MEMÒRIA DEL TREBALL DE FI DE GRAU DEL GRAU (ESCI-UPF)

Artificial Intelligence and Blockchain for food loss and waste prevention and reduction

AUTOR/A: Ot Valero i Solé	**NIA:** 104521
GRAU: GNMI	
CURS ACADÈMIC: 2021 - 2022	
DATA: 24/05/2022	
TUTOR/S: Tomislav Rimac	

Index

1. Introduction

There are 1.3 billion tons of food suitable for consumption wasted each year (FAO, 2011), a third of the world's food is lost and wasted. This waste occurs during all the stages of the food supply chain, which can be simplified as; production, postharvest handling and storage, processing and packaging, distribution, and consumption (Gustavsson et al., 2013). According to the FAO, around 13,8 percent of food produced is lost from post-harvest before reaching the retail stage (FAO, 2019). Furthermore, at the retail, food service, and consumer levels, 17 percent of available food is thrown away before being consumed (UNEP, 2021).

There are differences when referring to food loss and waste, but they can be classified as follows. Food loss refers to food that spills, spoils, or gets lost before it reaches the consumer, while food waste refers to food that is fit for human consumption but that does not get consumed because it is discarded (Lipinski, et al., 2013).

The leading causes of food loss include poor storage facilities, lack of refrigeration and poor infrastructure and transportation, inadequate market facilities, and poor packaging. On the other hand, the leading causes of food waste are quality standards, poor environmental conditions during food displays, lack of planning, "best-before-dates", and food leftovers (Gustavsson et al., 2011). Consequently, food loss is more common in low-income countries, where the highest loss and waste occur at the beginning of the supply chain. In contrast, food waste tends to be more common in medium and high-income countries during the end of the supply chain, at retail, food service, and household stages (Gustavsson et al., 2011). However, a lack of standard definition leads to referring to both terms interchangeably as food loss and waste. Hence the term FLW (Food Loss Waste) will be used.

For a clear overview of the supply chain and causes of Food Loss and Waste, appendix 1 consists of a table elaborated by FAO (2019).

<u>Why does reducing and preventing FLW matter?</u>

Considering pollution, Monier et al. (2010) estimate that at least 170 Mt of CO2 is generated in the European Union due to food waste, which was a 3% of total greenhouse gas emissions in the EU in 2008.

Current estimates suggest that the levels of food produced are enough to feed up to 10 billion people (Holt-Giménez et al., 2012), but in 2019, 690 million people were undernourished (FAO, 2020). The threshold for undernourishment is fewer than 1800 kcal per day (Action Against

Hunger, 2018). For context, the world's average food supply during 2013 was at 2884 kcal/capita/day[1].

Furthermore, as shown in appendix 2, daily per capita consumption is expected to keep growing. *"With the world's population expected to reach 9,7 billion by 2050 and in the absence of any deviations in our eating patterns, FAO (2018) reports that between 2012 and 2050, global agricultural output volumes, harvested (crop) areas, animal herd size and greenhouse gases (GHGs) could rise 50%, 23% (92 million hectares), 46% and 20%, respectively*." (Philippidis et al., 2021, pg.2).

FLW reduction is, therefore, crucial both in terms of economic impact and sustainability. Modern technologies might be one of the answers to solving this problem. Despite the many different technologies that can help, commonly referred to as Digital Agricultural Technologies (DAT), this work will focus on the implications of Artificial Intelligence and Blockchain.

The overall objective of this work will be to provide an analysis of a business ecosystem built on top of forecasting and traceability, understanding how the supply chain players can interact and adopt the technologies to solve the food loss waste challenge.

2. Background on food loss waste and digital agriculture technologies

2.1 Food waste and loss

Several reports are looking to tackle the FLW matter. The Food and Agriculture Organization of the United Nations is one of the most prominent sources of information with reports such as "The Global Food Losses and Food Waste" (FAO, 2011), a report that gave a global overview of the extent of food waste and loss, "The future of food and agriculture: Trends and challenges" (FAO, 2017), "e-agriculture 10-year Review Report" (FAO, 2015) or "The state of food and agriculture: Moving forward on food loss and waste reduction" (FAO, 2019) an up to date version of the 2011's report with newer and more accurate methodologies. Other institutional reports include the United Nations Environment Programme "The Food Waste Index Report 2021" (UNEP, 2021), which focuses on food waste in households, food services, and retail, or "Food losses and waste in the context of sustainable food systems" a report by The High-Level Panel of Experts on Food Security and Nutrition (HELP, 2014) that the FAO later published.

Reducing FLW has become a priority for many policymakers. The most relevant example of this is the UN Sustainable Development Goals, where goal 12.3 is aimed to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (UN, 2015, pp22). However, the consequences of

[1] FAO. (n.d.). Food Balances. FAOSTAT. Retrieved April 4, 2022, from https://www.fao.org/faostat/en/#data/FBSH/visualize

achieving such goals also need to be assessed, as a recent study shows that at the EU level, "*the losses in agricultural jobs amount to 325.000 (-2,9%) and 265.000 in food compared to the baseline (-4,6%). Accordingly, falling demand for agricultural workers (3,8%) depresses real wages by around 3,5%*" (Philippidis et al., 2019), including prices increases that oscillate around 5% if the FLW implies an increase in compliance costs (Philippidis et al., 2019). Not all the consequences are negative in terms of sustainability; land usage is expected to decrease in the EU between 4,421 and 9,554 km2 of land, a reduction in emissions that ranges from -1,6% and 3,5% (up to 16 million tonnes), and in a reduction of water abstraction for irrigation (Philippidis et al., 2019).

Another point to consider when aiming for FLW is the "Prevention Paradox". Many initiatives try to deal with food loss once it exists rather than working on its prevention; therefore, more than (the current focus on) waste management, the focus should be to reduce waste before the overproduction of food occurs (Messner et al., 2020).

Finally, research in FLW has also been centered around the accounting methodologies used. Nevertheless, the lack of a standard definition for food loss and waste also leads to different approaches and results that are not comparable over time nor useful for a basis of decision-making (Corrado et al., 2019). Furthermore, Corrado et al. (2019) mention the main challenges for FLW accounting, we can find usage of harmonized terminology, representativeness of primary data and its availability, or statistical uncertainties that can derive from it.

Following on the accounting methodologies topic, while Aulakh et al. (2013) wrote one of the most comprehensive reports on the matter where they established food waste as a subset of total post-harvest food loss, newer studies approach the definitions differently. The Food and Agriculture organization has worked towards harmonizing concepts where food loss and food waste are considered in different stages of the supply chain, meaning food loss occurs before it reaches the retail level while food waste is categorized in the retailers, food services, and consumer levels (FAO, 2019). As these previous examples have shown, proper accounting and data reporting is one of the most prominent challenges organizations face when working towards FLW.

2.2 Digital Agricultural Technologies (DAT)

When trying to solve and prevent FLW, many technologies can provide an edge and help in many ways that years ago were not possible. Research that has been done on these technologies, which have been named Digital Agricultural Technologies (DAT) is recent, however, very useful when trying to understand the current state and future lookouts on food loss waste.

The primary examples of Digital Agriculture Solutions include big data (Sarket et al., 2020; Bronson & Knezevic, 2016), food traceability (blockchain) (Kamilaris et al., 2019; World Economic Forum, 2019), Internet of things, artificial intelligence (Sama et al., 2020), and Information and communication technologies (El Bilali & Allahyari, 2018).

Most of the research on DAT has been focused on efficiency improvements, economic gains, and cost optimization rather than FLW reduction and prevention (Benyam et al., 2021). Other researchers noted the same, stating, "*in most of the reviewed papers food loss minimization is considered as a secondary scope with the main scope of cost decrease or profit increase*" (Paam et al., 2016). This leads to research gaps considering loss prevention and *"insufficient evidence-informed policy measures and/or implications of DAT in contributing toward the SDGs 12 Target 12.3*" (Benyam et al., 2021). Another critical issue when considering the implementation of DAT is the support from public local food policies that do not address the digitalization adequately nor assess the impact and support on small farmers (Rotz et al., 2019). Moreover, to prevent and manage FLW, coordination between the adopter of the technology and other supply chain stages is needed through vertical collaborations (Ciccullo et al., 2021). Another challenge in technology adoption is the cost-effectiveness of the technology implementation so the different stakeholders can have transparent and rapid exchanges of data (Astill et al., 2019), which is crucial for FLW prevention. For a more precise overview of DAT, in appendix 3, a figure with potential contributions of DAT technologies at the different areas and stages of the supply chain can be seen.

3. Objectives

This study aims to understand how AI and Blockchain technologies can be used in the food supply chain to prevent and reduce food waste.

To do so, an analysis of the waste levels will be performed, focusing on EU levels. Furthermore, a look into both technologies will be provided to understand their current uses, the potential of the technologies, and success cases where implementation of AI and Blockchain has proven to help, but also barriers to implementation and drawbacks faced by industry players.

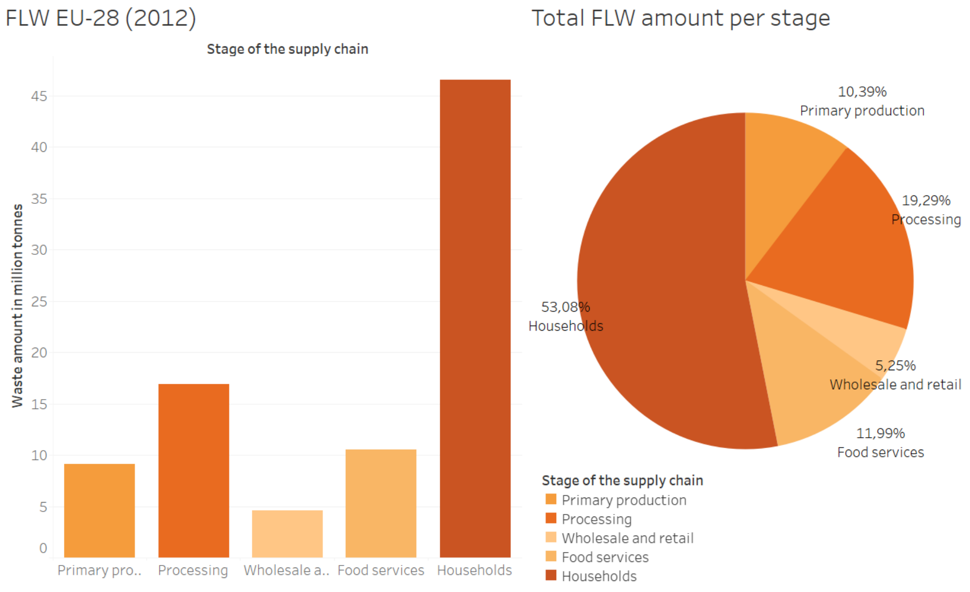
To conclude, a proposal for a business ecosystem that includes both technologies and considers the main challenges, findings, and adoption drivers will be provided.

4. Food waste in the European Union

4.1 Data on Food Loss Waste in the European Union

In the European Union, studies estimate that during 2012, across the EU-28, 88 million tonnes of FLW were generated (FUSIONS, 2016), which equals approximately 173 kg of food waste per person.

The amounts estimated show a moderate degree of uncertainty because of a small number of studies of sufficient quality (FUSIONS, 2016), only 4 member states provided high-quality data. The number of tonnes lost in each stage of the supply chain is 9 million tonnes from the production stage, 17 million tonnes from processing (13 million of confidence interval variance), 5 million from the wholesale and retail level, 11 million from food services, and 47 million from households (4 million of confidence interval variances). Information is presented in the figure below[2].



Economic costs associated with these levels of waste are estimated to be around 143 billion euros, in terms of economic costs household waste accounts for 98 billion euros (FUSIONS, 2016) which is more than 60% of all costs (calculated at the retail value of the food).

