYSTEM THAT ALLOWS AN IMPROVED POSITIONING FOR SMALL SCALE PRODUCERS OF HONEY ON LOCAL AND INTERNATIONAL MARKETS		TECHONEY
	PROJECT ACRONYM	**TECHONEY**		
	EC PROGRAMME	**PRIMA**	GRANT AGREEMENT NO	**+++.+++**
		PROGRAMME	Partnership on Research and Innovation in the Mediterranean Area	
		SECTION 2	Multitopic 2021	
		THEMATIC AREA 3	Agri-food chain	
		TOPIC 2.3.1	Increasing the resilience of small-scale farms to global challenges and COVID-like crisis by using adaptive technologies, smart agri-food supply chain and crisis management tools	
		FUNDING SCHEME	"Collaborative Project"	
		TYPE OF ACTION	"Research and Innovation Actions (RIA)"	
	COORDINATOR	**Tiziana de Magistris** · Principal Investigator Centro de Investigación y Tecnología Agroalimentaria de Aragón (**CITA**) · (Spain)		
	START DATE	01.May.2022	DURATION	**36 months**
	PROJECT URL	TECHONEY.org	E-MAIL	**info@techoney.org**
DELIVERABLE	DELIVERABLE	**D4.1 Design and architecture of the consortium blockchain platform**		
	WORK PACKAGE	WP4: Implementation of the blockchain distributed network		
	DATE OF DELIVERY	M18 (End October 2023)		
	NATURE	R (Report)	DISSEMINATION LEVEL	PU (Public)
	LEAD BENEFICIARY	Dr. Hakim Badis, LIGM, Gustave Eiffel University (**UGE**) · France		
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	APPROVER	Dra. Tiziana de Magistris (CITA)		
	FILENAME	TECHONEY_Deliverable_4.1.2		
	Abstract of the Deliverable	The deliverable's objective is twofold: identifying the problems in the agri-food supply chain in relation to the type of product, their cause (origin of the problem) and potential solutions, and inspecting various IoT tools and Blockchain platforms that are used to deploy applications to improve traceability, safety, quality and efficiency. In this deliverable, however, we limit the scope to agri-food products that are produced locally (raw and/or processed) by farmers and delivered to the consumers in their original form without any new processing and transformation in the supply chain by intermediaries like processors or manufacturers. This means that if there were to be any processing, the products are only permitted to be processed to a certain extent only by the farmers themselves, such as making cheese from milk and olive oil from olives.		

VERSION TRACKER

VERSION	REVIEWER	PARTNER	ISSUE DATE	CHANGES
0.1	Hakim Badis	LIGM	12.MAY.2023	Initial draft
2	Hakim Badis	LIGM	28.MAY.2023	Peer review input
3	Hakim Badis	LIGM	15.SEPTEMBER.2023	Peer review input
4	Muluken Eressa	LIGL	8.OCTOBER.2023	Peer review input
5	**Hakim Badis**	**LIGM**	**31.OCTOBER.2023**	**Final version**

STATEMENTS

ORIGINALITY

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REQUEST TO PARTNERS

This document fulfills **Project milestone #3** of **TECHONEY** PRIMA Proposal:[1]

- What: "Design and architecture of the consortium blockchain platform".
- When: M12 (month 12 – May 2023).
- How: Document uploaded in the private area of the project website

All partners are kindly asked to

- Read and understand this Deliverable.
- Use it for regular checking of actual performance vs project objectives.
- Report to project coordinator potential deviations of the project.

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[1] Depicted at "Project Milestones". Section 3.2 ("Management structure, milestones and procedures") of the PRIMA Full Proposal - Technical Annex (Part II)

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GLOSSARY: ACRONYMS

- **AI**: Artificial Intelligence
- **AR**: Augmented Reality
- **BDVA**: Big Data Value Association
- **C&D**: Communication and Dissemination.
- **CAP**: Common Agricultural Policy
- **CM**: Communication Manager
- **D**: Deliverable
- **DIAS**: Data and Information Access Services
- **EC**: European Commission
- **EU**: European Union
- **HILE**: Honey Innovation and Learning Living Lab
- **ICT**: Information and Communication Technologies
- **ICT**: Information and Communications Technology
- **KPI**: Key Performance Indicator
- **SC**: Steering Committee
- **SO**: Specific Objective
- **URL**: Uniform Resource Locator
- **WP**: Work Package

PROJECT ABSTRACT

TECHONEY project's main objective is to identify strategies and establish lines of resilience to the new challenges determined by the COVID-19 pandemic for beekeepers in the Mediterranean (Med) agricultural systems through the implementation, definition, enhancement and transfer of competitive, profitable, efficient and trustful honey supply-chain alternatives that address beekeepers' capacities and attractiveness to fulfil consumer needs on unexpected food market changes.

TECHONEY project proposes the development of a **traceability system to guarantee the quality and safety of honey within the supply chain** for more effective communication to consumers and to strengthen access to different markets (e-commerce, direct sales, etc.). This approach will be unfolded by the joint creation of two levels of interaction: **(1)** physical: characterization of honey; **(2)** "living laboratory": creation of a *Honey Community Living Lab* (**HCLL**) and a *Honey Innovation and Learning Ecosystem* (**HILE**) that will be the arena to collect information from beekeepers, stakeholders, and consumers to transfer and apply the new optimized models.

TECHONEY is structured in 4 main technological pillars: **(1)** creation of a consortium IoT (*Internet of Things*) Blockchain platform that involves various actors in the honey supply chain to ensure transparency and traceability, in addition to reducing costs and ensure the traceability in the honey supply chain; **(2)** creation of a transformative learning community to ensure a smart-short-resilient shared supply chain; **(3)** characterization of the quality of honey to guarantee its traceability within the Blockchain directly by consumers; **(4)** ICT tools for honey supply chain participants and consumers.

TECHONEY will be committed not only to promote the continuation of the direct sales of honey from producers to consumers even after the COVID crisis but also **develop a common methodology and clear new optimized resilience protocol** to be used by small-scale farmers, beekeepers, smallholders as a new business model with a more efficient added-value chain, sustainable with fair profit, accepted by final consumers, which will be replicable to other food products and supply chains.

TECHONEY will **help beekeepers to**: **(1)** generate a traceability mechanism for honey produced in the Med. Area; **(2)** diversify markets and distribution channels offers business flexibility and freedom from dependence on a single market, which will reduce risk in the event of a crisis; **(3)** cooperate and pool resources among themselves (pooling of the workforce, etc.) for logistical flexibility and solidarity in the supply chain, which will also reduce the risks in the event of a crisis.

TECHONEY proposes to design and develop a **multidimensional framework** to analyse 6 full honey supply chains (farm to table) that will integrate economic, social and environmental indicators and a traceability system, with a *bottom-up* approach considering the stakeholders´ perspectives. A consortium blockchain, coupled with IoT (*Internet of Things*), system will be created to offer real-time tracking and complete traceability of honey along the supply chain from the characterization of honey in a certified laboratory, the retailer, until the end consumer.

The characterization of the quality and safety aspects of local honey through **local certified laboratories jointly with the use of e-commerce and quality labeling schemes** will increase the opportunity for beekeepers to be identified locally, and allow them to gain access to new markets (foreign markets). The implementation of e-commerce with the mobile application will enable local honey to be **better traced by consumers who attach more value to local food and local beekeepers**.

TECHONEY contributes to increasing farm profitability and increasing flexibility and risk mitigation capabilities. A shared, short and circular supply chain will allow actors in the honey supply chain to **access markets** and have **higher incomes**, **share resources and skills** and **save money** by reducing costs (economies of scale) and increase the efficiency, sustainability and flexibility of processes to strengthen resilience and flexibility to face crises and lower risks. The learning community lab and the use of the Blockchain network will secure the storing of records, will **strengthen intellectual property rights**, as well as **bring transparency throughout the supply chain**; it will **reduce frauds**, **enhance food safety** and **improve the communication** between retailers and beekeepers. The traceability system offered will also allow consumers to give direct feedback to beekeepers.

To reach the overall objective, several **specific objectives** (SO) are set out as intermediate goals:

- **SO1:** Map the current added-value chains and complexity level for honey products in six case studies (Spain, Algeria, Tunisia, Turkey, Luxembourg and Morocco).

- **SO2:** Increase the competitiveness and power of the beekeeping supply chain by understanding consumers' and retailers' opinions and acceptance through non-hypothetical methods.
- **SO3:** To promote the traceability to differentiate local honey and guarantee food safety of honey produced in the Med. area by characterizing it in a reliable, certifiable, and documentable manner.
- **SO4:** Design and explore the feasibility of a new traceability ecosystems and effective business models across different stakeholders.
- **SO5:** Development of a new "Multichannel distribution" e-commerce platform implementing new business model as well as integrating and scaling up the outcomes from WPs 1, 2, 3 and 4.
- **SO6:** Maximize outreach and beneficial influence of the project results and reach the target users (beekeepers, small-scale food manufacturers and local distributors, canteens and retailers, local public authorities) through an effectively established communication and dissemination plan, including innovative training capsules.

