The potential of Distributed Ledger Technologies embedded in a systemic approach for increased food security

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Summary

With the world and its food chains becoming more interconnected as the rate of globalization increases, any issues in the food supply chain can negatively affect potentially millions of people which confirms that the need for food security continues to be of great importance. Simultaneously, developments in Distributed Ledger Technologies (DLTs) allow the increase of transparency and trust in the food supply chain, and thus potentially increase overall food security.

With this information at hand, this report sets out to answer the following question**: "to what extent can today`s agri-food supply chain be made more secure within the next ten years by integrating distributed ledger technologies?”**. This is done primarily using literature review.

Applying literature review in addition to the input of a detailed presentation on the concept and operations of the firm FET Global, resulted in finding verified answers to three devised sub-questions:

1. The key problem areas in the agri-food supply chain which are causing today’s food insecurity can be attributed to limited food availability, food unsafety, limited food access, and limited food utilization.
2. With the implementation of DLTs, transparency and trust between the actors in the food supply chain will be drastically improved. Using the data received by these DLTs, problem areas in the chain concerning production (food availability) and quality (food safety) can be more easily detected and solved, and thus will improve some aspects of food security. The most suitable technologies in relation to DLTs were determined to be blockchain, sensors, and smart contracts.
3. A possible integral solution with embedded DLTs, could look like the GreenZone platform solution as presented by FET Global. This systemic solution proposes to create a database of measuring points, to develop a self-assessment tool for farms, standard operation procedures (SOP), certifications and audits for farms and key country distributors, resulting in qualified and transparently traced products from seed to trade. To ensure all procedures are followed and the products will be tracked and traced in a transparent, verified manner, DLTs in combination with intermittent audits and lab produce checks are implemented to ensure the validity of the claims made on the food, SOP compliance and involved parties.

Answering the sub-questions leads to the conclusion that DLTs on their own are not a complete solution in making the agri-food supply chain more secure, but instead DLTs require a system in which they are embedded.

1. Introduction

The United Nations` Food and Agriculture Organization (FAO) defines food security as "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2020).

Ending global hunger by 2030 was one of the Sustainable Development Goals adopted by all United Nations member states in 2015. In the prior 15 years, the world had seen a reduction of half of all undernourished people, largely accredited to international investment in agricultural economic infrastructure (Samberg, 2018). However, this trend seemed to worsen from 2014 onwards. 690 million people were undernourished in 2019. At the end of 2020, the Covid-19 pandemic only added to the severity of issues such as man-made conflicts, economic downturn, and compounding climate change related trends such as diminishing availability of land, soil impoverishment, biodiversity degradation and more frequent and severe weather events (FAO, 2020).

In addition, malnutrition is taking a heavy toll across developing and developed nations. More than two billion adults, adolescents and children are now obese or overweight. The consequences are severe for public health, for national wealth, and for individuals' and communities' quality of life. Also, the World Health Organization officially recognizes "that foodborne diseases significantly affect people's health and well-being and have economic consequences for individuals, families, communities, businesses, and countries" (WHO, 2002). Such outbreaks of foodborne diseases have the potential to damage the economy and overall public health, capable of damaging a nations tourism and trade, leading to a loss of earnings and increased unemployment (Aung & Chang, 2014).

As contradictory as it may sound however, today there is more than enough food being produced to feed the entire global population. Yet, with the world population expected to reach ten billion by 2050, the demand for food security and increased production is only rising (Tomlinson, 2013).

<u>Considerations for solutions for the food security problem: technology & services</u>

In its OECD-FAO Outlook 2020-2029 the OECD and FAO underscore the continuing need to invest in building productive, resilient, and sustainable food systems in the face of uncertainties (OECD/FAO, 2020). Agriculture farming is key in this approach and this report. Beyond Covid-19, current challenges include the locust invasion in East Africa and Asia, the continued spread of African swine fever, more frequent extreme climatic events, and trade tensions among major trading powers. The food system will also need to adapt to evolving diets and consumer preferences and take advantage of digital innovations in agri-food supply chains. Innovation will remain critical in improving the resilience of food systems in the face of multiple challenges. A big part of the innovation opportunity lies in data-related digitalization and innovations (FAO, 2020).