When analyzing the data shown beforehand from FUSIONS (2016), it should be noted that "*Data have not been previously compiled in this way with this definition. Comparing with data from other studies is challenging since the boundaries and definitions used are different*" (FUSIONS, 2016, pg. 33). This clearly relates to issues raised when discussing the accounting

[2] Source: Author's own creation based on data from FUSIONS (2016). The figure shows the FLW distribution in the different supply chain stages of EU-28 during 2012.

methodologies, mostly data availability, data uncertainty, or harmonized definitions, and findings from Gustavsson et al. (2011) that showed that in high-income countries FLW tended to happen at the end of the supply chain. The high percentage of household waste could be, however, the result of a high degree of uncertainty that exists in the measurement of other stages where data is harder to get.

4.2 Policymakers' initiatives in the EU

As it has been briefly mentioned during the background review, there are several initiatives coming from governments and supranational organizations looking to solve the FLW challenge. Now a review will be done of the current initiatives that are being taken at the European level, in appendix 4 an overview of waste data and initiatives being undertaken at the state, and regional levels, in this case, Spain and Catalonia is provided.

At the supranational level, the most important initiative that is being carried out is the United Nations 2030 Agenda for Sustainable Development, adopted in 2015 by UN member states, which consists of 17 Sustainable Development Goals (SDGs). The goal that is closely related to FLW prevention and reduction is goal 12.3. This goal aims to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (UN, 2015, pp22). However, there are many other goals that benefit from FLW prevention and reduction and the advantages that DAT can provide to the issue. Among these benefits, we could find improvements in food security, food nutrition, better usage of natural resources, and positive environmental developments. For more information on the SDGs and their relation to FLW refer to appendix 5.

As for a more European Union focused initiative, we can find the European Green Deal, "a set of proposals to make EU's climate, energy, transport, and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030" (European Commission, 2021a). Concerning agriculture, the "Farm to Fork" strategy aims for fair, healthy, and environmentally friendly food systems (European Commission, 2021b). Inside the "Farm to Fork" strategy action plan, point 2.5 is centered around the reduction of food loss waste. In this point, the SDG 12.3 is reinforced, and the EU Commission looks to "use the new methodology for measuring food waste and the data expected from the Member States in 2022" and "set a baseline and propose legally binding targets to reduce food waste across the EU" (European Commission, 2020). Data and methodologies mentioned in the "Farm to Fork" strategy concerning FLW are taken from FUSIONS (2016), which has already been covered when analyzing FLW in the European Union.

5. Technologies and their application to FLW

Having an understandable overview of the status of FLW at both global and EU levels, some of the DAT technologies that have been mentioned when reviewing past literature will be thoroughly analyzed. Specifically, the technologies that this work will consider are Artificial Intelligence, as a method of forecasting, whether it is at a retailer, wholesaler, or producer level, to improve demand planning, and Blockchain, focusing on the traceability possibilities and verification processes that the technology offers.

In each case, the work will provide a brief introduction to the technology to understand its fundamentals, its applications for FLW, and a review of companies that have successfully implemented the technology into the supply chain and are currently looking to solve the FLW challenge.

5.1 Artificial Intelligence

5.1.1 Introduction to AI

While different definitions of AI have been made during the past years, Professor John McCarthy from Stanford University defined Artificial Intelligence as "*The science and engineering of making intelligent machines, especially intelligent computer programs.*" (McCarthy, 2004).

To provide a more concise understanding "*artificial intelligence is a field, which combines computer science and robust datasets, to enable problem-solving*" (IBM Cloud Education, 2020).

There are two types of AI: strong AI and weak AI. Strong AI, also referred to as General AI, is human-like intelligence with self-awareness, however, "*strong AI is still entirely theoretical with no practical examples in use today*" (IBM Cloud Education, 2020). Weak AI, also referred to as Narrow AI, is AI capable of performing specific tasks for which it has been trained. Nowadays, when referring to AI, it is narrow AI that is being discussed.

To understand how AI works, we can simplify it as: An input (data) is given to the AI and, through neural networks or algorithms, an output is produced.

When talking about AI it is important to understand two subsets of Artificial Intelligence, these are Machine Learning and Deep Learning. They differ in how the input information is dealt with and how the algorithms learn. For more detailed information on AI, Machine Learning, and Deep Learning refer to appendix 6.

The most common application of AI that this work will deal with will be predictive behavior for forecasting.

5.1.2 AI applications for FLW

When considering the applications of the technologies a look throughout the supply chain is needed. However, it should be noted that "*Food and loss waste was rarely the principal technology adoption driver*" (Benyam et al., 2021). Therefore, even if "*Spending on AI technologies and solutions alone in Agriculture is predicted to grow from $1 billion in 2020 to $4 billion in 2026*" (Columbus, 2021) most of the spending is geared towards efficiency increases. FLW reduction and prevention are a consequence of efficiency improvements.

Some of the AI applications at the production level include, but are not limited to, real-time monitoring to identify problems, improvements in crop yield prediction through real-time data and visual analytics, price forecasting based on yield rates and total volume produced, optimization of irrigation systems, and monitoring of livestock's health (Columbus, 2021).

Nevertheless, these efficiency improvements arise the issue that the FLW is just moved downstream on the supply chain. Making imperative the collaboration of different actors. The crucial match between supply and demand can be achieved through demand forecasting from following players along the supply chain, however, as Cicculo et al. (2021) noted "*Only in one case the relationship with the supplier is in the form of full integration of information in order to design ad-hoc forecasting application based on artificial intelligence*" (Cicculo et al., 2021, pg. 8).

Moving into the storage and transportation or processing stages of the supply chain, AI can play relevant roles with track-and-trace systems that can "*rely on advanced sensors to gain greater knowledge of each shipment's condition. RFID and IoT sensors are now becoming more commonplace across manufacturing*" (Columbus, 2021).

At the manufacturing and processing stages of the supply chain, only a few opportunities can be found. Traceability during the processing stage is as important as during storage and transportation, furthermore, companies can use real-time data to improve manufacturing processes and avoid losses during them.

Where AI tends to shine is with predictive behavior and forecasting at wholesale and retail levels, where most of the ordering challenges retail faces are related to product availability (short-dated products or product quality and delivery inconsistencies), inventory management, and unpredictability of the ordering process (Shelf Engine, 2021). Wholesale and retail forecasting is essential as they act as a bridge between the processing stage of the supply chain and food services or households. Proper inventory management to optimize selling processes and "best-before-dates" problems are vital to FLW prevention.

It is at the household and food services levels (consumption) where FLW prevention and reduction face its biggest challenge. Food services, for instance, can embrace some sort of forecasting to optimize their costs and efficiencies and food waste management to improve their orders, but at the household (individual) level curated forecasting and process optimization is not a priority.

FLW prevention and reduction at the household or consumer level can be achieved through educational programs, which seem to have a higher impact, to promote awareness on FLW, or through the implementation of additional regulation, however, this last option may appear as a punishment (Zamri et al., 2020).

Not only is household consumption the stage that generates the most waste, but it is also the level where technologies have less impact. Nonetheless, it could be expected that optimization of FLW in all prior stages of the supply chain could lead to less waste at the consumer level, although no research can confirm this statement.

In appendix 7, AI uses and opportunities in the supply chain are shown differentiated by stages in a visual manner.

5.1.3 Artificial Intelligence companies working on FLW

AI and machine learning have been present in our society for a long time, this has led to the development of many different companies that specialize in concrete tasks along the supply chain.

IBM: One of the companies that have managed to leverage technologies and produce applications for supply chain management, among many other offerings, is IBM. This tech giant has a wide offering of products and services that take advantage of AI. One of the most known IBM's products is Watson, "*IBM's portfolio of business-ready tools, applications and solutions*" (IBM, 2019b) which uses range from business operations, security, risk and finance, and supply chain. In that last segment, IBM provides *IBM Sterling Supply Chain Business Network*, which combines AI and Blockchain capabilities to provide businesses with an open platform that gives end-to-end visibility, real-time information, and recommendations for supply chain management (IBM, 2022a).

While IBM Sterling was centered on the overall supply chain management, IBM also provides "Watson Decision Platform for Agriculture" as part of The Weather Company (which they acquired in 2016), centered on providing AI insights for agriculture ecosystems. Providing farmers with accurate weather data, soil data, equipment data, farm practices and workflow data, and high-definition visual imagery (The Weather Company, 2019).

Gamaya: Gamaya takes advantage of artificial intelligence and remote sensing technologies to improve crop production efficiency for large farming businesses. This allows producers to optimize costs and minimize environmental impact, detect diseases to reduce potential crop losses, and have a better prediction of yields (Gamaya, 2022).

Tupl Agro: Tupl Agro is a Spanish company centered on using AI to track and control crops. Its product Agro Advisor supports farmers' decision-making in agricultural activities. Their software works with olive groves, citrus, vineyards, cereals, vegetables, and subtropical crops (Tupl Agro, 2022).

Seebo: This Israel-based firm offers food manufacturers an AI solution to prevent and predict losses in their production processes. The technology provides root cause analysis to understand where in the manufacturing processes losses occur so companies can optimize the processes and prevent future losses, this is achieved by using processes modeling with different sources of data from the manufacturers and retrieves recommendations and alerts for production teams (Seebo, 2022).

Shelf Engine: Moving down the supply chain, Shelf Engine offers retailers intelligent forecasting that uses ML and predictive models to generate accurate orders. Using the store's historical data, daily sales data, and data from external sources to provide ideal order forecasting, automated ordering, and stockout minimization. They are also integrated with suppliers and distributors to enhance the quality of data and predictions (Shelf Engine, 2022).

Wasteless: Wasteless uses AI-powered dynamic pricing to help supermarkets and online groceries avoid food waste. Their pricing engine learns from consumer response to dynamic pricing and finds the optimal discounting policy. This allows retailers to achieve higher revenues as food waste is avoided (Wasteless, 2022).

Relex: Relex offers a living retail platform that uses an AI-driven inventory management system for demand planning, business operations, supply chain, and merchandise. Their technology helps avoid markdowns and spoilage for retailers. Claiming a 30% reduction in inventory and 40% waste reduction thanks to their process's optimization (Relex, 2022).

Winnow: Winnow provides food services kitchens with a food waste management system (Winnow App) and an AI waste tracking analytics platform (Winnow Hub). These analytics offer businesses with actionable insights, in-kitchen reporting, and planning (Winnow, 2022).

Other food waste tracking solutions: Companies offering similar value propositions as Winnow's AI for food waste management and tracking for food services include **Phood** (Phood Solutions, 2022), **Lumitics** (Lumitics, 2022), **Orbisk** (Orbisk, 2022).

TotalCtrl: TotalCtrl has developed digital kitchen inventory management software for restaurants, hotels, and households. For businesses, TotalCtrl provides real-time inventory analytics, routine automation, and reporting. For consumers, it also provides inventory tracking, but in addition, gives households recipes using the soon expiring food and available ingredients (TotalCtrl, 2022).

It should be useful to remark that the firms previously mentioned are only a few of the many that operate in the ecosystem but are representative enough to demonstrate in which areas of the supply chain there is more concentration, and in which scopes they are centered. For a clearer view of how these companies are distributed along the supply chain, in appendix 8 they have been laid out in a table.

5.2 Blockchain

5.2.1 Introduction to Blockchain

Many eyebrows are raised when the topic of Blockchain is mentioned as it is some sort of black magic that only tech-savvy people can understand. Reality is simpler, as long as we focus on how it works and its advantages, rather than on the technology behind it.

Blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way (Iansiti & Lakhani, 2018). Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network (IBM, 2021).

What can be taken clear from these two descriptions of blockchain is the fact that it allows recording transactions which are open, meaning that the transactions can be verified by the participants of the network, and cannot be modified once the transactions have been approved. These transactions are recorded in the form of “blocks” of data which are added to the existent chain of blocks, forming the ledger, providing order due to the time and sequence of the transactions, and blocking them.

One of the most important characteristics of the blockchain is the fact that this ledger is decentralized (distributed among all participants), meaning that the information is not controlled by a single party and there is no need for intermediaries. All parties can verify the transactions directly.

The technology is already used for verifying and tracking items along complex supply chains, providing trust and security to the participants of the network, who know that the records are real and will not be modified.