Moreover, a **TECHONEY** web ICT tool consumer/farmer-centred will be developed, by testing and evaluating several machine and deep learning algorithms, providing small-scale beekeepers with key information on new markets and opportunities, contributing to a better decision making and to ensure the traceability of their product. Consumers will have exhaustive knowledge of the different honeys of the Med. area, knowing their traceability from the initial producer, guaranteeing the quality and safety of each product.

TECHONEY *is a project coordinated by CITA (Spain) and funded through the PRIMA Section 2 Multitopic 2021 – Thematic Area 3-Agrofood chain – Topic 2.3.1 Increasing the resilience of small-scale farms to global challenges and COVID-like crisis by using adapted technologies, smart agri-food supply chain and crisis management tools. (RIA*[5])" under the funding scheme of "Collaborative Project" and type of Action "Research and Innovation Actions (RIA)."*

EXECUTIVE SUMMARY OF THE DELIVERABLE

This Deliverable D4.1 is the **Design and architecture of the consortium blockchain platform** for the **TECHONEY** Project. Its objectives are to review the problems confronting agri-food products on short/regional supply chains, inspect the IOT and blockchain-based platforms either proposed in research or currently used in agri-food supply chain and facilitate the deployment of digital solutions such as mobile apps, web interfaces or data analysis techniques to mitigate these problems using **end-to-end real-time traceability**. Specifically, this document studies the latest research contributions in the areas of IOT and blockchain-based traceability for the short agri-food supply chain. The results from the first iteration of a systematic review strategy will be used to identify the usefulness and appropriateness of the deployed digital technologies stated in the literature.

DOCUMENT STRUCTURE

This D4.1 document is organized according to the following structure:

- **INTRODUCTION:** Depicts the context, purpose and scope of the document.
- **SHORT AGRI-FOOD SUPPLY CHAIN:** Limits the participants in the supply chain to only farmer/producer, distributor, wholesaler/retailer and consumer.
- **PROBLEMS RELATED TO AGRI-FOOD PRODUCTS:** Shows the three common and major problems in agri-food products: waste, safety and fraud.
- **DETECTING AND PREVENTING AGRI-FOOD PROBLEMS USING DIGITAL SOLUTIONS:** Briefly reviews digital solutions employed to detect and prevent agri-food problems.
- **DIGITAL TRACEABILITY IN AGRI-FOOD SUPPLY CHAIN:** Explains the benefits of digital traceability in agri-food supply chains and ways how it can be ensured.
- **BACKGROUND ON BLOCKCHAIN TECHNOLOGY:** Provides a short overview of blockchain technology, identifies the key functional characteristics, and explains the architectural design of the blockchain-based applications.
- **IOT AND BLOCKCHAIN-BASED PLATFORMS FOR AGRI-FOOD SUPPLY CHAIN TRACEABILITY:** Reviews the IoT and blockchain-based platforms that are currently developed and/or proposed to enhance the traceability of agri-food products.
- **MONITORING, INDICATORS, RISKS:** Describes the mechanisms that will be applied to ensure the project stays on track.
- **ANNEXES:** including templates for **TECHONEY** presentation slides

INTRODUCTION

The agri-food sector plays an essential role in satisfying the basic human need for sustenance, ensuring its food security and reducing poverty. Consumers access to agri-food products is guaranteed through a short or a long agri-food supply chains that transport goods from farms to the end consumers. These supply chains include a wide range of stakeholders, such as suppliers, farmers, distributors, processors, wholesalers, retailers and consumers, working together to meet the consumers demand. In this document, we specifically focus on agri-food products that are produced locally (raw and/or processed) by farmers and delivered to consumers without any additional processing, tampering or transformation in the supply chain by the intermediaries like processors, distributors, wholesalers, retailers or manufacturers. So that, the products can be delivered from farmers to consumers with its originality kept intact.

Agri-food products are exposed to intentional and unintentional problems which can potentially degrade their quantity and/or quality during transit in the supply chain, resulting in risks related to health, finance and economy. In this document, in parallel with our context, we will explore in detail the origin of these problems in three categories: food waste/loss, food safety, and food fraud. We will also list the main contributing factors at each stage of the supply chain.

Several data analysis techniques have been proposed in literature to detect and prevent problems arising in agri-food supply chains. These techniques are mainly based on mathematical, statistical or machine learning approaches and principles. However, they all require data collection, storage and computing platforms. To that end, agri-food supply chain traceability systems have been developed to identify, track and trace products as it moves along the supply chain from farmers to consumers in real-time. Such systems inherently generate a high volume of data. The collected data from various connected devices, such as mobile phones, laptops and sensors (identification, environment, motion, localization, vision, etc.), are stored in a remote server. These data can later be used for model development, training or optimization. The main objective of this deliverable is to inspect IoT solutions and blockchain-based agri-food supply chain traceability systems that have been currently deployed or proposed in research for regional agri-food producers who would like to export and sell their original, untampered and untainted products to different regions and counties, while at the same time giving the consumers the possibility to appreciate and recognize the origin and quality of their product.

SHORT AGRI-FOOD SUPPLY CHAIN

A **short food supply chain** as defined by the Regulation 1305/2013 of the European Union on the support for rural development is "*a supply chain involving a limited number of economic operators, committed to cooperation, local economic development, and close geographical and social relations between producers, processors and consumers*". It involves a direct connection between farmers and consumers, with only limited involvement by the intermediaries or processors.

This direct connection allows for a greater transparency in the supply chain and a better traceability of products resulting in a fresh and potentially a higher quality product delivery to the end consumers. It also supports the development of local economy and strengthens the relationship between producers and consumers.

We limit the scope of this definition to all types of food that are produced in agriculture (agri-food), making it a short **agri-**food supply chain. Additionally, we leave out any food processing or modfication at the intermediate steps. Meaning that if and when it is necessary, such modifications are only carried out to a certain extent by the farmers themselves. For instance, producing cheese from milk, olive oil from olives so and so forth. Assigning such privilege only to the farmers will help in keeping the originality of the product. Thus, in this deliverable, the short agri-food supply chain considered is formed by the following stakeholders: Farmer, Distributor, Wholesaler/Retailer and Consumer as shown in Figure 1.

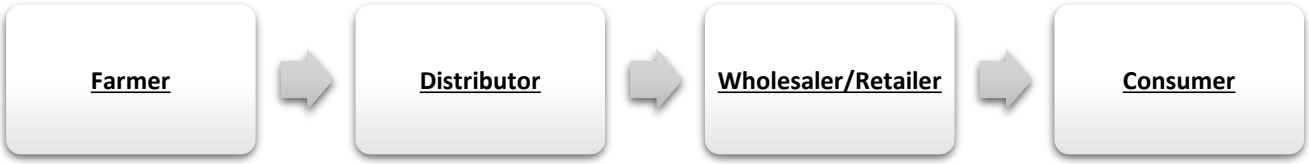

Figure 1. *The short agri-food supply chain considered in this deliverable.*

As per its definition the short supply chain targets local economies and close geographic ties. In spite of that we anticipate farmers will have the opportunity to expand their agri-food product markets to areas beyond their usual boundaries, if the same level of transparency is applied in regards to its traceability and quality insurance.

PROBLEMS RELATED TO AGRI-FOOD PRODUCTS

After an in-depth analysis of the literature relevant to our context, we have identified the following categories of problems: **food waste**, **food safety**, and **food fraud**. We will explore each of these categories in detail, their primary causes and provide some examples. We limit the analysis and the origin of these causes mainly on the steps of production, distribution, wholesaling and retailing. There is one problem/cause that could potentially be linked to the stage of consumption, however the root of the problem lies in the other stages of the supply chain.

FOOD WASTE

Food waste refers to any food or agricultural products that are discarded, either intentionally or not, involving all echelons within the short food supply chain. Excluding the food waste at the consumer side, this reference also applies to the unharvested food that has been lost during transportation or storage, and then failed to be sold at supermarkets, or thrown away by consumers.

Food waste is a major global problem having not only economical consequences but also affects environmental and social aspects. It is estimated that approximately one-third of all food produced globally is lost or wasted each year, which amounts to around 1.3 billion tons of food [1]. This waste, in addition to representing a significant loss of resources and economic potential but also contributes to greenhouse gas emissions and other environmental problems.