One of the most optimal methods to promote innovation is by investing in new technologies, resulting in services and solutions accompanied by uniform global (data) standards and policies that enable farmers to sustainably increase high-quality yields, receive continued education, get easier market access and lower levels of risk and uncertainty by connecting with information and institutions, and by creating reliable accessible global agri-food tracking-tracing standards and solutions from farm to fork (Samberg, 2018). Governments and companies have started to develop various methods to ensure the food is safe for consumption. One such method is food traceability systems, which legally still only need to look one step back and one step forward (Bulut & Lawrence, 2007).

A 2017 working paper by the CGIAR Research Program on Climate Change, Agriculture, and Food Security, attests that in rural agriculture the most encouraging developments are technology- and service-based. "With access to data, markets, and financial services, farmers can plant, fertilize, harvest, and sell products more effectively" (CGIAR, 2017; Samberg, 2018). Currently, innovations such as these are not distinctly incorporated in most hunger-alleviation strategies. This is slowly changing however, especially as more people in emerging economies connect to mobile networks, and obtain access to apps designed to collect and share agricultural information (Samberg, 2018). 2021 seems to be therefore an excellent momentum to study in this report how the key issues around the global food security challenge can best be tackled with the use of technologies (primarily focused on areas around mainly data, networking/connecting and financial transactions) such as Distributed Ledger Technologies (DLTs) (which in the scope of this report for example also includes Internet-of-Things (IoT) sensors, smart contracts and blockchain technology). Distributed ledger technology as a concept is relatively simple to understand. In its very essence it is a database that exists across several locations or among multiple participants (as opposed to the currently mostly used centralized databases that live in a fixed location and essentially have a single point of failure). A distributed ledger is decentralized to eliminate the need for a central authority or intermediary to process, validate or authenticate transactions. Enterprises use distributed ledger technology to process, validate or authenticate transactions or other types of data exchanges. Typically, these records are only ever stored in the ledger when consensus has been reached by the parties involved through validation. All files in the distributed ledger are subsequently timestamped and given a unique cryptographic signature. All of the participants on the distributed ledger can view all of the records in question (transparency and accessibility). The technology provides a verifiable and auditable history of all information stored on that particular dataset.

Complexity and collaborations

Food and the global food system itself is a complex topic. Fundamentally connected to topics such as identity, culture and integration, food is more than just a product and a source of nutrition; food is a fundamental need and right. Many nations have committed themselves in providing this right to their people. Farmers, manufacturers, buyers, processors, distributors, regulators, and consumers, as actors in the value chain, contribute to shaping its quality and safety practices, its ability to sustainably and healthily supply the world, and in determining the value chains carbon footprint. From water conservation to maintaining soil health, the promotion of biodiversity and better yields and incomes for smallholder farmers and improving nutrition through school food programs or the establishment of urban food policy councils, best practice in food sustainability falls under a multitude of practices (The Economist Intelligence Unit, 2018).

To this the Economist Intelligence Unit (2018) adds:

> Climate change adaptation and mitigation strategies will be essential in creating a more sustainable food system since agricultural activities make a significant contribution to climate change, accounting for up to 30% of global greenhouse gas (GHG) emissions, according to some

estimates. Water conservation is also critical since agriculture is responsible for 70% of global freshwater withdrawals.

With a view to the above complexity of all aspects influencing the food security problem it becomes apparent that food security, or the UN Sustainable Development Goal (SDG) 2 (zero hunger), does not stand on its own and the 17 SDGs do not represent a set of individual global issues; they are each affecting the other in myriad ways.