5.2.2 Blockchain applications for FLW: The case of traceability

Distinctively from AI, which can have specific uses in different stages of the supply chain, Blockchain utility occurs all along the food supply chain.

The traceability capabilities of blockchain can be helpful in the food supply chain in the following ways: enhancement of food safety, validation and verifiability of product sources, meeting consumer demand for food production transparency, and optimization and food-loss reduction (World Economic Forum, 2019).

Traceability in the food supply chain allows for tracking the food from harvest to retailers or food services. Creating a single historical record of all the steps involved with the product; its production or harvesting, for how long has it been stored or how many days it took to transport, if it has been processed (and which other products have been used during the processing service), and when and in which status did it reach the wholesaler or retailer. This transparency at all stages of the supply chain can decrease the FLW occurring during supply chain operations, but also can reduce food waste after purchase (Astill et al., 2019).

As information is made available and the technology allows for more efficient and faster supply chains, the time before products expire is greater. Furthermore, smart contracts allow for automated processes and interactions between partners, increasing supply chain speed even further. An example of a hypothetical smart contract from "The rise of blockchain technology in agriculture and food supply chains" (Kamilaris et al., 2019) can be found in appendix 9.

Another benefit of using blockchain as a traceability technology that indirectly impacts FLW appears when dealing with food safety issues. *"Traceability could reduce the exposure to food outbreak risks by making it faster, more efficient and more feasible to identify a source of food contamination precisely"* (World Economic Forum, 2019, pg. 15). If food contamination can be precisely tracked and discarded, food in proper conditions for consumption is not discarded, as it would have happened if accurate traceability mechanisms were not in place. An example of traceability when dealing with food contaminations outbreaks from "Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations" (World Economic Forum, 2019) is shown in appendix 10.

In addition, appendix 11 shows a table extracted from "Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations" (World Economic Forum, 2019), where the authors listed a set of potential benefits, challenges, and enabling priorities regarding the implementation of the technologies into the food supply chain.

5.2.3 Blockchain companies working on FLW

Companies that want to implement Blockchain traceability to their supply chain can use different technologies or protocols (they do not need to build the ledger themselves). These include, but are not limited to, Ethereum, Hyperledger Fabric, Hyperledger Sawtooth, BigchainDB, or blockchain solutions that are developed in-home by the companies (Kamilaris et al., 2019). In appendix 12 a description of how blockchain protocols work, as well as the different types of blockchain that exist, will be explained. Some of the companies that leveraged blockchain technology to offer traceability solutions to food supply chain actors are among the following.

IBM: One of the most robust offerings concerning the space comes in the form of IBM's Food Trust. IBM Food Trust covers all stages of the food supply chain and grants efficiency, food safety, food freshness, and helps avoid food fraud and food waste while ensuring sustainability (IBM, 2019a). Some of IBM Food Trust's clients include worldwide known brands such as Walmart (Miller, 2018), Nestlé (Pollock, 2020), and Carrefour (Carrefour, 2018).

Ripe.io: Combines blockchain technology along with IoT and machine learning to provide real-time data to the network uses while and predictive consumer analytics. Partners can track and trace food data from their mobile app and access the verifiable data stored in the cloud whenever they need it (Ripe, 2022).

Vottun: This Spanish firm is one of the leaders in enterprise blockchain solutions. Providing services such as payments, procurements, credentials, certificates, health, sustainability, and tracing. Its tracing services are focused on food and precious materials (Vottun, 2022).

Other blockchain traceability providers: As there has been an incredible surge in the use of blockchain technology in recent years, many companies have sought to develop their own ledger solutions. Along with the companies previously mentioned, we can also find the Brazilian **Amachains**, a company that focuses on Family Farming and gives a huge emphasis on sustainability compliance (Amachains, 2018), **PeerLedger** which focuses its traceability efforts on food, apparel, metals & minerals, and cosmetics industries (PeerLedger, 2022), **CrystalChain**, with a focus on food & beverages, and luxury & fashion (CrystalChain, 2022), **Wholechain** using traceability to coordinate traditionally fragmented food supply chains (Wholechain, 2022), **Mojix**, which blockchain traceability solution aims to digitize and automate supply chains (MOJIX, 2022), **TagOne**, centered around minimizing legal and regulatory risks from "seed-to-sale" (TagOne, 2022), and companies that center its efforts in providing food safety and transparency to end consumers such as **Greenfence** (Greenfence, 2022), **Transparent Path**, centered around perishables such as seafood, meat, and fruits (Transparent Path, 2022), or the Spanish **FoodXain** (FoodXain, 2022).

6. Implementation of the technologies

6.1 Considerations about technology implementation

Certain considerations should be noted before moving into a possible implementation of the technologies. There are many players involved in the food industry and all along its supply chain, from small farmers to corporations, whether these are producers or retailers. These disparities in size between players create huge discrepancies when considering negotiation power, capital resources, data availability, or technological knowledge of the players.

As Benyam et al. (2021) noted, there is no one-size-fits-all solution that would be able to solve FLW with the usage of technology, and most of the time, different digital agriculture technologies can aim to improve different stages of the supply chain with spillover effects on FLW prevention.

Take for instance the need for reliable data for forecasting, access to large datasets to drive decision-making is crucial, however, small actors in the supply chain may not have the necessary resources to access the data or implement the needed technologies to acquire it. Furthermore, "*most of the companies in the agri-food supply chain rely on the technology providers for technical assistance to support the elaboration and interpretation of data*" (Ciccullo et al., 2021, pg. 8).

Ensuring that all parties that participate in the supply chain can have access to reliable data (and the technological means to interpret it) and can fully cooperate with other actors in the form of integration of information flows is indispensable when looking to take advantage of DAT to prevent FLW. If this issue is not solved properly, it could lead to marginalizing small farmers while providing an unfair advantage to agri-food corporations with the available means to implement the solutions (Rotz et al., 2019).

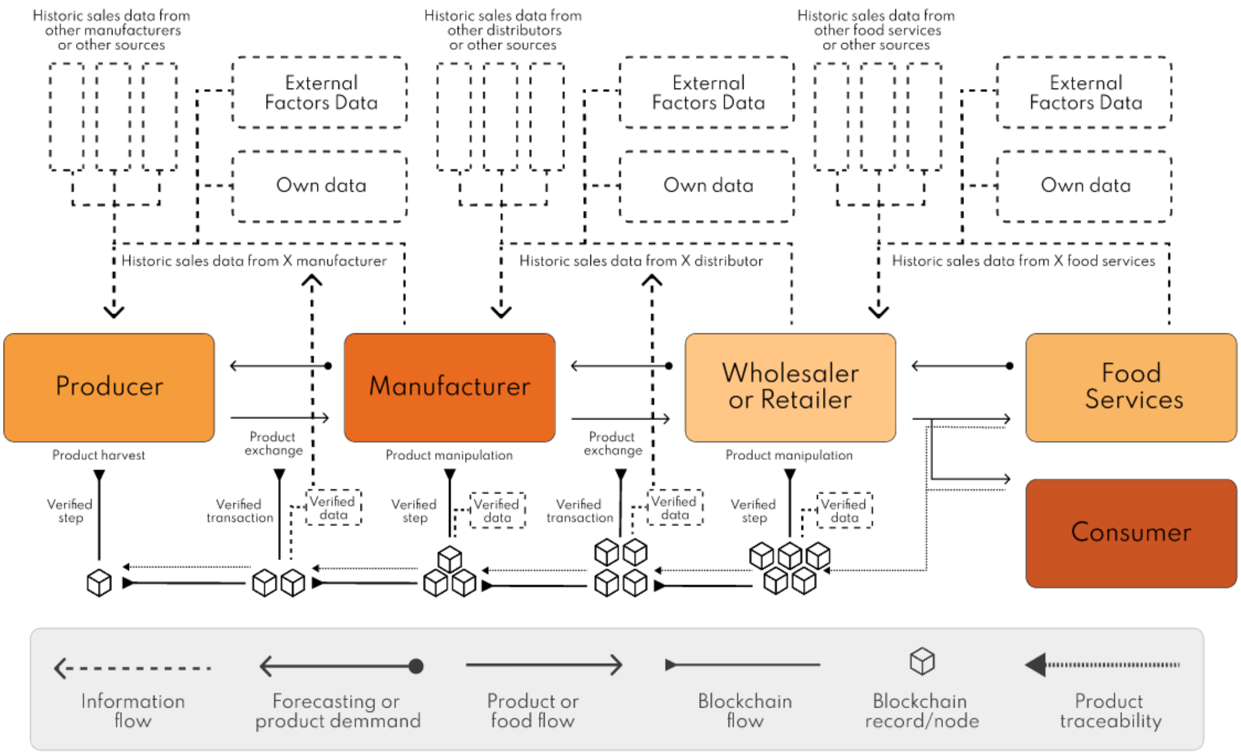
Summing up some of the most important challenges that need to be addressed are the upfront capital investments needed to implement the technology, unclear data governance and ownership, expensive requirements (both in terms of resources and knowledge of the technologies), and the fact that some actors may be reluctant to provide their data (which may serve as a competitive advantage) upstream or downstream in the supply chain to their suppliers or distributors (World Economic Forum, 2019).

If a solution is wanted to be implemented in the space, it should provide small players with the technological means and data to make proper use of it, be a "low-cost" solution to avoid the intensive capital investments, provide incentives to all players along the supply chain (mostly corporations) in order to cooperate and allow for integration of the information, and to be easily accessible and understandable for all different actors or stakeholders that take part in it.

6.2 Building a business ecosystem around AI and Blockchain technologies

Building an ecosystem based on forecasting (demand planning) and traceability of all the products in the food supply chain, which at the same time links the different players' operations, is complex. There are many nodes along the supply chain, and even if the technologies are needed to be consistent throughout the supply chain, the implementation should start with one of the nodes and later expand to others. When analyzing which players are the most optimal in terms of being the first to adopt the technology, starting the implementation with major food manufacturer corporations who are more likely to adopt the technologies seems the most feasible option since they (1) have the capital resources to implement it, (2) have large amounts of data available, (3) serve as a nexus between farmers and distributors, so it is easier to move the technology upward and downward the supply chain, and (4) they tend to be more technology-driven (in the case of agri-food corporations) and it is more plausible for them to be early adopters of the technology.

The figure below[3] depicts a simplified version of the food supply chain showing how the different players could interact using the technologies. Analyzing the figure from a food manufacturer's point of view, data coming from the own firm, external factors, and historic sales to distributors can be used to accurately predict future demand from distributors and produce forecasts to purchase to the farmers/producers. Data is stored in the blockchain (it can be verified) and can be traced back to the different farmers from which they have purchased.



[3] Source: Author's own creation.

Due to the complexity of the supply chain, the implementation of a single technology solution able to combine AI (for forecasting) and blockchain (for traceability) is not viable. A farmer can sell to different manufacturers or distributors. If they used different solutions, the farmer (the step of the supply chain which is the most fragmented, with less negotiating power, and with fewer capital resources) would be obliged to operate with the different technologies, incurring in cost duplicities and more complex operations. A one-size-fits-all solution is, therefore, discarded as an effective solution, as it does not appear to be a low-cost solution that players such as farmers can adopt, opening the door to interoperability systems, and the appearance of integrators that would connect the systems (as some sort of technical partner for the players).

In terms of AI and its applications, as has been seen previously in point 5.2.3, there are many companies offering specialized services. Examples ranged from applications tailored to wholesalers and retailers, such as intelligent forecasting, inventory management, or dynamic pricing, to manufacturers with optimization of the production processes to avoid losses, and to farmers to enhance efficiency and optimize production. These solutions, adjusted to certain steps and uses, bring a superior experience that can be much more useful to players in the supply chain than an overall single AI application that manages the supply chain end-to-end.

When it comes to blockchain technology it is more feasible to implement the technology all along the supply chain, or at least from farmer to retailer (and making, later, traceability information available to consumers using QR codes). With the possibility of a single technological application that combines both AI and blockchain discarded, when aiming to provide the technology without it being a hurdle to the different players, a reasonable approach could be the implementation of a blockchain ledger that relied mostly on the manufacturer side and worked with the other partners automatically on the backend.