There are several causes attributed to a number of factors and stakeholders. We have focused only on identifying the primary causes and have categorized them based on their association within the stages of the supply chain, such as **processing and handling**, **storage**, and **transportation**. Hence, food waste could arise:

PROCESSING AND HANDLING

- **Inappropriate raw materials and additives**: Problems that arise due to the raw materials and inputs used in the agri-food supply chain. These problems can be caused as part of unintentional errors or malicious actions.
    - Examples: inconsistency in the number of ingredients; used oils and retailed wastes including lubrication, hydraulic and cotton.
- **Bad food handling and processing**: Shortcomings in food processing and handling during treatment or manufacturing.
    - Examples: process loss; harmful fishing techniques; fish falling from containers during handling; processing and carcass handling issue; poor quality packaging; inadequate sorting; water loss; spillage and degradation; damage; poor machine setup.

STORAGE

- **Improper food storage and warehousing**: Issues related to storage and warehousing practices. These issues can happen in various stages of the supply chain.
    - Examples: lack of appropriate storage infrastructure and service; damage; improper storage; inappropriate storage conditions; poor transportation and storage facilities; spillage and degradation.

TRANSPORTATION

- **Poor food transportation system**: Issues associated with the transportation of either finished or semi-finished products.
    - Examples: poor roads and transportation facilities leading to the delivery of broken packages.

MULTIPLE OR OTHER FACTORS

- **Contamination**: Presence of external phenomena that can affect the product. These issues can impact all stages of the supply chain.
    - Examples: Microbial or pest infestation, insect and bird and rodent predation.
- **Inadequate temperature and humidity**: Poor thermal, physical or other environmental conditions that may have an impact on the product. These issues can happen in all stages of the supply chain.
    - Examples: cold chain deficiency; absence of shilling on port; inappropriate humidity and temperature; reduction in relative humidity; lack of freezing; transportation under unsuitable temperature.
- **Mislabeling**: Labeling deficiencies or gaps in providing accurate information that mislead the consumers.
    - Examples: Label confusion.
- **Non-compliance with standards and regulations**: Non-conformity with acceptable standards.
    - Examples: in grading for size, quality, or labeling.
- **Mismatch between supply and demand**: Inbalance in demand supply equilibrium. When the Demand is not as high as the supply and vice versa.
    - Examples: overproduction or excessive stock; inadequate demand forecasting; inadequate demand ordering, supply demand issues.

- **Unachieved consumer expectations**: Failure to meet consumer satisfaction.
    - Examples: rejection.

FOOD SAFETY

Food safety refers to the different measures and practices taken to ensure food is free from harmful contaminants such as bacteria, viruses, toxins, and other hazardous substances and made safe for human consumption. Food safety encompasses many areas, including food handling, preparation, storage, transportation, and consumption. Furthermore, other contributing factors for food safety concern can emanates from the quality of ingredients, hygiene practices, temperature control, and sanitation [2].

Within the supply chain food safety concerns can arise:

PROCESSING AND HANDLING

- **Inappropriate raw materials and additives**: When the raw materials are already in a bad condition, or the products are getting contaminated by harmful additives leading to quality deterioration.
    - Examples: Inflections and other mycotoxins; source and microbial contamination; diseases like pest's bacteria.
- **Bad food handling and processing**
    - Examples: incorrect/ineffective packaging; poor record keeping allowing some products to exceed shelf life; handling of meat, processing and carcass handling issues; poor hygiene; poor water quality for cleaning fish.

STORAGE

- **Improper food storage and warehousing**: Storing food in bad or inappropriate containers/environment.
    - Examples: the use of baskets instead of crate storage; wrong storage of meat

TRANSPORTATION

- **Poor food transportation system**: Issues associated with the transportation of either finished or semi-finished products.
    - Examples: Poor roads and transportation facilities leading to the delivery of broken packages.

MULTIPLE OR OTHER FACTORS

- **Contamination**: Presence of external phenomena that affect the quality of the product. These issues can happen in all stages of the supply chain.
    - Examples: Microorganisms: poor record keeping allowing some products to exceed shelf life; poor hygiene; unsafe practice.
- **Inadequate temperature and humidity**: Poor thermal, physical or other conditions that may have an impact on the product. These issues can happen in all stages of the supply chain.
    - Examples: cold chain deficiency; absence of shilling on port; problem of humidity and temperature; reduction in relative humidity; lack of freezing; transportation at unsuitable temperature and conditions.
- **Mislabeling**: Labeling deficiencies or gaps in providing accurate information that mislead the consumer.
    - Examples: misrepresentation of quality statements.
- **Non-compliance with standards and regulations**: Non-conformity with acceptable standards.
    - Examples: violation of safety standards in food production, storage and transportation.
- **Unachieved consumer expectations**: Failure to meet consumer satisfaction.

- Examples: short shelf-life; near expiry product.

FOOD FRAUD

Food Fraud refers to any intentional or deliberate misrepresentation of food products or their ingredients for financial gain. This can include the use of lower quality ingredients, mislabeling of products, and intentional contamination or adulteration of food. Few examples of food fraud can include selling meat that is falsely labeled as having a higher quality, presenting it as a more expensive type of meat, or selling horse meat as beef. Few more examples can also include adding fillers or substitutes to food products, such as using cheaper oils instead of olive oil, or adding sugar or other sweeteners to fruit juices to make them taste sweeter.

Food fraud presents a serious danger to the end consumer., In addition to consuming contaminated or mislabeled products and risking their health, it could also results in financial losses from purchasing products that do not come as advertised. Governments and regulatory agencies around the world try to prevent and mitigate food fraud through inspections, testing, and other measures, but it remains a persistent problem in the food industry [3].

Within the supply chain food fraud can arise [3]:

PROCESSING AND HANDLING

- **Inappropriate raw materials and additives**
  - Examples: Cheese adulterated with cheaper animal or vegetable fats; use of non-milk substance; substitution of milk by different milk from other regions; melamine added to milk; addition of water; dilution of olive oil with other under quality oils; intervention and substitution of higher value species with lower value species; undeclared or illegal presence of substances such as antibiotics and growth hormones; mixing of gluten-containing cereals with non-gluten products (a threat to celiac individuals); unethical mixing with cheaper and low-grade honey, sugars, and other substances; indirect adulteration via feeding of bees; organic adulteration; adulteration of protein products with toxic melamine; addition of undeclared compounds to enhance the quality attributes or prolong the shelf life of meat products (e.g. colourants, preservatives such as nitrates, and water).
- **Bad food handling and processing:** concealment of processing techniques.
  - Examples: chemical extraction instead of cold-pressed physical extraction of native extra virgin olive oil.

MULTIPLE OR OTHER FACTORS

- **Mislabeling**: Labeling deficiencies or gaps that may mislead the consumer, esp. fraudulent claims and misleading statements.
  - Examples: country of origin, geographical indicator; breed; production method (organic, grass-fed claims, free range); type of sea food sea food; poor quality fish instead of their superior parents; slaughter age of meat; distribution of counterfeit products; thawed meat claimed as fresh; changed expiry information.
- **Non-compliance with standards and regulations**: violating laws at the production/farming stage.
  - Examples: exploit quotas and catch undersized fishes; harvesting in areas closed for harvest; unlicensed or unapproved hatchery or nursery operation.
- **Unachieved consumer expectations**: Failure to meet consumer satisfaction.
  - Examples: Short shelf-life; near expiry product.

PROBLEMS AND CAUSES IN RELATION TO THE SHORT AGRI-FOOD SUPPLY CHAIN

The problems described in the previous sections and their causes have not been fully identified in relation to the different stages within the short food supply chain. Table 1 and table 2 provide these details corresponding to the categories and stages of the supply chain respectively.

One can see that there is a strong overlap between the problems and causes that impact food waste and safety. This is not a big surprise because every cause that impact the safety of a product likely leads to the product being rejected and unsaleable.

The majority cases of fraud happen at the farmer side during the production process.. On the other hand, Mislabeling has been associated with a cause for fraud at distributor or wholesaler/retailer stage. There might be scenarios in which a food fraud can happen when it is processed or sold after contamination, was facing inadequate temperature and humidity, or any other problem that might arise from inappropriate storage. We did not list these elements as a potential cause for fraud in the table, because they are already been subsumed as part of bad food handling and processing.

	Waste				Safety				Fraud		
	Farmer	Distr.	Who/Ret.	Cons	Farmer	Distr.	Who/Ret.	Cons	Farmer	Distr.	Who/Ret.
Mismatch between supply and demand	●										
Mislabeling	●				●				●	●	●
Non-compliance with standards	●				●	●	●		●		
Inappropriate raw materials and additives	●				●				●		
Bad food handling and processing	●				●				●		
Improper food storage and warehousing	●	●	●		●	●	●				
Contamination	●	●	●		●	●	●				
Inadequate temperature and humidity	●	●	●		●	●	●				
Poor food transportation system		●	●			●	●				
Unachieved consumer expectations				●				●			

TABLE 1. *The identified causes in relation to the main problems: waste, safety, and fraud*.