Linking all 17 UN Sustainable Development Goals (SDGs), food is a commonality in the interconnected social, economic, and environmental dimensions of food systems. The 2030 UN Sustainable Development Goals are problems of enormous complexity and magnitude which can only be solved through collaborations and systemic thinking and working with all the SDGs and each other in balance. (The Economist Intelligence Unit, 2018).

The Fixing Food 2018 report describes the SDGs of a systemic sustainable food system in the below figure with the following key elements: Access to Food, Sustainable and Healthy Diets and Wise Food Production and Distribution in a self-explanatory equally balanced Venn-diagram of integrated social, economic, and environmental dimensions relating to sustainable food systems (The Economist Intelligence Unit, 2018).

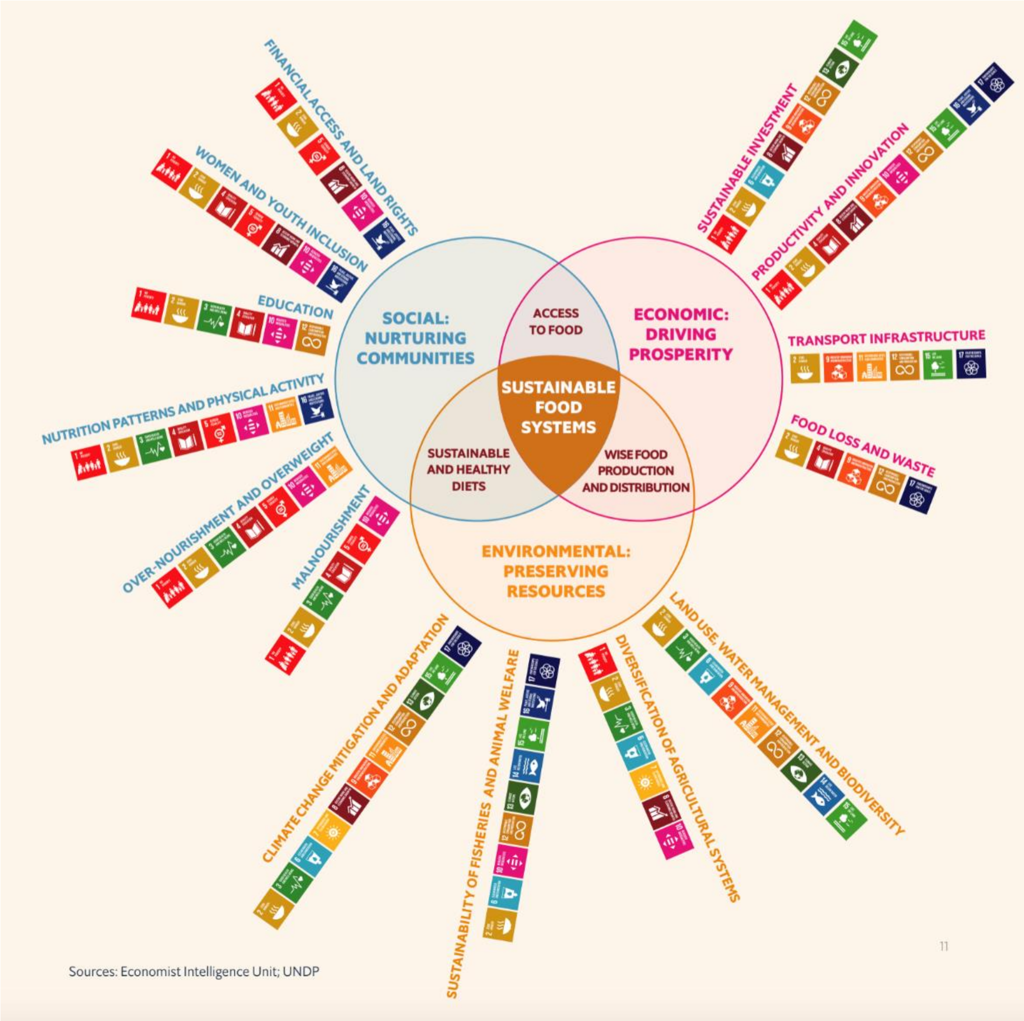

Figure 1 SDGs Contributing to a Sustainable Food System (The Economist Intelligence Unit, 2018)