In this case, the manufacturer would be the lead player in the implementation and the partners would participate via a series of automation processes. This would solve the problem of the farmers producing for several manufacturers, as only when they would ship to the manufacturer with the ledger, the records would be recorded in it. This would require technical partners and setup help for the farmers but could be expected to have low maintenance requirements afterward implementation (more in appendix 13). The ledger would be, consequently, a permission ledger, which could only be accessed by companies belonging to the supply chain (up to the manufacturer, who is the lead, to authorize) and could be built on top of an open-source protocol like Hyperledger Fabric. Using Hyperledger Fabric could solve the data challenge as enterprises could choose when and which partners can access it, more information on Hyperledger Fabric is provided in appendix 12.

It would be interesting if the data stored in the blockchain could be sent to the different AI solutions providers to enhance forecasting activities, as that data is verifiable and non-modifiable. This could be achieved with service integrations with other technology providers and could open the door to partnerships to foster the implementation of blockchain technology in companies that so far only used AI solutions.

The overall idea behind the blockchain structure is that it should be as simple as possible to promote its adoption, and should be working mostly through automation, so those less tech-savvy companies should not face the difficulties of operating it. Furthermore, it could be entrancing that all the data and information could be accessed through already existing management tools using an API integration, so the companies do not face the need of operating several dashboards with various sources of information.

The issue of granting overall information access to all players to improve the information flow is still unsolved. Giving incentives to large corporations to provide anonymized data as a form of boosting forecasts and predictions could be a starting point, although which incentives should be used are unclear and further research is needed to make a proper assessment of the challenge.

7. Conclusion

After analyzing waste data and understanding the ecosystem (food supply chain), the following quote from the FAO's "The State of Food and Agriculture" study seems to summarize the findings pretty well: *"While the reduction of food loss and waste appears as a clear and desirable objective, actual implementation is not simple and its complete elimination may not be realistic"* (FAO, 2019).

The complexity of the supply chain and interactions of its many, and in some cases fragmented, actors, make technology implementation in the food space hard, and a one-size-fits-all solution aiming to prevent and avoid FLW cannot be possibly conceived. Truth is there are many distinct solutions that aim to help specific segments of the supply chain, most of which are focused on improving efficiency and optimizing operations (not focusing on FLW), however, these technologies end up having spillover effects in different stages of the supply chain and improving FLW reduction and prevention.

Furthermore, data showed that, at least in the European Union, most food waste was produced at the consumer level, initiatives in this space are not included in the scope of the work, but would cover educational efforts, smart appliances, and other newer technologies. And, while one could argue that the technological solutions discussed in this work are not able to solve the consumer waste, nevertheless, improvements in efficiency such as faster supply chains due to the use of blockchain can lead to longer "best-before dates", reducing waste as it would take longer for food to expire, one of the spillover effects previously mentioned.

The use and opportunities of technology to face the food loss and waste challenge are clear, even so, as it has been seen when analyzing the business ecosystem, it is only achievable if companies start cooperating and coordinating their actions, meaning they should help each other with information integration and worrying less about their own gains inside the supply chain but in the overall supply chain success. Heavy digitalization of small farmers is needed to avoid their marginalization in an increasingly digitalized supply chain, and governments could make themselves useful by pioneering initiatives to support small farmers' digitalization initiatives, to see some examples of digitalized farms refer to appendix 14.

Some of the technological solutions of the food supply chain are fairly new and it is unclear if they will be successful and achieve their expected objectives. Only time will tell if we can live in a world where optimization of the food supply chain has reached a level where FLW is nonexistent. However, the development of the technologies is looking promising.

8. References

Action Against Hunger. (2018, October). World Hunger: Key Facts and Statistics. Action against Hunger. https://www.actionagainsthunger.org/world-hunger-facts-statistics

Amachains. (2018, March 10). Amachains - Amazônia Blockchain Solutions. https://amachains.com/en/

Astill, J., Dara, R. A., Campbell, M., Farber, J. M., Fraser, E. D. G., Sharif, S., & Yada, R. Y. (2019). Transparency in food supply chains: A review of enabling technology solutions. Trends in Food Science & Technology, 91, 240–247. https://doi.org/10.1016/j.tifs.2019.07.024

Aulakh, J.K., & Regmi, A. (2013). POST-HARVEST FOOD LOSSES ESTIMATION-DEVELOPMENT OF CONSISTENT METHODOLOGY

Benyam, A., Soma, T., & Fraser, E. (2021). Digital agricultural technologies for food loss and waste prevention and reduction: Global trends, adoption opportunities and barriers. Journal of Cleaner Production, 323(129099). https://doi.org/10.1016/j.jclepro.2021.129099

Bosona, T., & Gebresenbet, G. (2013). Food traceability as an integral part of logistics management in food and agricultural supply chain. Food Control, 33(1), 32–48. https://doi.org/10.1016/j.foodcont.2013.02.004

Bronson, K., & Knezevic, I. (2016). Big Data in food and agriculture. Big Data & Society, 3(1), 205395171664817. https://doi.org/10.1177/2053951716648174

Carrefour. (2018, November 20). CARREFOUR LANZA EL PRIMER BLOCKCHAIN ALIMENTARIO EN ESPAÑA - Detalle Nota de Prensa - Carrefour España. Www.carrefour.es. https://www.carrefour.es/grupo-carrefour/sala-de-prensa/noticias2015.aspx?tcm=tcm:5-50248

Ciccullo, F., Cagliano, R., Bartezzaghi, G., & Perego, A. (2021). Implementing the circular economy paradigm in the agri-food supply chain: The role of food waste prevention technologies. Resources, Conservation and Recycling, 164, 105114. https://doi.org/10.1016/j.resconrec.2020.105114

Columbus, L. (2021, February 17). 10 Ways AI Has The Potential To Improve Agriculture In 2021. Forbes. https://www.forbes.com/sites/louiscolumbus/2021/02/17/10-ways-ai-has-the-potential-to-improve-agriculture-in-2021/?sh=2a7c56307f3b

Corrado, S., Caldeira, C., Eriksson, M., Hanssen, O. J., Hauser, H.-E., van Holsteijn, F., Liu, G., Östergren, K., Parry, A., Secondi, L., Stenmarck, Å., & Sala, S. (2019). Food waste accounting methodologies: Challenges, opportunities, and further advancements. Global Food Security, 20, 93–100. https://doi.org/10.1016/j.gfs.2019.01.002

CrystalChain. (2022). Food & beverages. Crystalchain. https://crystalchain.io/en/food-beverages/

El Bilali, H., & Allahyari, M. S. (2018). Transition towards sustainability in agriculture and food systems: Role of information and communication technologies. Information Processing in Agriculture, 5(4), 456–464. https://doi.org/10.1016/j.inpa.2018.06.006

Eric Holt-Giménez, Annie Shattuck, Miguel Altieri, Hans Herren & Steve Gliessman (2012) We Already Grow Enough Food for 10 Billion People … and Still Can't End Hunger, Journal of Sustainable Agriculture, 36:6, 595-598, DOI: 10.1080/10440046.2012.695331

European Commission. (2020). Farm to Fork strategy: For a fair, healthy and environmentally-friendly food system. https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf

European Commission. (2021a). A European Green Deal. European Commission. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Commission. (2021b). Farm to Fork Strategy. Ec.europa.eu. https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en

European Commission. (2021c). Latest data on food waste in Spanish households. Ec.europa.eu. https://ec.europa.eu/newsroom/sante/items/716383/en

FAO. (2011). Global food losses and food waste - Extent, causes and prevention.

FAO. (2015). e-agriculture 10 year Review Report: Implementation of the World Summit on the Information Society (WSIS). https://www.fao.org/3/I4605E/i4605e.pdf

FAO. (2017). The future of food and agriculture: Trends and challenges. https://www.fao.org/3/I6583e/I6583e.pdf

FAO. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. https://www.fao.org/3/ca6030en/ca6030en.pdf

FAO, IFAD, UNICEF, WFP and WHO. 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. https://doi.org/10.4060/ca9692en

FAO. (n.d.). Food Balances. FAOSTAT. Retrieved April 4, 2022, from https://www.fao.org/faostat/en/#data/FBSH/visualize

FoodXain. (2022). Food Xain: Blockchain Techonology. https://foodxain.com/

Gamaya. (2022). Precision Ag: technologies for smart farming | Gamaya. Www.gamaya.com. https://www.gamaya.com/

Greenfence. (2022). Greenfence. Greenfence -. https://origin.greenfence.com/

Gustavsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). The methodology of the FAO study: Global Food Losses and Food Waste - extent, causes and prevention"- FAO, 2011.

Gustavsson, J., Sonesson, U., & Cederberg, C. (2011). Global Food Losses and Food Waste. https://www.researchgate.net/publication/267919405_Global_Food_Losses_and_Food_Waste

High Level Panel Experts on Food Security and Nutrition. (2014). Food losses and waste in the context of sustainable foods. FAO. http://www.fao.org/3/a-i3901e.pdf

Iansiti, M., & Lakhani, K. (2018, March 6). The Truth About Blockchain. Harvard Business Review. https://hbr.org/2017/01/the-truth-about-blockchain

IBM. (2019a). IBM Food Trust. Ibm.com. https://www.ibm.com/blockchain/solutions/food-trust

IBM. (2019b). IBM Watson. Ibm.com. https://www.ibm.com/watson

IBM. (2021). What is Blockchain Technology? Www.ibm.com. https://www.ibm.com/topics/what-is-blockchain

IBM. (2022a). IBM Sterling | Build Smarter Business Networks. Www.ibm.com. https://www.ibm.com/supply-chain/sterling

IBM. (2022b). What are smart contracts on blockchain? Www.ibm.com. https://www.ibm.com/topics/smart-contracts

IBM Cloud Education. (2020, June 3). What is artificial intelligence (AI)? IBM. https://www.ibm.com/cloud/learn/what-is-artificial-intelligence

Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. Trends in Food Science & Technology, 91, 640–652. https://doi.org/10.1016/j.tifs.2019.07.034

La Moncloa. (2021, October 11). The Government of Spain pushes through first law to combat food waste. Www.lamoncloa.gob.es. https://www.lamoncloa.gob.es/lang/en/gobierno/councilministers/Paginas/2021/20211011_council.aspx

Lipinski, B. et al. (2013). Reducing Food Loss and Waste. World Resources Institute. http://pdf.wri.org/reducing_food_loss_and_waste.pdfWorking Paper, Installment 2 of Creating a Sustainable Food Future

Lumitics. (2022). Food Waste Solution | Food Waste Management. Lumitics. https://lumitics.com/

McCarthy, J. (2004). What is Artificial Intelligence? Stanford University: Computer Science Department.

Messner, R., Richards, C. & Johnson, H. (2020). The "Prevention Paradox": food waste prevention and the quandary of systemic surplus production. Agric Hum Values 37, 805–817. https://doi.org/10.1007/s10460-019-10014-7

Miller, R. (2018, September 24). Walmart is betting on the blockchain to improve food safety. TechCrunch; TechCrunch. https://techcrunch.com/2018/09/24/walmart-is-betting-on-the-blockchain-to-improve-food-safety/

MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE (MAGRAMA). (2014). Las pérdidas y el desperdicio de alimentos generado por la producción primaria de alimentos en España. https://menosdesperdicio.es/sites/default/files/documentos/relacionados/resumen_perdidas_desperdicio_agricolas_2014.pdf

Ministry of Agriculture, Fisheries, and Food (MAPA). (2018). More Food, Less Waste Strategy (2017 – 2020).

MOJIX. (2022). Mojix: A new wave of digital transformation. Mojix. https://www.mojix.com/

Monier, V., Mudgal, S., Escalon, V., O'Connor, C., Gibon, T., Anderson, G., Montoux, H.,Reisinger, H., Dolley, P., Ogilvie, S., Morton, G., (2010). Preparatory

Study on FoodWaste across EU 27. https://doi.org/10.2779/85947.