	Farmer			Distributor			Wholesaler/Retailer			Consumer	
	Waste	Safety	Fraud	Waste	Safety	Fraud	Waste	Safety	Fraud	Waste	Safety
Mismatch between supply and demand	●										
Mislabeling	●	●	●			●			●		
Non-compliance with standards	●	●	●		●			●			

Inappropriate raw materials and additives	●	●	●								
Bad food handling and processing	●	●	●								
Improper food storage and warehousing	●	●		●	●		●	●			
Contamination	●	●		●	●		●	●			
Inadequate temperature and humidity	●	●		●	●		●	●			
Poor food transportation system				●	●		●	●			
Unachieved consumer expectations										●	●

TABLE 2. *The identified causes in relation to the stages of the supply chain: framer/producer; distributor; wholesaler/retailer; consumer*.

DETECTING AND PREVENTING AGRI-FOOD PROBLEMS USING DIGITAL SOLUTIONS

Digital solutions play a significant role in minimizing food waste, ensuring its safety and in fraud detection, prevention and reduction. These solutions include several steps. Such as traceability, data collection, storage, data sharing, data analysis, so and so forth. While traceability information systems help in tracking, collecting, storing and sharing data about agri-food products (production process, storage and transportation conditions, environmental factors, etc.), it is the data analysis techniques that help in detecting and preventing agri-food problems. In this deliverable, we only focus on traceability information systems in agri-food supply chain.

Traceability information systems (see Figure 2) utilize mainly three technologies: Identification and Monitoring Technologies (IMTs), Communication Technologies (CTs) and Data Management Technologies (DMTs). The first category, IMTs, involves various types of wireless/wired sensors such as identification sensors (RFID sensor tags, NFC stickers, etc.), environmental sensors (temperature and humidity, gas, light, air pressure, air quality, etc.), localization sensors (GPS, camera, lidars, PIR, etc.), biosensors (enzyme-based, tissue-based, etc.). Other devices can also be used such as mobile scanning devices, mobile phones, tablets and laptops as shown in Figure 3. While sensors are generally embedded into farm equipment, shipments, storage infrastructure, containers, vehicles, etc., other device can also be utilized subjectively by the stakeholders as per their demand.

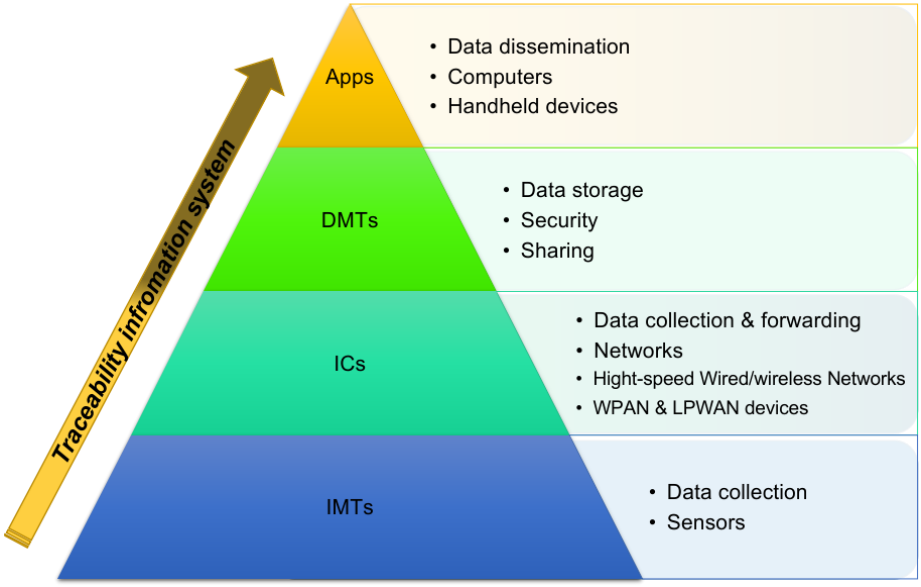

Figure 2. Traceability information system components.

In the case of the communication technologies (CTs), the agri-food supply chain can use multiple wireless and wired communication systems to collect data from IMTs devices and forward them to remote servers hosted in cloud or edge as shown in Figure 3. According to the requirements and depending on the data rate, coverage area, latency, power consumption, IMTs device type, etc. both long/short range and high/low data rate wireless technologies can be employed. For data collection, however, the short-range low power/rate wireless devices are mostly utilized. For instance, Proximity (NFC, RFID) [9] and WPAN (Bluetooth, Z-wave, IEEE 802.15.4/Zigbee, IEEE 802.15.4/6LoWPAN, IEEE 802.15.4/THREAD etc.) [10] are widely employed for a small range data collection. However, in some scenarios, such as remote monitoring or when collecting small amount of data over long distance, long range low power wireless technologies (i.e., LPWAN) such as the likes of Sigfox, LoRa, Nb-IoT and LTE-M are preferred [11]. The minimal power consumption coupled with a reduced operational cost makes LPWAN ideal for a wide area data collection. On the other hand, for data forwarding, we mostly use high rate or speed wired/wireless technologies such as, Fiber Optics/ADSL and WiFi/3G/4G/5G for wired and wireless transfer respectively. For instance, Farmers and other stakeholders in the agri-food supply chain can use mobile apps and web interfaces to aggregate and forward data using the available high-speed wired/wireless devices. Besides the actual devices used for data collection and forwarding, several techniques are also implemented when transmitting

the data. For instance, based on the allowed bandwidth, resources, delays, redundancy, etc., the data transmission technique can be a triggered data transfer, a continuous data transfer, a batch data transfer, an asynchronous data transfer, an FTP etc. Furthermore, a number of application protocols for data transmission and dissemination are also available such as MQTT, OPC UA, EXMPP, REST, WebSockets, CoAp, AMQp, etc., user interaction using phones, EMT devices so and so forth.

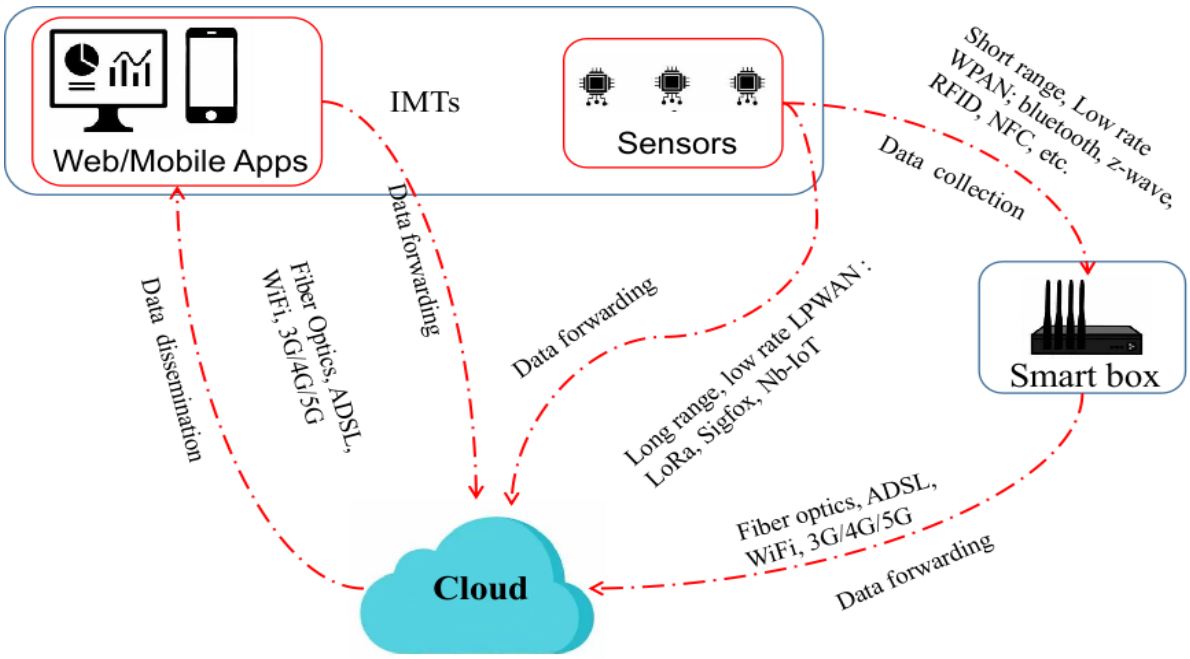

Figure 3. A sample communication technologies (CTs) for a block-based supply chain.