At the core of SDG 2 on zero hunger stands nutrition, a concept linked tightly with other SDGs such as in particular “good health and wellbeing (SDG 3), clean water and sanitation (SDG 6), climate action (SDG 13), and sustainable consumption and production patterns, including waste reduction (SDG 12).” (The Economist Intelligence Unit, 2018).

To disrupt the cycles at work that have made the SDGs necessary, it is also necessary to disrupt the ways in which people work together to achieve systemic change. SDG 17, Partnerships for the Goals, may therefore perhaps be considered as one the most important Sustainable Development Goals to reap the benefits of a world truly working together towards zero hunger and food security for all. If steps aren’t made to coordinate, collaborate, and convene within and between countries and stakeholders to work together towards the SDGs, the likelihood of achieving them becomes slimmer year after year.

One of the many collaborations needs for example relates to finding global data management solutions and standards to food security related issues. The UN Statistics Division launched a guide about data management needs and the SDGs (specifically focusing on data interoperability). They highlight the needs for effective data governance, standardized data languages and accessibility of data (Morales & Orrell, 2018).

Technology and a grand solution for food insecurity?

This report will largely look at how Distributed Ledger Technologies (DLTs) in a broad sense can improve food security by improving amongst others trust, traceability, and physical access to safe and nutritious food. Hence, the aim of this report is to answer the following main question:

To what extent can today`s agri-food supply chain be made more secure within the next ten years by integrating distributed ledger technologies?

To better answer and analyze the main question, the following underlying sub-questions will be answered:

a) What are the key problem areas in the agri-food supply chain causing today`s food insecurity? (chapter 3.1)

b) What kind of DLT and DLT-associated technologies (in an applied context) currently exist, or are under development, that could be applied to solve the distinguished key problem areas? (chapter 3.2)

c) What could the integral solution for a reliable supply of produce in which DLT and DLT-associated technologies are potentially look like? (chapter 3.3)

2. Material and Methods

The chosen methodology consisted mainly of literature review, which was approached from a qualitative research approach. This meant that primarily non-numerical data, such as text, video, and audio were collected and analyzed until it was ultimately either chosen or rejected to be of relevance to the topic of the report. In addition, there were several non-structured open online interviews held with one of the founders of FET Global and various materials of FET Global were researched.

The way the literature review was envisioned went according to plan. Although time-intensive, literature review is in principle dry but relatively simple to execute. Using the initially determined keywords to search for, once suitable literature was found it would quickly become apparent how to find the next relevant source based on ideas, references, or different keywords found in the initially chosen literature. However, despite the numerous papers read and analyzed, there are still hundreds of additional reports and papers that could be found that have not been read and thus were not incorporated into this report. The sheer size of information available, made it unfeasible to create a complete and fully non-biased report in a timely manner.

Innovations and developments in terms of technology have been happening at an unprecedented pace over the past few decades. This means that literature that was written only five years ago for example, may already hold outdated notions of the discussed technologies or do not mention new key developments that have occurred within the last five years. This means that the perceived benefits and disadvantages of technologies, to an extent, become less reliable with every year that passes once the literature has been published. With this in mind, the most recent literature was favored over others wherever possible. However, for the sake of finding relevant information and keeping the narrative flowing between the different chapters, exemptions to this rule were made. This means that although the information in the report is reliably sourced and cited, in terms of technological developments, it may not be 100% reliably up to date. This should be considered throughout the reading of the report.