Orbisk. (2022). Orbisk - Automatically reduce food waste in your kitchen. Orbisk.com. https://www.orbisk.com/en

Paam, P., Berretta, R., Heydar, M., Middleton, R. H., García-Flores, R., & Juliano, P. (2016). Planning Models to Optimize the Agri-Fresh Food Supply Chain for Loss Minimization: A Review. Reference Module in Food Science. https://doi.org/10.1016/b978-0-08-100596-5.21069-x

PeerLedger. (2022). Food. Peer Ledger - the Responsible Supply Chain Company. https://www.peerledger.com/food

Philippidis, G., Ferrer Pérez, H., Gracia de Rentería, P., M'barek, R., & Sanjuán López, A. I. (2021). Eating your greens: a global sustainability assessment. Resources, Conservation and Recycling, 168(105460). https://doi.org/10.1016/j.resconrec.2021.105460

Philippidis, G., Sartori, M., Ferrari, E., & M'Barek, R. (2019). Waste not, want not: A bio-economic impact assessment of household food waste reductions in the EU. Resources, Conservation and Recycling, 146, 514–522. https://doi.org/10.1016/j.resconrec.2019.04.016

Phood Solutions. (2022). Phood | Food Waste Ends Here. Phood. https://www.phoodsolutions.com/

Plenary Assembly of Parliament. (2020). Law 3/2020, of 11 March, on Food Loss and Wastage Prevention. https://www.parlament.cat/document/intrade/65773897

Pollock, D. (2020, April 15). Nestlé Expands Use Of IBM Food Trust Blockchain To Its Zoégas Coffee Brand. Forbes. https://www.forbes.com/sites/darrynpollock/2020/04/15/nestl-expands-use-of-ibm-food-trust-blockchain-to-its-zogas-coffee-brand

Relex. (2022). RELEX Solutions: Optimizing Retail for Every Future. RELEX Solutions. https://www.relexsolutions.com/

Ripe. (2022). Ripe.io: Blockchain of food. Ripe.io. https://www.ripe.io/about

Rotz, S., Duncan, E., Small, M., Botschner, J., Dara, R., Mosby, I., Reed, M., & Fraser, E. D. G. (2019). The Politics of Digital Agricultural Technologies: A Preliminary Review. Sociologia Ruralis, 59(2), 203–229. https://doi.org/10.1111/soru.12233

Sama, L., Makkar, A., Prokshitha, P., Sharma, B., & Dhaloria, D. (2020). AI based management of Food Wastage. http://ceur-ws.org/Vol-2786/Paper56.pdf

Sarker, Md & Murmu, Hilarius & Rozario, Elizabeth. (2020). Role of Big Data On Digital Farming. International Journal of Scientific & Technology Research. 9. 1-11.

Seebo. (2022, March 13). The Predictive Quality and Yield Solution, powered by process-based Artificial Intelligence. Seebo. https://www.seebo.com/

Shelf Engine. (2021). What's your biggest ordering challenge? In Shelf Engine. https://www.shelfengine.com/resources/ordering-challenges-infographic/

Shelf Engine. (2022). Solutions. Shelf Engine. https://www.shelfengine.com/solutions/

Spanish Agency for Consumer Affairs, Food Safety and Nutrition (AESAN). (2017, December 18). New horizon for the Strategy "More food, less waste." Www.aesan.gob.es. https://www.aesan.gob.es/en/AECOSAN/web/noticias_y_actualizaciones/noticias/2017/nuevo_horizonte.htm

Stenmarck, Åsa & Jensen, Carl & Quested, Tom & Moates, Graham. (2016). FUSIONS. Estimates of European food waste levels. 10.13140/RG.2.1.4658.4721.

TagOne. (2022). Supply Chain Tech Traceability | TagOne | CBD | Natural Products| Princeton. TagOne: Traceability. https://www.tagone.com/

The Weather Company. (2019). Watson Decision Platform for Agriculture. In ibm.com. https://www.ibm.com/downloads/cas/ONVXEB2A

TotalCtrl. (2022). Inventory Management Software | Inventory Count | Food Inventory. TotalCtrl. https://totalctrl.com/

Transparent Path. (2022). Transparent Path. https://xparent.io/

Tupl Agro. (2022). Tupl Agro - Digital Agriculture. Tuplagro.com. https://www.tuplagro.com/en/

UN, 2015. United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development; Resolution, Adopted by the General Assembly on 25 September 2015.New York. https://www.unfpa.org/sites/default/files/resource-pdf/Resolution_A_RES_70_1_EN.pdf

United Nations Environment Programme. (2021). Food Waste Index Report 2021. https://www.unep.org/resources/report/unep-food-waste-index-report-2021

Vottun. (2022). VOTTUNTrace. Vottun. https://vottun.com/solutions/vottuntrace/

Wasteless. (2022). Wasteless. https://www.wasteless.com/

Wholechain. (2022). Wholechain® — Blockchain Based Supply Chain Traceability. Wholechain®. https://wholechain.com/

Winnow. (2022). Food Waste Tracking Analytics | Winnow. Www.winnowsolutions.com. https://www.winnowsolutions.com/product/food-waste-tracking-system

World Economic Forum. (2019). Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations. In Weforum. https://www3.weforum.org/docs/WEF_Traceability_in_food_value_chains_Digital.pdf

Zamri, G. B., Azizal, N. K. A., Nakamura, S., Okada, K., Nordin, N. H., Othman, N., MD Akhir, F. N., Sobian, A., Kaida, N., & Hara, H. (2020). Delivery, impact and approach of household food waste reduction campaigns. Journal of Cleaner Production, 246, 118969. https://doi.org/10.1016/j.jclepro.2019.118969

9. Appendixes

Appendix 1: Potential direct causes and indirect drivers of FLW

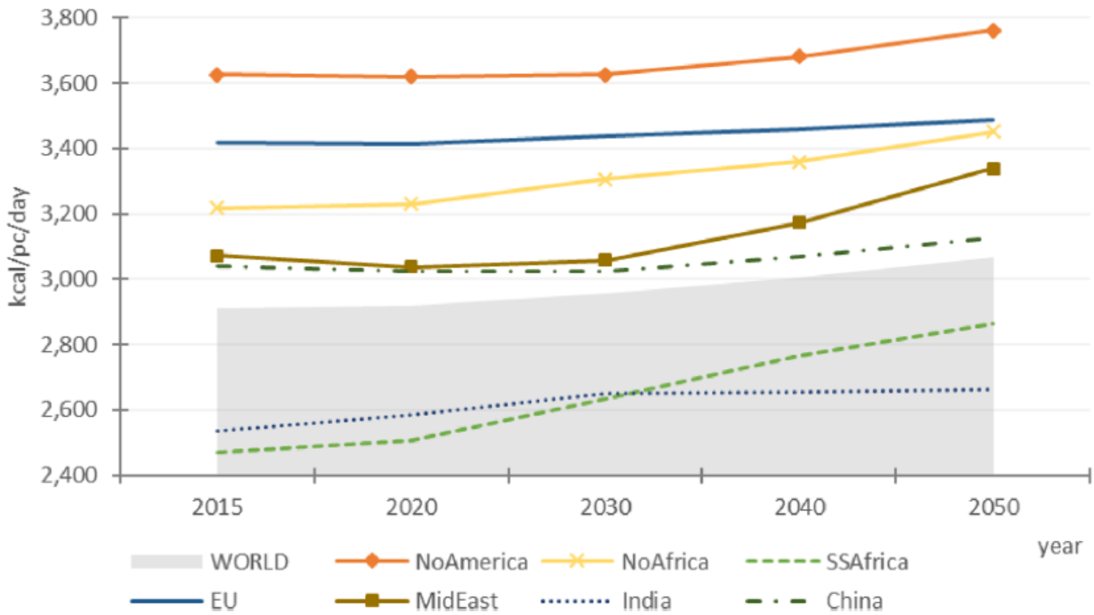
In this figure, we can analyze the direct and indirect causes of Food Loss Waste in the different stages of the food supply chain. To summarize, in the harvesting stage most causes are related to crop production quality. In the transport and storage stage, the main issues relate to product management and its possible spoilage. When working in processing, most issues regard the business operations. At the wholesale or retail, improper demand forecast (overstocking and varying demand for perishables) is the main challenge to overcome FLW. Finally, at the consumption stage expiration of perishable foods is what causes most FLW.

AGRICULTURAL PRODUCTION AND HARVEST, SLAUGHTER OR CATCH	STORAGE AND TRANSPORTATION	PROCESSING AND PACKAGING	WHOLESALE AND RETAIL	CONSUMPTION: HOUSEHOLDS AND FOOD SERVICES
INDIRECT DRIVERS (not exhaustive)				
Left in the field due to quality standards or sharp drop in prices	Lack of proper storage or transportation facilities (e.g. refrigerated trucks)	Inadequate processing capacity for seasonal production gluts	Variability of demand for perishable products	Multitude of date labels
DIRECT CAUSES (not exhaustive)				
Production and agronomic practices and choices (e.g. choice of crop varieties)	Poor management of temperature and humidity	Technical malfunctions (wrong size or damaged packaging)	Inappropriate product display and packaging	Confusion between expiration and preferred consumption date labels
Machine or labourer damage	Prolonged storage (e.g. due to lack of transportation)	Lack of proper process management	Removal of "imperfect"-looking foods	Poor storage or stock management in the home
Poor harvest scheduling	Logistical mismanagement (poor handling of delicate produce)	Excessive trimming to attain a certain aesthetic	Overstocking	Oversized portions

Source: FAO. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. Pg. 16. https://www.fao.org/3/ca6030en/ca6030en.pdf. Elaborated on data from Lipinski, B. et al. (2013)

Appendix 2: Daily per capita kilocalories trends

This figure shows the increasing need for food production output as per capita daily kilocalories trends are expected to keep increasing. The increasing trends in calorie consumption are expected to affect mostly South Saharan Africa, the Middle East, and northern Africa.



Source: Philippidis, G., Ferrer Pérez, H., Gracia de Rentería, P., M'barek, R., & Sanjuán López, A. I. (2021). Eating your greens: a global sustainability assessment. Resources, Conservation and Recycling, 168(105460). https://doi.org/10.1016/j.resconrec.2021.105460

Appendix 3: Potential contributions offered by DATs to FLW prevention and reduction

In this figure, we can see an overview of Digital Agriculture Technologies focused on Food Loss Waste, the authors of the paper (Benyam et al., 2021) group DAT into five different technology groups. Precision agriculture, cold chain, Information and Communication Technologies, remote sensing, and Blockchain.

In the inner circle of the figure, the technology is named, followed by its potential use, and the stage of the supply chain where it can be applied (outer circle). In this analysis, Artificial Intelligence is not mentioned as an independent technology but is inferred in technological uses for remote sensing or on the cold chain.

Source: Benyam, A., Soma, T., & Fraser, E. (2021). Digital agricultural technologies for food loss and waste prevention and reduction: Global trends, adoption opportunities and barriers. Journal of Cleaner Production, 323(129099). https://doi.org/10.1016/j.jclepro.2021.129099

Appendix 4: Spanish and Catalan initiatives for FLW

At the Spanish level, FLW is estimated to be around 26,06% of the agricultural production in the country (MAGRAMA, 2014). At the household level, estimates show an average of 31kg per capita of food waste, which implies a waste rate of 4,3% of the food that is being purchased by households (European Commission, 2021c). Moreover, "Spain is the seventh Member State which wastes most food in absolute figures at 7.7 million tonnes per year, equivalent to a cost of 3000 million Euros per annum" (AESAN, 2017)

To tackle the issue and accomplish the objectives of SDGs set by the UN, the Ministry of Agriculture, Fisheries, and Food (MAPA[4]) launched the "More Food, Less Waste" program in 2013, which is periodically revised and updated. The program aims to improve the following objectives: generation of knowledge, training and awareness, fostering of best practices, collaboration with stakeholders, sector-specific agreements, regulatory aspects, research and innovation (MAPA, 2018).

Furthermore, the Spanish government presented in October 2021 the Draft Bill on the Prevention of Food Loss and Waste, making Spain the 3rd country in the EU to legislate on food waste (La Moncloa, 2021).