The Data Management Technologies (DMTs), on the other hand, involve in an overall management of the security, storage, analysis and dissemination of data. These services are mainly provided by remote private/public servers. In scenarios where there is a resources constraint or high management cost, these services can be virtualized, aggregated and shared with a less management overhead through cloud services [12]. The data storage is primarily can take either a centralized or a decentralized/distributed storage approach. Storing data in a centralized data storage has its own perks in simplifying data management, however, it suffers from a scalability, data security and single point of failures problems. Hence, currently a distributed and decentralized data storage approaches such as IPFS, Storj, Filecoin, MaidSafe, etc., are gaining much attention [see next section]. Furthermore, its distributed nature helps in enhancing data security by allowing decentralization, redundancy, data partitioning, encryption, etc., problems such as single point of failures, security breaches can be avoided. Thereby ensuring the integrity of the stored data.

Based on the shared data provided by the traceability system machine learning-based applications can be applied to detect and prevent supply chain problems at any stage. Especially supervised machine learning models for regression and classification tasks can be implemented to monitor environmental conditions and other parameters that may affect the supply chain.

DIGITAL TRACEABILITY IN AGRI-FOOD SUPPLY CHAIN

Digital traceability for agri-food refers to the use of technology to track and trace the movement of food products along the supply chain, from farm to fork. It plays a critical role in ensuring food quality and provenance, food safety, accountability, and sustainability. By providing transparency and visibility into the entire supply chain, it allows consumers to make decisions about the food they buy and eat, and help them to know what the products are made from, where, at what time, and at what environmental conditions. On the other hand, these issues provide information to producers, retailers, and customers for detecting any risks that may arise during production or distribution stages.

According to studies [1-4,12], we have identified the following benefits of digital traceability in agri-food supply chains:

- **Improved food safety**: Identifying the source of any food borne illness outbreaks, enables quick and targeted recalls of contaminated products.
- **Enhanced quality control**: Tracking and monitoring every step of the production and distribution process; or identifying quality issues before they become widespread.
- **Increased transparency**: Providing consumers with detailed information about the provenance (e.g., its origin), the production, and the processing of the food they buy, enables them to make better purchase decisions.
- **Improved sustainability**: Reducing food waste or ensuring that food products are produced and distributed in an environmentally responsible manner.
- **Reduced fraudulent practices**: Giving information about the origin and the authenticity of food products. It could also prevent from mislabeling of products or counterfeiting, or adulteration.
- **Achieve environmental concerns**: Identifying where environmental damage may have occurred, such as the overuse of pesticides or the destruction of wildlife habitats.

There are two types of traceability system models in agri-food supply chain: centralized and the decentralized systems. Centralized supply chain traceability systems are highly dependent on a single authority ensuring data collection, storage, and sharing. Few examples of a centralized storage systems that are currently operational are: the centralized ledgers (Amazon's Quantum Ledger Database, etc.) and the cloud storage (Amazon Simple Storage Service). While these systems can bring many benefits to the agri-food sector, there are also some potential limitations to consider, such as [6-8]:

- **Data accuracy and completeness**: accuracy and completeness of data are crucial for the success of a traceability system, as the quality of data is impacted by errors, omissions, or delays in data entry or transmission. In addition, the lack of standardization across different systems leads to difficult integration and effective data analysis.
- **Data Privacy and cybersecurity**: a centralized system of traceability involves the collection and storage of large amounts of sensitive data, including business secrets about contractual relationships as well as personal data of individuals that are involved in the agri-food supply chain. This raises concerns about data privacy and IT security and also about cybersecurity risks of data breaches or unauthorized access.
- **Limited coverage**: A centralized system of traceability may not cover all aspects of the agri-food supply chain, particularly in regions with limited technological infrastructure or in small-scale farming operations.
- **Limited international harmonization**: while centralized systems can improve traceability within a specific region or country, there may be challenges in achieving international harmonization due to different regulations, standards, and cultural differences.
- **Trust issues**: fraud, corruption, tempering, falsification of information. In order to remedy the problems mentioned above, the need for a new model of traceability is essential, for this a decentralized system based on blockchain technology was proposed.

Decentralized traceability systems are gaining interest due to their capabilities in solving some of the major challenges associated with centralized systems. These systems are based on a peer-to-peer decentralized data

storage and immutable data access. Regarding the techniques of data storage and access, three type of architectures can be applied: Distributed File System (DFS), Distributed Ledger Technology (DLT), and combination DLT/DFS. While DLT shares and maintain the same copy of ledger with its nodes, DFS peers do not store the same data. Various DFS and DLT frameworks have been developed. For DFS frameworks, we can find: IPFS, BitTorrent, Storj, Sia, Hypercore, Holo, etc., and for DLT frameworks we can find: blockchain (Bitcoin, Ethereum, Hyperledger, …), Hashgraph, Iota Tangle, R3 Corda, etc.

The goal of this document is to explore decentralized traceability systems based on IoT and blockchain to collect, store, share and trace data, related to agri-food products on the supply chain, in a way that is secure, efficient, and transparent.

BACKGROUND ON BLOCKCHAIN TECHNOLOGY

Blockchain technology was first introduced by research scientists Stuart Haber and W. Scott Stornetta in 1991 to store time-stamped documents and prevent backdating, using a cryptographically secured chain of blocks.
This concept remained relatively unused, until Satoshi Nakamoto created the first digital cryptocurrency, Bitcoin, in 2009. The cryptocurrency was the first successful blockchain application, showing that blockchain platforms offer more security and resiliency by design. Apart from its success in cryptocurrencies, the open-source Blockchain technology is rapidly growing and maturing, and it is being investigated and integrated in multiple other use-cases and applications.

Blockchain can play different roles in a given software architecture. As a replicated ledger kept by multiple parties, blockchain can function as a decentralized data storage, and as newer generations of blockchain support smart contracts, it can also be used for decentralized computing. Blockchain also has interesting non-functional properties like immutability, integrity, transparency between nodes and non-repudiation. Other properties like decentralization, data privacy and scalability depend on the type of blockchain. There are 3 types: Public, Private and Consortium. These types depend on configuration factors like permissions, participation in consensus and data access. Table 3. presents a comparison between the three types based on different properties and factors.

Property	Public	Private	Consortium
Permission	Permission-less	Permissioned	Permissioned
Consensus node	Any node	Owner	Designated nodes
Infrastructure	Decentralized	Distributed	Decentralized
Data access	Transparent	Private	Private
Scalability	High	Low	Medium
Performance	Low	High	High

TABLE 3. *A comparison between blockchain types*.

A GENERAL BLOCKCHAIN LAYERED ARCHITECTURE

A general Blockchain architecture is presented in the literature as an architecture that includes five layers (Figure 4): network/physical layer, transaction layer, data layer, consensus layer and application layer.

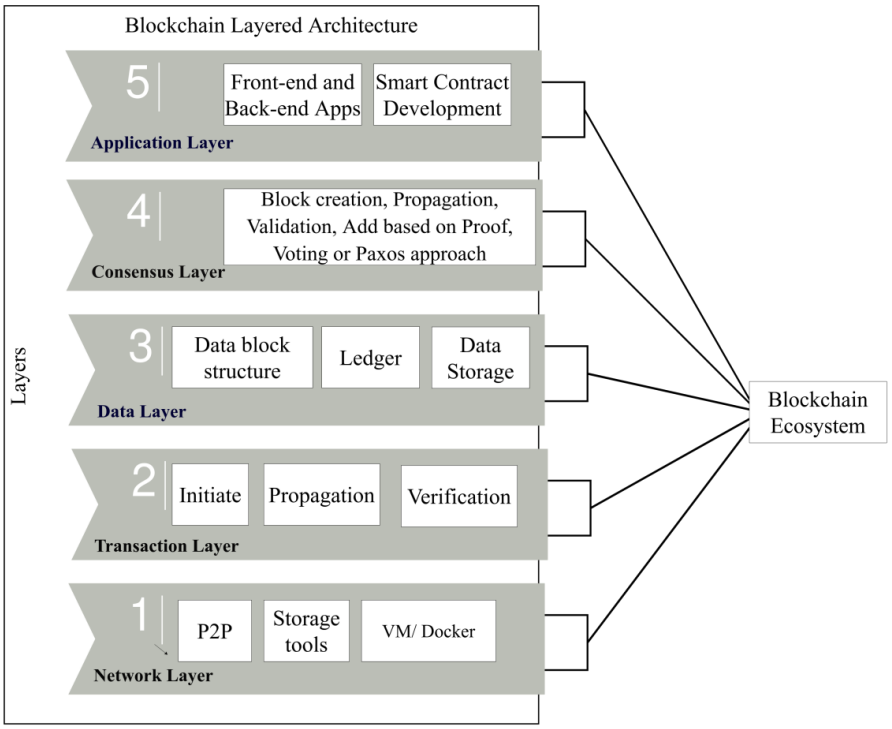

Figure 4. Blockchain Layered Architecture.

NETWORK LAYER

Peer-to-peer network (P2P) plays an important role in the realization of the fundamental concepts of Blockchain. Without it, the decentralized and distributed nature of the Blockchain that helps in maintaining the trust of all participants by keeping a copy of transactional ledger on P2P network will not be possible. Such architecture not only offers transparency among its participants, but also a robust security compared to centralized networks. In addition to the cryptographic security, the distributed nature of the P2P network eliminates single point of failure by providing a redundant pathway for those that require a P2P consensus mechanism and extra layer of security for keeping data storage quality and integrity [13]. Furthermore, the P2P networks creates an efficient mechanism for broadcasting transactional data through gossip protocol. However, being part of a P2P network comes with a commitment. A commitment where the participants are willing to dedicate a portion of their computational resources such as processing power, disk storage, network bandwidth, printers, etc., to be shared among the group without a central authority [13]. Such scenarios significantly increase the computing power that is available to Blockchain at any given time as shown in Figure 3. However, it also presents a challenge when it comes to the principles of distributed ledgers storage, the amount of data that is needed to be stored and the fraction of disk storage that is available at the participating nodes. Hence, data storage in Blockchain networks is restricted to a transactional hash data. Alternative mechanisms such as IPFS that guarantee data availability when needed and accessible network connection when required is used for large data file storage.

TRANSACTION LAYER

In Blockchain the term transaction stands for the transfer of asset from one party to the next including the creation, validation and execution of transactions. As such, the transaction layer represents one of the fundamental blocks of a Blockchain. It plays a critical role in securing the transparency, integrity and accuracy of transactional ledgers across all participants of the Blockchain. As a result, consistent and coherent steps are followed for a successful transaction. For instance, before the client initiate a transaction through smart contracts, tokens, etc., the transaction must be digitally signed using the client's assigned cryptographic keys for authenticity. This digital signature signifies a proof of ownership [13]. Once authenticated and the necessary conditions are met, the layer initiate a consensus for adding the transaction to the block of transactions. Depending on the framework a variety of consensus algorithms such as proof of work, proof of stakes, proof of weight, etc., are implemented. Before their final inclusion to the distributed ledgers, the transaction will pass through the validation and verification steps to check for consistency in regards to the authenticity of the sender, available assets, transaction, consensus regulations so and so forth. Miners or network nodes responsible for adding a block to the exiting Blockchain play a significant role in this layer [14].

DATA LAYER

The data layer represents another key infrastructure for the success of a Blockchain and it is mostly embedded within the transaction layer. This layer is responsible for the management and storage of data in a manner that is consistent and accessible for all participants. Inherently, a Blockchain is composed of linked blocks, each containing a finite set of transactions. A number of factors affect the data size of these blocks. Such as the frameworks (i.e., fixed like bitcoin vs dynamics like Ethereum), the data size of the transaction, frequency of transactions, etc. In addition to the data, blocks also utilize hash pointers and Merkle hash tree to ensure the integrity of the data and the consistency of the connected blocks in a chain. Each block contains the hash value of the block that precede it. Thus, forming a cascaded and chronological ordered chain of blocks, hence the name Blockchain. The chain provides a traceable transactional history that is accessible and the cryptographic hash ensures the storage of an immutable records as shown in Figure 5. The decentralized nature of the Blockchain further strength a redundant ledger storage that is fault tolerant [13-15].

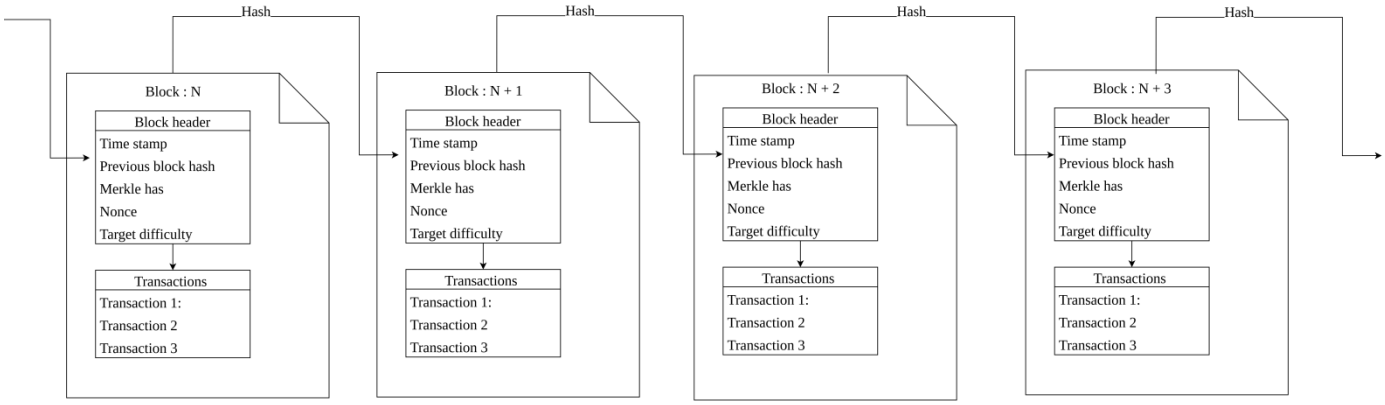

Figure 5. Chronologically ordered linked blocks of records

CONSENSUS LAYER

Blockchain achieves data consistency across the distributed networks through predefined rules. The consensus mechanisms facilitate agreement between consenting nodes on the specific transaction and its order in a block that is to be added to the shared ledger. Each consensus mechanism mainly includes four steps: block creation, block propagation between peers, block validation and block add. Depending on the frameworks, three consensus mechanisms are widely implemented: proof class such as proof of work (PoW) and proof of Stake (PoS) in Bitcoin Ethereum; voting class like the Practical Byzantine Fault Tolerance (PBFT) in Fabric version 0.6; and Paxos class like the Paxos and Raft in Fabric version 1.4.4. The specific consensus algorithm employed is dependent on the level of security and performance desired. Especially, those blockchain that utilize PoW as the preferred algorithm incurs a huge computational resources requirement such as energy consumption, storage capacity, processing power, network bandwidth so and so forth. Furthermore, since the kind of participants asked to participate in the consensus depends on the network configuration, it is fair to say that the kind of the consensus algorithm determines the data access and governance on the blockchain. As security is paramount in public blockchain, these frameworks usually utilize PoW, whereas private and consortium blockchain rely on trusted network participants, as such a less resource intensive algorithm is employed. The impact of consensus algorithms on the performance and security of the underlying blockchain framework can be better illustrated by analyzing the key blockchain features. The following Figure 5 illustrates the fulfillment of key blockchain features corresponding to the different frameworks.

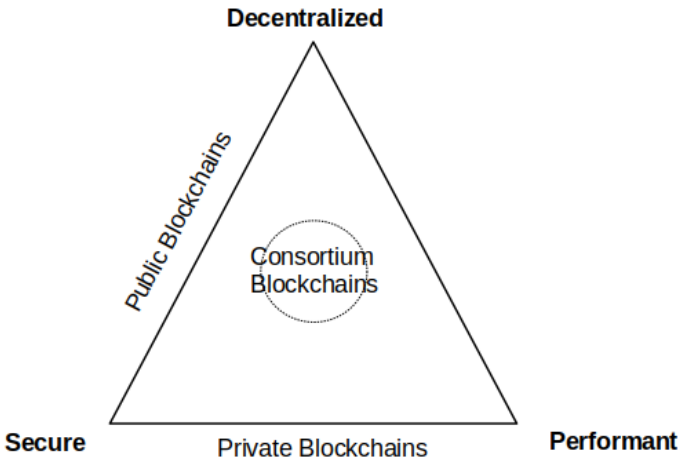

Figure 5. *Blockchain main properties satisfaction for each blockchain type, in the form of a Zookoo triangle*.

As the comparison shows, public blockchains generally don't meet the requirements of applications in terms of performance. The throughput is very limited. Ethereum for example handles twenty transactions per second (20 TxPS) and Bitcoin is limited to seven (7 TxPS). On the other hand, public blockchains are highly decentralized, which is not the case for private blockchains that are performant but controlled and owned by a single entity. Consortium blockchains can satisfy the three needs better than any other type, they are decentralized as they are maintained

by multiple entities with equal rights on the network, and they are secure and performant since consensus only concerns designated nodes and can be faster than other types of consensus in public networks. Consortium blockchains promote shared governance between stakeholders and creates neutral secure platforms for collaboration between different entities. Interoperability is another key feature to consider while choosing a blockchain platform to build a solution on. It has become a crucial feature for blockchain networks to be able to integrate different components and work-along different systems in a given ecosystem. More research work is being invested on methods to interoperate blockchain technology with other systems and even other blockchains [6-8]. These features that are either built in blockchains by design or chosen by configuration are what enables blockchain-based applications. We consecrate the following subsection to present blockchain-based applications, called decentralized applications or DAPP, and their general architectural pattern.