Moving to a regional level, if we focus on Catalonia, estimates indicate that during 2012 7% of the food purchased at the household and food services level was wasted. Amounting to 35 kg of food waste or its equivalent of 112€ per inhabitant (Zero Waste Europe, 2021).

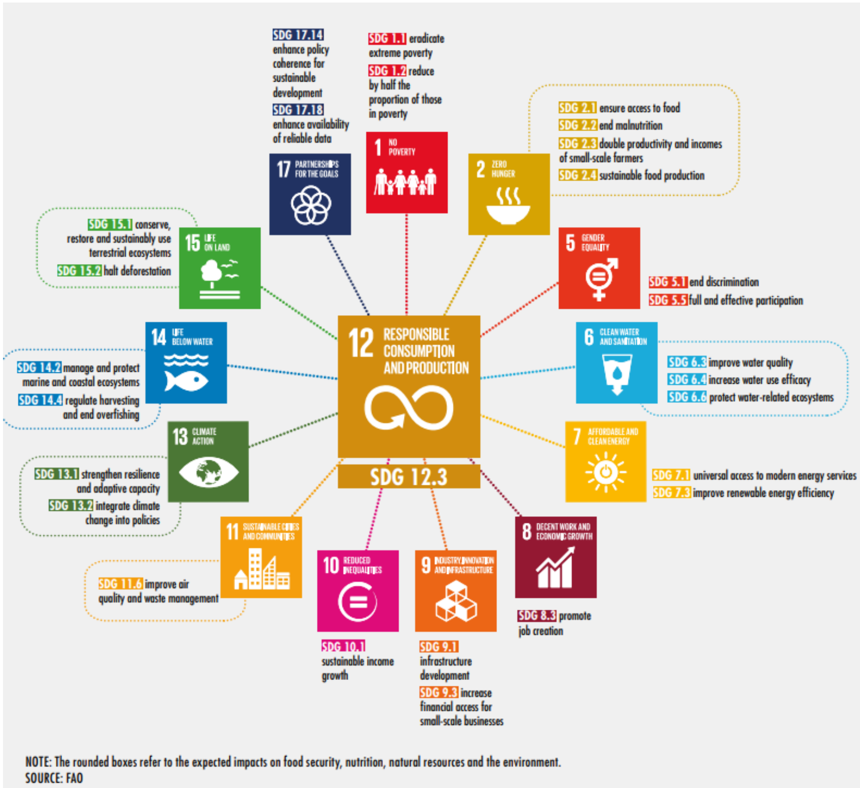
Regional legislation to solve the FLW issue was adopted by the Plenary Assembly of Parliament, by the name Law 3/2020, of 11 March, on Food Loss and Wastage Prevention. This law aims to reduce FLW and is centered in all the supply chain stages, moreover, it focuses on food waste prevention rather than waste management (Plenary Assembly of Parliament, 2020), critical to accomplishing the SDGs and avoiding the "Prevention Paradox" (Messner et al., 2020).

[4] MAPA for its Spanish acronym of "Ministerio de Agricultura, Pesca y Alimentación", formerly referred as MAGRAMA.

Appendix 5: SDGs and their relation to FLW

The Sustainable Development Goals (SDGs) are the heart of the 2030 Agenda for Sustainable Development. These goals consist of a shared blueprint for peace and prosperity for people and the planet[5]. The 17 SDGs include (1) no poverty, (2) zero hunger, (3) good health and well-being, (4) quality education, (5) gender equality, (6) clean water and sanitation, (7) affordable and clean energy, (8) decent work and economic growth, (9) industry, innovation, and infrastructure, (10) reduced inequalities, (11) sustainable cities and communities, (12) responsible consumption and production, (13) climate action, (14) life below water, (15) life on land, (16) peace justice and strong institutions, and (17) partnerships for the goal. Each of the goals contains certain targets that should be accomplished, publications regarding their development, events, and actions that are currently being taken to address them.

Even if the target more in line with FLW is 12.3. Synergies and complementary actions can exist between the different goals and targets. In the figure below, elaborated by FAO, related goals to FLW are shown, with the rounded boxes referring to the expected impacts on food security, nutrition, natural resources, and the environment.

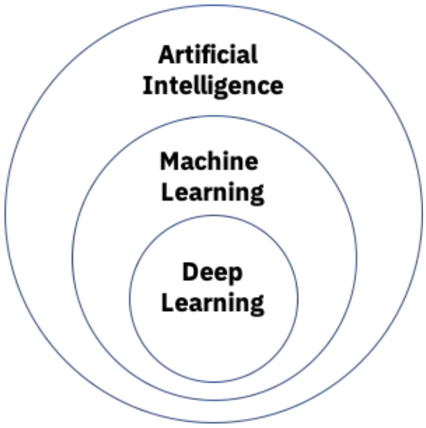


Source: FAO. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. Pg. 3. https://www.fao.org/3/ca6030en/ca6030en.pdf

[5] United Nations (2015). The 17 sustainable development goals. [online] United Nations. Available at: https://sdgs.un.org/goals [Accessed 29 Apr. 2022].

Appendix 6: A closer look at machine learning and deep learning

As has been mentioned in point 5.1.1, both machine learning (ML) and deep learning (DL) are sub-fields of Artificial Intelligence, furthermore, DL is a sub-field of ML (see graphic representation next to the text).



Source: IBM Cloud Education, 2020

While AI's goal is to teach a machine or a computer how to perform specific tasks, machine learning enables computers to learn from the data that is given to them, this way in the future, they can recognize patterns that have been taught to them or make predictions from new datasets.

Machine learning can have different forms[6]:

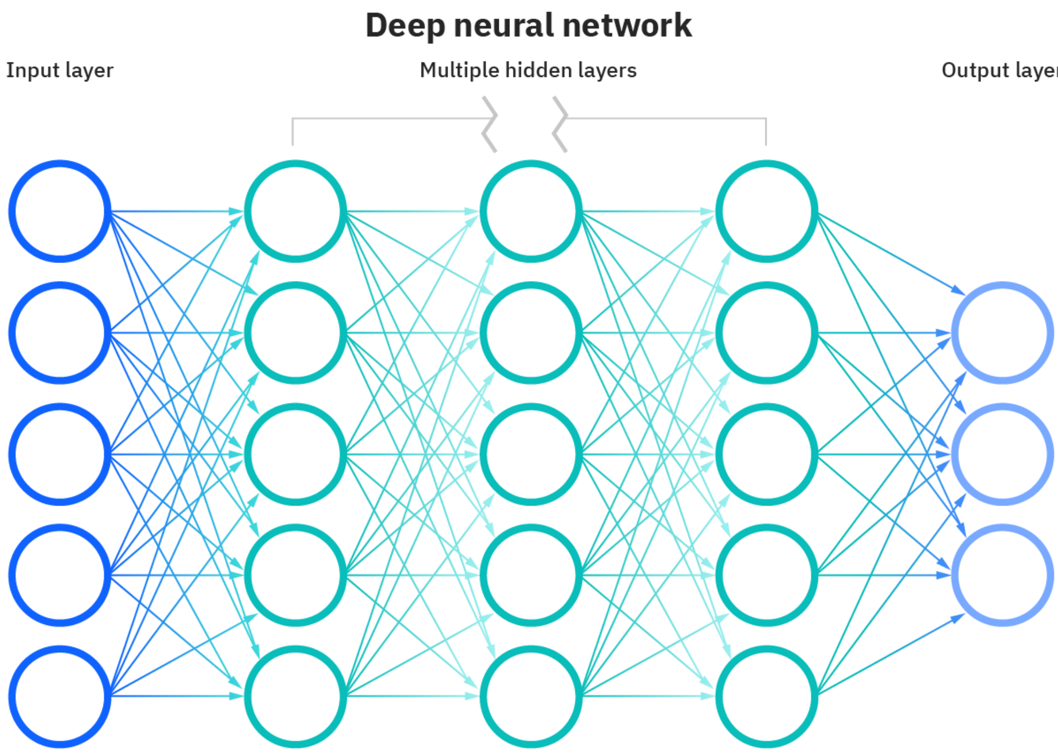
1. Supervised learning: Input data and output data (labeled data/training data) are given (feed) to the algorithm so it can understand the relationship (between input and output) and later predict or perform the desired tasks autonomously.
2. Unsupervised learning: These algorithms only use input data (unlabeled data), useful when the results are "priorly unknown", and output data does not exist. This allows finding structure in the data and insights that are first unknown.
3. Reinforcement learning: In this third case, the algorithm learns from trial-and-error and its own feedback loops. The algorithm knows there is a "right" output and uses unlabeled data feed as an input (again and again) trying to maximize the output.

If machine learning is dependent on human intervention (feed proper data) and supervision, deep learning does not require that degree of intervention. *"Deep learning automates much of the feature extraction piece of the process, eliminating some of the manual human intervention required and enabling the use of larger data sets"* (IBM Cloud Education, 2020).

These DL algorithms are more complex than ML ones and can analyze data in a similar way in which humans, using a logic structure, come to a conclusion. DL algorithms consist of a layered algorithm structure called a Deep Neural Network (shown in the following figure) that somehow resembles the neural network of a human brain. These neural networks consist of an input layer (where the data is fed), hidden intermediate layers (the more hidden layers, the more complex the algorithms are), and an output layer (the output that the algorithm retrieves). The hidden layers go through self-learning and automatic feature engineering, which "*automatically*

[6] Levity (n.d.). *How do machines learn?* [online] levity.ai. Available at: https://levity.ai/blog/how-do-machines-learn [Accessed 29 Apr. 2022]

determine the hierarchy of features which distinguish different categories of data from one another" (IBM Cloud Education, 2020), to reach the output that will result. To perform deep learning larger amounts of data and large computing power is needed.



Source: IBM Cloud Education. (2020, June 3). What is artificial intelligence (AI)? IBM. https://www.ibm.com/cloud/learn/what-is-artificial-intelligence

Appendix 7: AI uses and opportunities in the Supply chain

Artificial Intelligence uses along the supply chain can vary deeply depending on the stage. There is, however, a predominance of forecasting to ensure resource optimization prevalent in almost all stages. The stage with more varied opportunities is the harvesting and production stage. At the wholesaler and retailer level, even if the main opportunity relies on forecasting, as they face many different challenges related to it, AI becomes important too.

Production and harvest	Storage and transportation	Processing and manufacture	Wholesale and retail	Food Services	Household and consumers
Real time crop field monitoring Improve crop yield prediction with real-time data and visual analytics Price forecasting based on yield rates and total volume produced Yield mapping based on ML algorithms to find patterns Optimization of irrigation systems Monitoring of livestock's health	Track-and-trace systems that use RFID and IoT Optimization of storage confiditions to avoid spoilage and loss	Track-and-trace systems that use RFID and IoT Optimization of business processes to prevent losses in manufacturing	Forecasting to improve demmand planning in order to improve: • Product availability • Inventory management • Product variability • Product pricing • Unpredictable with the ordering process	Forecasting to improve demmand planning and reduce food waste Food waste management system to improve orders	Not specific or relevant enough opportunities at the consumer level

Source: Author's own creation data from 5.1.2: AI applications for FLW

Appendix 8: AI companies working in the food supply chain

Companies shown in 5.1.3 are distributed along the supply chain. It can be seen how most of the efforts of AI in the food supply chain are focused on the production and harvest stage, the wholesale and retail level, or even on food services for waste management. The stages with fewer companies working on it are the manufacturing and processing stage, due to difficulty and variety of business operations, and the consumer level, in which difficulties for technology implementation regarding FLW have been already explained.

Source: Author's own creation, data from 5.1.3: Artificial Intelligence companies working on FLW

Appendix 9: The use of blockchain and smart contracts in the food supply chain

A hypothetical example of blockchain usage for automating transactions between partners using smart contracts, elaborated by Kamilaris et al. (2019). The illustration shows AfroCoop, a fictitious cooperative of farmers/producers, and TransAfro, a fictitious distributor that wants to sell the crops in Europe. The smart contract facilitates the cereal sale through automatic transfers that occur once certain criteria stipulated in the smart contract are met, in this case, $10,000 needs to be sent to AfroCoop's blockchain address. The process shown also involves smart storage linked to the smart contract, making the pickup only accessible once TransAfro transfers the money.