APPLICATION LAYER

The application layer represents the upper layer of the blockchain architecture that contains the business logic and rules specific to the task at hand. This layer facilitates client-side interactions using front-end UIs so that users can initiate, query and commit transactions in a blockchain ecosystem [15]. From an architectural point of view, blockchain enables decentralized applications where a client side running on a device relies on a blockchain platform acting as a back-end server. Blockchain replaces typical servers and adds more transparency and shared governance between running nodes, which is crucial for some applications that require establishing trust between stakeholders.

Smart contracts in newer generations of blockchain enable the implementation of business logic for a decentralized application. Their capabilities are being improved with the evolution of the technology. These codes running on a decentralized-shared platform provide functional autonomy and trusted computing. Functional autonomy is guaranteed by smart contracts that are self-executing once the terms agreed between different actors are fulfilled. In their book Architecture for Blockchain Applications [5], Xiwei Xu et al present different possible roles for blockchain in a given software and essential architectural and design processes for blockchain-based applications. It is shown that blockchain is suitable as a component for computing via smart contracts, for storage via replicated ledgers and for asset management and access control via tokens. Figure 6 gives a general architectural pattern that decentralized applications follow, along with different components used in the applications.

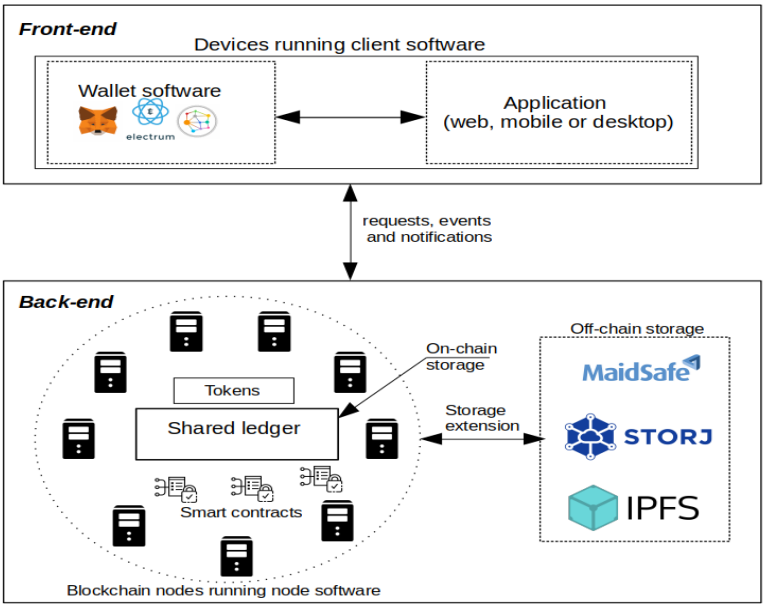

Figure 6. *General architectural pattern for blockchain-based applications. Blockchain is used in the back-end for computing, storage, communication between network entities and other purposes.*

IOT AND BLOCKCHAIN-BASED PLATFORMS FOR AGRI-FOOD SUPPLY CHAIN TRACEABILITY

RESEARCH METHODOLOGY

This document studies the latest research contributions in IoT and blockchain-based traceability in the short agri-food supply chain. The results from the first iteration of a systematic review strategy from the literature will be used to identify the usefulness and appropriateness of digital technologies. The literature review was conducted mainly through Google Scholar, using the IEEE, Elsevier, and Springer. In addition, we have consulted publicly available studies from our project partners and government agencies. Our emphasis was on the most recent literature from 2016 – 2023. The keywords used for the research were:

- Food supply chain problems;
- Food supply chain traceability;
- Blockchain for traceability of short food supply chains.

Exclusion criteria also included articles written in languages other than English. We identified 75 peer-reviewed scientific papers, including journal articles, book chapters, and conference proceedings.

FINDINGS

The review of papers was done in two rounds. After the first round, a table with 41 description feature is completed

1ST ROUND REVIEW

We have defined 41 description features to extract from each paper (journal or conference). We have classified these description features into 4 groups:

- **Initiative/project status**
  - **Initiative/Project**: name of the project
  - **Year**: year of publication
  - **Technology Readiness Level (TRL)**: maturity level
  - **Software License**: agreement that grants a user access to software and its functions (open-source, proprietary, etc.)
- **Agri-food supply chain specifications**
  - **Agri-food products**: name of the product
  - **Food origin/country**: country or place of origin
  - **Label information**: ingredients list and quantities, conditions of storage, etc.
  - **Supply chain type**: short, long, direct, local, regional, global, etc.
  - **Supply chain steps**: stages of the supply chain (producing, processing, distribution, retail, wholesale, and consumption)
  - **Internal stakeholders**: direct participants in the supply chain that that handle consumer products (farmers, distributors, wholesalers, retailers, consumers)
  - **External stakeholders**: indirect participants in the supply chain (Insurance companies, government, laboratories, etc.)
  - **Product identification**: QR codes, traditional barcodes, 2D barcodes, and RFID/NFC tags
  - **Product certification**: certificate authority

- **Product transformation**: if the agri-food product is transformed into finished products
- **IoT devices**: used sensors and mobile devices in the supply chain

- **Blockchain specifications**
  - **Goal of using blockchain**: why blockchain is used?
  - **Blockchain framework**: Ethereum, Hyperledger, Bitcoin, etc.
  - **Blockchain Governance**: public, consortium or private.
  - **Infrastructure provider**: who host the blockchain?
  - **Blockchain users**: who use applications-based blockchain among stakeholders?
  - **Smart contract use**: indicate the presence of contracts that are coded, stored on the Blockchain and executed by peers.
  - **Number of peers**: number of participating machines in the peer-to-peer-network
  - **Consensus protocol**: Raft, pBFT, FBA, PoS, etc.
  - **Block size**: amount of data stored in block.
  - **Stakeholder identity**: signed cryptographic hashes, etc.
  - **Type of transactional data**: financial data and/or non-financial-data.
  - **In/Off-chain storage**: data are stored in the blockchain or out the Blockchain.
  - **Data privacy (if yes, by what mechanism?)**: is data protected from unauthorized access?
  - **Devices used by stakeholders to communicate with Blockchain network**: laptops, mobile phones, etc.

- **Quantitative or qualitative evaluation criteria**
  - **Traceability and its application**: food safety, food fraud, food wastage, visibility, supervision, etc.
  - **Transparency**: level of sharing data
  - **Responsiveness**: the ability of the supply chain to respond to problems and meet the needs of the consumers
  - **Flexibility**: the ability of the supply chain to adapt its behaviour to deal with problems
  - **Scalability**: the ability of the supply chain to adapt its behaviour to deal with an increasing number of stakeholders.
  - **Cost management**: the ability of the supply chain to reduce costs and improve the profitability stakeholders.
  - **Lead time**: the ability of the supply chain to reduce delivery times.
  - **Coordination and Collaborative planning**: relationship/interactions process between stakeholders.
  - **Customer satisfaction**: degree to which a customer is satisfied with a agri-food product and delivery service.

The results of the 1st round review are shown in the embedded excel file (First-Round-Review-TECHONEY-WP4.xlsx). We can see from the results that several description features are not discussed or given in most of the reviewed papers. The missing elements are related to the Blockchain in-depth technical details such as consensus

protocol, block size, number of peers, data privacy, etc., or to the quantitative or qualitative evaluation criteria. This can be explained by the fact that most of the reviewed papers are not based on real testbeds or experimental infrastructure which can be helpful to list the Blockchain configuration or provide performance evaluation. However, we can see that the most utilized frameworks are Hyperledger and Ethereum. The storage can be either in-chain or out-chain using local database or DFS, like IPFS. Also, multiple IoT devices are deployed across the supply chain to identify the products and possible damages, monitor real-time environmental conditions, track location, and more.

2ND ROUND REVIEW

Based on the results of the 1st round review, we have decided to remove all unnecessary description features from the embedded excel file, and illustrate the results through a branching tree to make the data more presentable and easier to understand. This tree has 4 levels.

The first level represents the problems that impact the agri-food products in the supply chain. We have identified three main problems:

- **Waste**
- **Safety**
- **Fraud**

The second level represents the agri-food products studied in the IoT and blockchain-based short agri-food supply chain papers. For optimal aggregation, we have classified the agri-food products into two categories:

- **Processed**: cheese, olive oil
- **Unprocessed**
    - **Meat and fish**: seafood (sardine), meat.
    - **Fruit and vegetables**: fruit (bananas), vegetables.
    - **Grains**: grains, coffee, cacao.
    - **Other**: milk, honey, tea, egg.

The third level represents the agri-food supply chain stages:

- **Production**
- **Distribution**
- **Wholesaling/retailing**
- **Consumption**

The last level represents the blockchain frameworks and IoT devices used by the decentralized traceability system to collect, store and share data related to the agri-food products and their environment.

- **Blockchain framework**: Hyperledger fabric, Hyperledger Sawtooth, Ethereum**.**
- **IoT devices**: RFID/NFC, sensors, GPS, QR code scanner and barcode scanner

Due to space limitation, we split the tree to three sub-trees, each having a category of problem as a root node. Figure 7 shows a taxonomy of proposed IoT and blockchain-based traceability system for agri-food waste in short supply chains. We can see that only five agri-food (grain, coffee, cacao, bananas and vegetables) were targeted in literature. Agri-food waste can happen at any stage within the supply chain. We would like to point out that the traceability system is based on Hyperledger, an open-source consortium blockchain, and various IoT devices such as RDIF and QR code scanner to identify products, GPS to track products at any time, and sensors for continuous measurement along the agri-food supply chain for temperature, humidity, gas composition, pressure, vibration, weight of products, etc. All the collected data are stored and shared by the blockchain, and can be used by the waste applications to reduce and/or manage wastage in agri-foods in a more economical way.

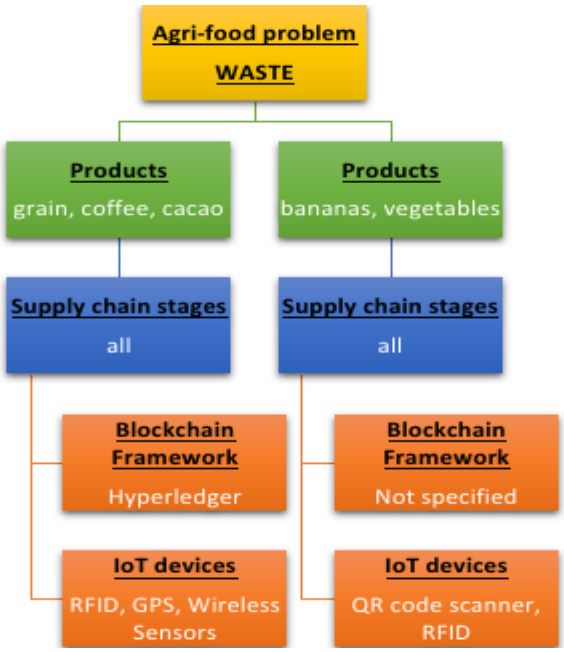

Figure 7. *Taxonomy of proposed IoT and blockchain-based traceability system for agri-food waste in short supply chains*.

Figure 8 shows a taxonomy of proposed IoT and blockchain-based traceability system for agri-food safety in short supply chains. The literature covers a small set of agri-food products: grain, coffee, cacao, sardine and meat, where the main challenge is to mitigate agri-food safety risks. As this problem can be produced at each stage of the supply chain and could potentially propagate, sensors are deployed along the supply chain to ensure continues monitoring in terms of environmental indicators, chemicals, toxins, or unwanted pathogens. Both Hyperledger and Ethereum frameworks are used.

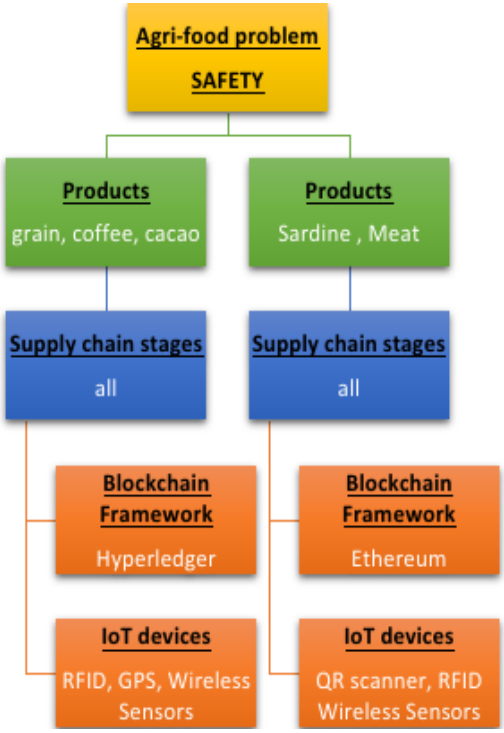

Figure 8. *Taxonomy of proposed IoT and blockchain-based traceability system for agri-food safety in short supply chains*.

Figure 9 shows a taxonomy of proposed IoT and blockchain-based traceability system for agri-food fraud in short supply chains. This problem has been documented more thoroughly than food waste and safety due to its impacts on the economy, health and the environment. Several agri-food products have been considered: grain, coffee, cacao, milk, honey, tea, eggs, bananas, vegetables, sardine, meat, cheese and olive oil. We would like to point out

that agri-food fraud is supposed to be perpetrated at all stages of the supply chain except at the consumption stage. However, agri-food fraud can be also perpetrated by consumers such as restaurants. To detect, reduce and prevent fraud, and improve the agri-food recall process, IoT devices such as QR code scanner, smart labels, environmental sensors, location sensors, chemical sensors, video sensors, etc., are used for real-time tracking and testing. The collected data are then, stored and shared using blockchains based on Hyperledger or Ethereum.

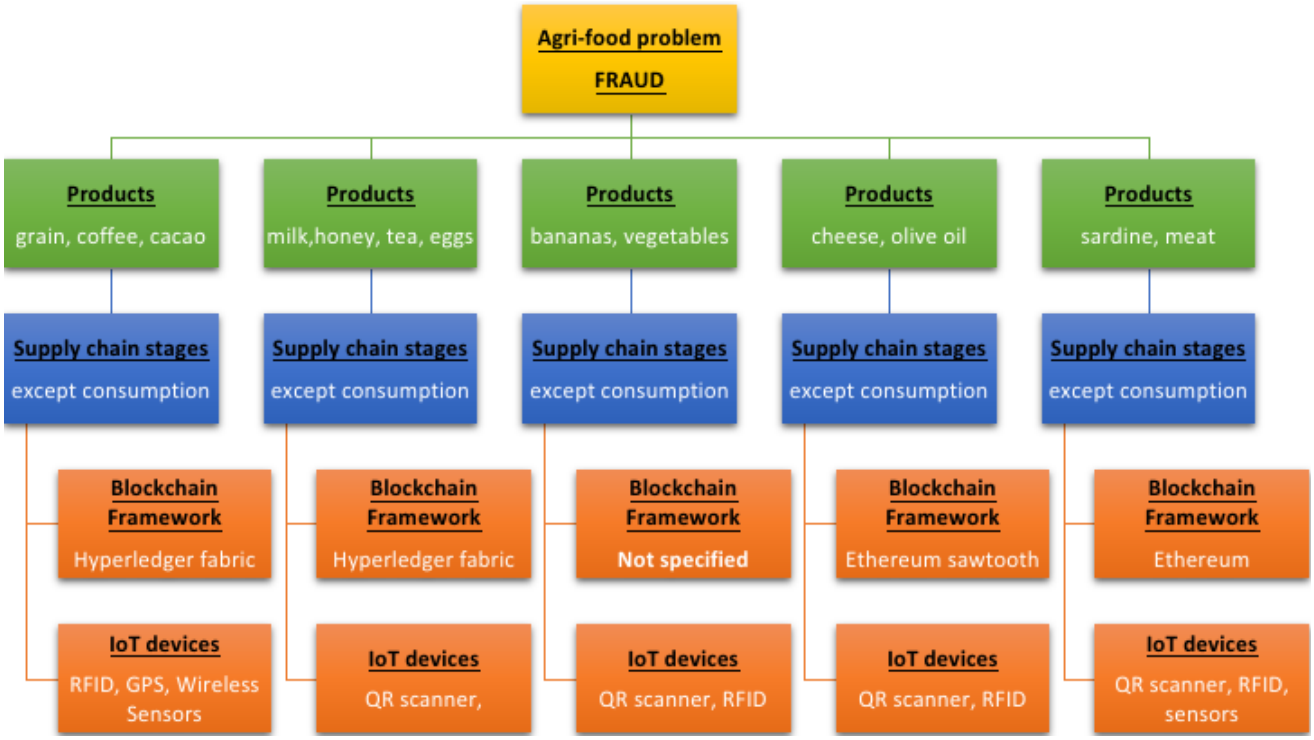

Figure 9. *Taxonomy of proposed IoT and blockchain-based traceability system for agri-food fraud in short supply chains*.

ANNEX II: BIBLIOGRAPHY

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