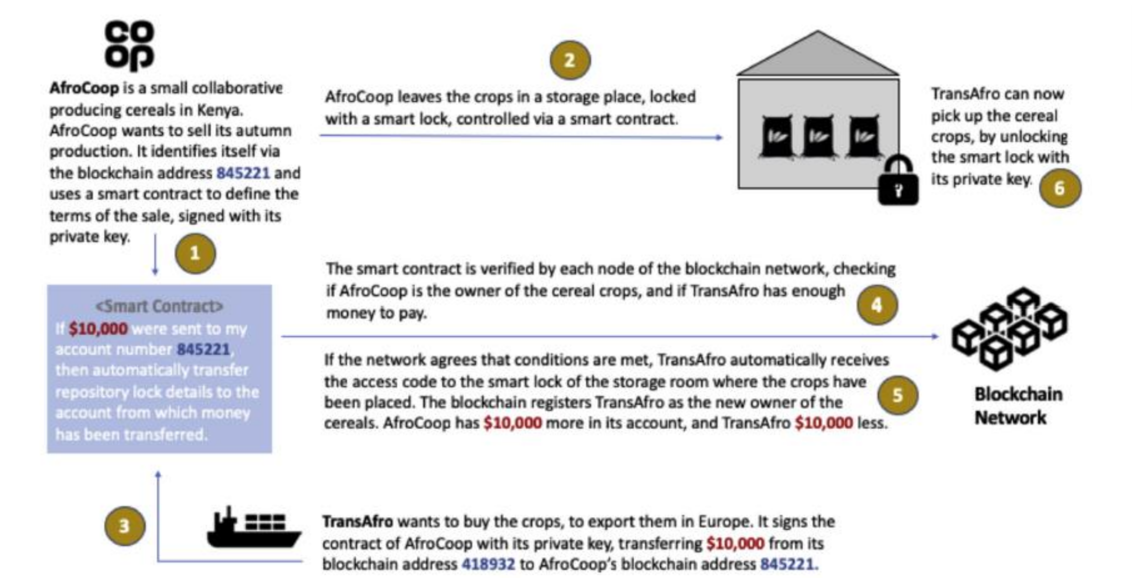


Fig. 3. An example demonstrating how a smart contract could be executed in 6 steps, for automating and enhancing trust in transactions involving small farmers and cooperatives of small farmers.

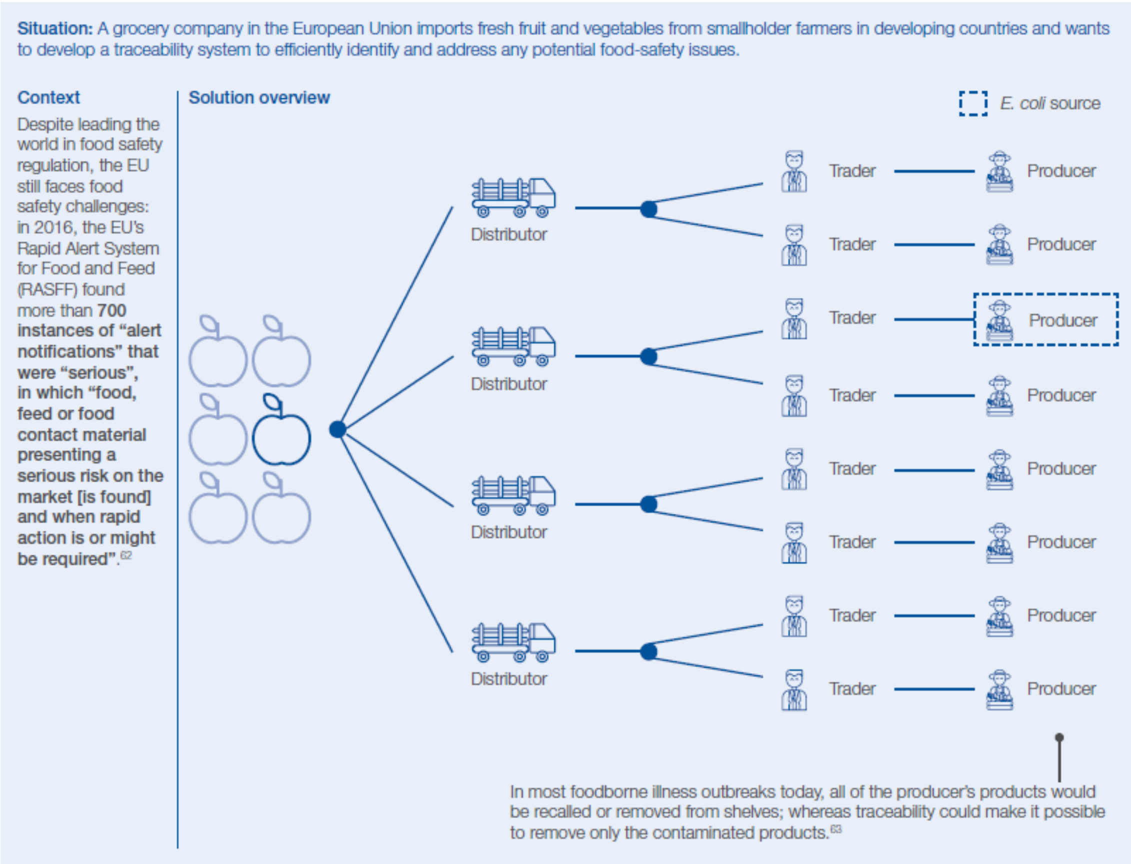
Source: Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. Trends in Food Science & Technology, 91, 640–652. https://doi.org/10.1016/j.tifs.2019.07.034

Appendix 10: Traceability for food security and food loss prevention

"Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations" (World Economic Forum, 2019) provides a clear overview of how traceability solutions can help deal with food contamination.

As shown in the figure, even if a foodborne illness outbreak is discovered at the retail level, traceability allows to reach all the way through the food supply chain (backward) and discover in which stage, or which source was the foodborne illness originated.

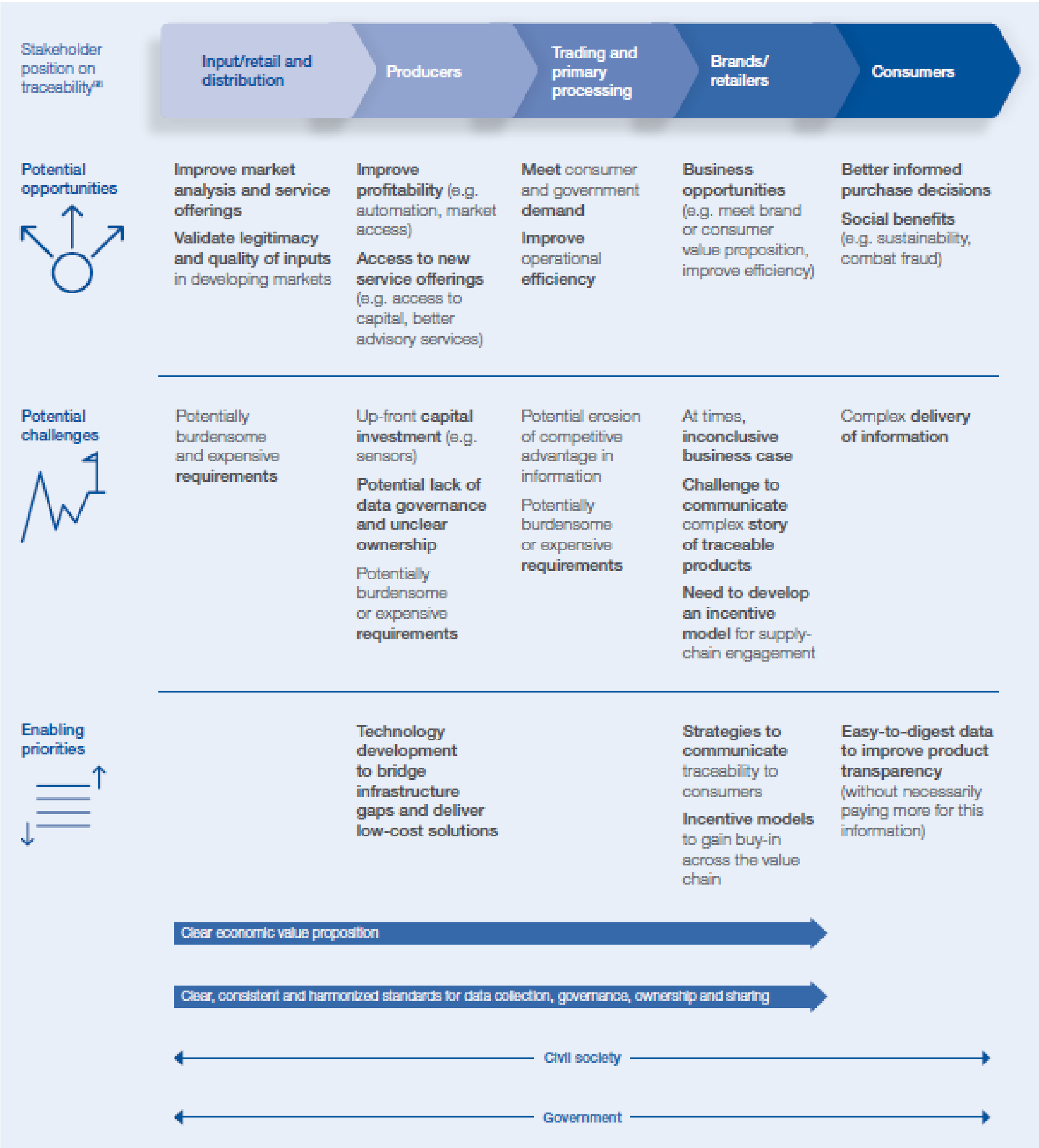
By doing so, the products coming from that same producer (or processed products that have used that producer's ingredients) can be traced and removed from the supermarkets. If traceability could not be achieved, not only would those products be removed from the supermarkets, but also similar products from different suppliers, incurring food waste of food suitable for consumption.



Source: World Economic Forum. (2019). Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations. In Weforum. https://www3.weforum.org/docs/WEF_Traceability_in_food_value_chains_Digital.pdf

Appendix 11: Blockchain opportunities, challenges, and priorities for adoption

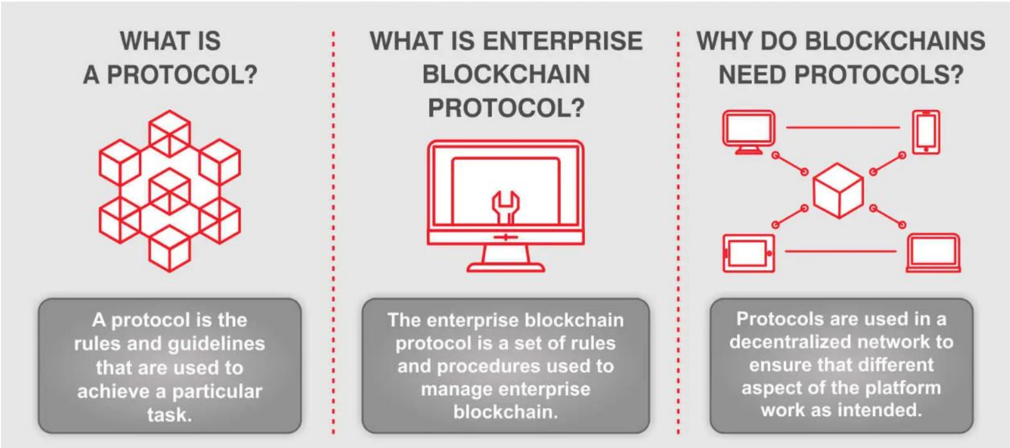
As Blockchain is a relatively new technology, there are many opportunities and benefits laying ahead, however, the challenges of implementing the technology can't be ignored. The figure below displays a representation of potential opportunities, potential challenges, and enabling priorities for blockchain implementation.



Source: World Economic Forum. (2019). Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations. In Weforum. https://www3.weforum.org/docs/WEF_Traceability_in_food_value_chains_Digital.pdf

Appendix 12: Blockchain protocols, what are they needed for?

A blockchain protocol is a set of rules and procedures that govern the different parts of blockchain technology and allow for data transfers across the network. There is a term (besides the distributed ledger and smart contracts that have already been mentioned) that needs to be explained to understand how protocols work, this is the consensus algorithms or mechanisms. In the following figure, a simple explanation of protocols is provided.



Source: 101 Blockchains. (2021, January 31). Top 5 Enterprise Blockchain Protocols. 101 Blockchains. https://101blockchains.com/blockchain-protocol/

Consensus algorithm: Algorithm that determines who is responsible for block validation and authentication. Ensuring a standard agreement among the network participants (Singh, 2021). These consensus mechanisms can vary depending on the protocol and technology, some of the most used are proof of work, proof of stake, pluggable consensus, and (probabilistic) voting protocols:

- Proof of work: *"Proof-of-work blockchains are secured and verified by virtual miners around the world racing to be the first to solve a math puzzle. The winner gets to update the blockchain with the latest verified transactions and is rewarded by the network with a predetermined amount of crypto*". (Coinbase, 2020)
- Proof of stake: "*Proof of stake blockchains employ a network of "validators" who contribute — or "stake" — their own crypto in exchange for a chance of getting to validate a new transaction, update the blockchain, and earn a reward. The network selects a winner based on the amount of crypto each validator has in the pool and the length of time they've had it there*" (Coinbase, 2020). Proof of stake was developed to avoid using proof of work, the original consensus mechanism that appeared with Bitcoin, aiming to be a less resource-intensive (and faster) consensus mechanism. Proof of work and proof of stake is used by blockchain protocols that also have

cryptocurrencies as crypto rewards are the main incentive for network participants to mine or stake.

- Pluggable Consensus: "*The ordering of transactions is delegated to a modular component for consensus that is logically decoupled from the peers that execute transactions and maintain the ledger. Specifically, the ordering service. Since consensus is modular, its implementation can be tailored to the trust assumption of a particular deployment or solution. This modular architecture allows the platform to rely on well-established toolkits for CFT (crash fault-tolerant) or BFT (byzantine fault-tolerant) ordering*" (Hyperledger, 2022 updated).

Furthermore, the ledger or blockchain can be differentiated by their types (DataFlair Team, 2018):

- Public blockchain: Also known as a permission-less distribution ledger is a ledger where anyone can have access and become an authorized node of the blockchain network (verify transactions, access records…). Most public blockchain uses are related to crypto and some examples are Bitcoin and Ethereum.
- Private blockchain: Also known as permission distribution ledgers are ledgers used in an organization that can be accessed only by a selected number of members or participants. The controlling organization is, therefore, the one that controls the level of security, authorizations, accessibility, and members' permissions. Current uses of permissioned ledgers are related to digital identity, supply chain management, asset ownership, and voting. Some examples of this type of ledger are Hyperledger, Multichain, or Corda.
- Consortium blockchain: Semi-decentralized network where more than one organization can manage and act as a node. Usually, these consortium ledgers are used by banks and government organizations.
- Hybrid blockchain: Hybrid blockchains use features from both permissionless and permission ledgers in order to provide a flexible hybrid system. Users control who can access the data or which data is made available to the public. Hybrid blockchains tend to be verified by their own network users but can also be "released" to the public blockchain to get verified, enhancing security and transparency.

As it has been mentioned previously there are many different enterprise blockchain protocols that can be used by companies. Next, an explanation of one of the most prominent ledger protocols will be provided, seeing an example of open-source permission enterprise blockchain technology with Hyperledger Fabric.

Hyperledger Fabric, developed by the Linux Foundation, is an open-source modular blockchain framework (IBM, 2021), from Hyperledger's whitepaper we can see how: "Hyperledger Fabric is an enterprise-grade, distributed ledger platform that offers modularity and versatility for a broad set of industry use cases" (Hyperledger Foundation, 2020). This modular and versatile blockchain platform, allows for plug-and-play components, so organizations can build a framework best suited to their needs.

This permission system grants a secure platform ready to be scalable, with private transactions and confidential contracts and a strong emphasis on data privacy and governance. Some key features of Hyperledger Fabric include (Hyperledger Foundation, 2020):

- Permissioned architecture
- Highly modular
- Pluggable consensus
- Open smart contract model — flexibility to implement any desired solution model
- Low latency of finality/confirmation
- Flexible approach to data privacy: data isolation using 'channels', or sharing private data on a need-to-know basis using private data 'collections'
- Designed for continuous operations
- Governance and versioning of smart contracts
- Flexible endorsement model for achieving consensus across required organizations

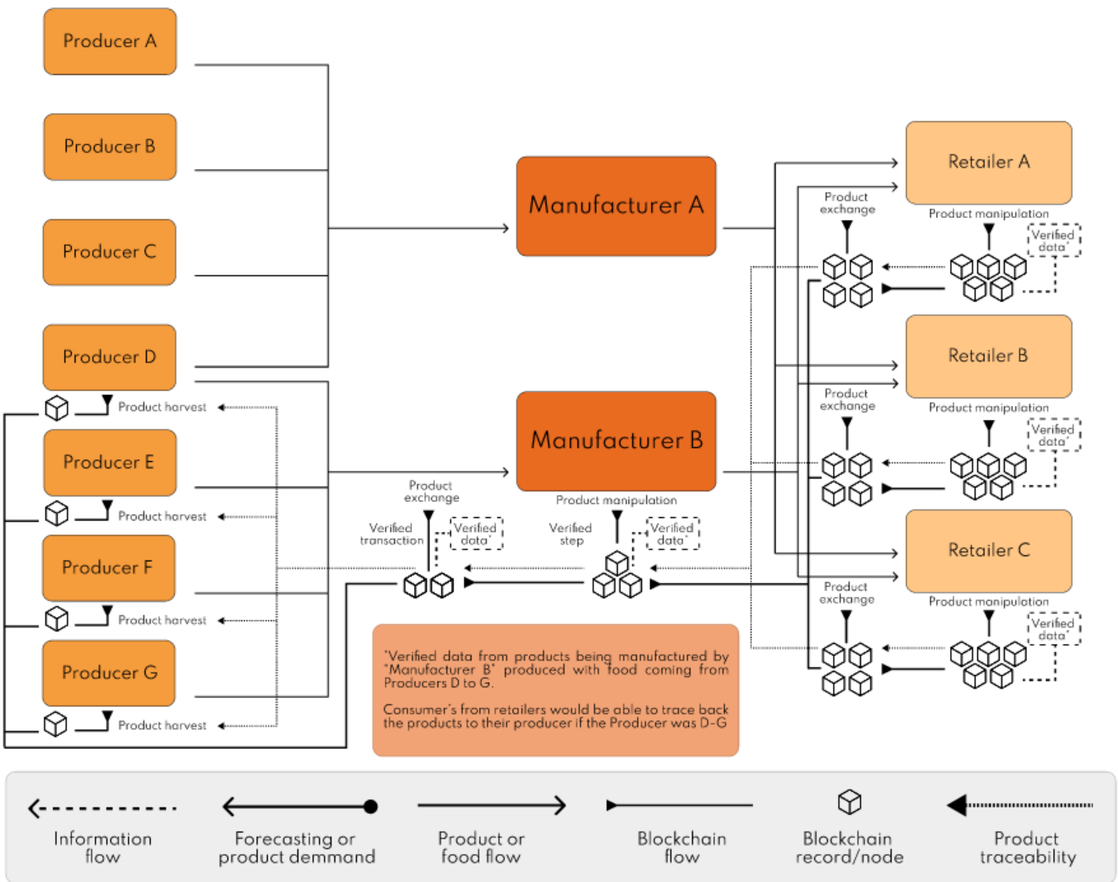
Furthermore, the technology enjoys the breadth of adoption by major Cloud Services Providers, including Amazon Web Services, IBM, Google, and Oracle (Hyperledger Foundation, 2020).

Appendix 13: Comparison of supply chains with a manufacturer that uses traceability solutions and one that does not

In this example, which is centered around the implementation of the blockchain technology, Manufacturer B is the lead implementer of it (traceability technology), and distributors from D to G cooperate with Manufacturer B and enter the permission ledger where records are stored. Finally, products are shipped to retailers (A to C) all of whom are part of Manufacturer B's permission ledger. Once in the supermarket, products that have been manufactured by Manufacturer B can be traced back to the original producer (D to G).

In addition, producers from A to D (D produces both for A and B but only transactions of products for Manufacturer B are stored in the blockchain) produce for Manufacturer A, as Manufacturer A has not implemented a traceability solution, once its products reach the supermarket, they cannot be traced back to the producer. This could give an advantage to products from Manufacturer B to consumers who are more environmentally conscious and want to know where the products they consume are coming from.

A representative view of the ecosystem:



Source: Author's own creation

Appendix 14: Example of digitalized farms and precision agriculture

The Netherlands is one of the countries where the pioneering implementation of precision farming (digitalized farms) is more widespread. The first image shows a view of greenhouses in Westland (South Holland) – for tomato production - with double-glass roofs to preserve heat. Furthermore, most of the farms use mineral wool bags to grow tomatoes. (Auctor, 2019)

The second image shows a closer look inside of one of these tomatoes' greenhouses, it is estimated that production with the use of precision farming, yields 10 times the production of an open field farm.

Source: Auctor, A. (2019, April 21). Netherlands Leading World in Agricultural Innovation. Nspirement. [*https://www.nspirement.com/2019/04/21/netherlands-leading-world-in-agricultural-innovation.html*](https://www.nspirement.com/2019/04/21/netherlands-leading-world-in-agricultural-innovation.html)

10. References of the appendixes

101 Blockchains. (2021, January 31). Top 5 Enterprise Blockchain Protocols. 101 Blockchains. https://101blockchains.com/blockchain-protocol/

Auctor, A. (2019, April 21). Netherlands Leading World in Agricultural Innovation. Nspirement. https://www.nspirement.com/2019/04/21/netherlands-leading-world-in-agricultural-innovation.html

Coinbase. (2020). What is “proof of work” or “proof of stake”? Www.coinbase.com. https://www.coinbase.com/es/learn/crypto-basics/what-is-proof-of-work-or-proof-of-stake

DataFlair Team. (2018, June 4). Types of Blockchains - Decide which one is better for your Investment Needs - DataFlair. DataFlair. https://data-flair.training/blogs/types-of-blockchain/

Hyperledger. (2022). Introduction — hyperledger-fabricdocs master documentation. Hyperledger-Fabric.readthedocs.io. https://hyperledger-fabric.readthedocs.io/en/release-2.2/whatis.html#pluggable-consensus

Hyperledger Foundation. (2020). Hyperledger Fabric Whitepaper. https://www.hyperledger.org/wp-content/uploads/2020/03/hyperledger_fabric_whitepaper.pdf

IBM. (2021). What is Hyperledger Fabric. Www.ibm.com. https://www.ibm.com/topics/hyperledger

Levity. (n.d.). How do machines learn? Levity.ai. Retrieved April 29, 2022, from https://levity.ai/blog/how-do-machines-learn

Singh, A. (2021, May 10). Top 5 Enterprise Blockchain Protocols You Must Know. Brandlitic. https://medium.com/brandlitic/top-5-enterprise-blockchain-protocols-you-must-know-4e9903d812aa#:~:text=Blockchain%20protocols%2C%20also%20known%20as

United Nations. (2015). The 17 sustainable development goals. United Nations. https://sdgs.un.org/goals

Zero Waste Europe (2021). The Catalan law on food loss and waste prevention - Food WastePrevention Legislation.https://zerowasteeurope.eu/wp-content/uploads/2021/11/zwe_11_2021_factsheet_catalonia_en.pdf