One limitation as a result of writing a report based on literature review instead of a practical experiment is that comparing literature review to different literature review to validate the results, seems ineffective as it comes down to trusting one report over the other, which in the end once again is determined by personal bias.

Furthermore, a limitation of using personal interviews and materials from only one business project without comparing and reviewing other projects may lead to some subjectivity due to the bias in the questions by the researcher, the bias in the answers of the interviewee and the bias of the supporting project materials provided by the project initiators, leading to a non-compared biased reflection in the research report.

2.1 Research Type and Data Collection

Since the research question defined in Chapter 1 is open-ended and has a broad scope, a qualitative research approach to gain insight in the subject was best suited to write this report. Due to the nature of this research report traditional review methods have been applied to answer all three defined sub-questions. Despite the risk of bias entering the conclusion and not having fully comprehensive searches with traditional review, as opposed to systematic review, traditional review was nevertheless selected whereas the search strategy was non-detailed, the search was done with the use of keywords. Additionally, all sub-questions were answered through literature review. This implied that due to time constraints it is unfeasible to go through all sources and databases related to research in a timely manner, as would be required with systematic literature review. The goal was that through critical appraisal of the sources found, a well-researched and structured report would be compiled.

Information was largely collected through sources such as online books, journal entries and peer reviewed reports, mainly found through google scholar or found via the school library. Due to the nature of this data collection, this data was analyzed through descriptive analysis. Only in respect of sub-question 3 did was the opportunity presented to be introduced to FET Global`s detailed recent business idea and roll-out relating to the designs of a relevant case study.

To answer the main research question and its underlying sub-questions, information on the current food system and current technological trends and innovations in the food system were found, verified, and analyzed. Only peer-reviewed papers ranged mainly between about 2000 and 2020 were used, with papers from the last ten years receiving preferential treatment.

2.2 Answering Sub-question 1

In order to answer sub question 1 *"What are the key problem areas in the agri-food supply chain causing today`s food insecurity?"*, a traditional literature review on traditional problem areas within the agri-food supply chain was completed. To achieve this, important reports such as from the FAO and UNDP were read and evaluated, and the following search words were entered in google scholar to find and select the relevant papers:

- "Agri-food" AND "Systemic issues"
- "Agri-food supply chain" AND "Food insecurity"

Once initial overarching themes concerning the key problem areas were found, sources primarily from the UNPD and FAO, were then used to further explore these problem areas in a detailed and well-written manner. Finally, the key findings were summarized and collected into one comprehensive table.

2.3 Answering Sub-question 2

Literature review on modern open data technologies applicable in the agri-food sector were researched to answer sub question 2: *"What kind of DLT and DLT-associated technologies currently exist (or are under development)?"* The following key search terms were used to find the appropriate papers:

- "Distributed Ledger Technologies"
- "Internet of Things"
- "Blockchain Technologies"
- "Smart contracts"
- "DLT" AND "Cryptocurrency"

This sub-chapter was structured to first explain the various needs and uses for trust and traceability in the supply chain, after which various literature was used to describe the technology evaluated to be best suited to answer this question.

2.4 Answering Sub-question 3

Answering sub question 3 *"What could the integral solution for a reliable supply of produce in which DLT and DLT-associated technologies are potentially look like?"* involved literature review on the role and effectiveness of systemics, DLT and data in traceability systems today, as well as naming and describing an exemplary firm who is developing a solution and is involved themselves in these endeavors. Fortunately, contact was established with one of the founders of FET Global, who graciously explained their company's stance and solution to the issue and gave permission for it to be included in this report. In addition to that presentation and the relevant literature found in answering the previous sub questions, the following search terms were used in google scholar:

- "Agri-food" AND "Future DLT"
- "DLT systems in development"
- "Future systemics" AND "Agri-food"

This sub-chapter starts by summarizing the key problems and findings found which is then followed up by recommendations on the properties that the solution must possess, based on relevant notes found in literature review. As a highlight of the research journey set out in this report, the solution of FET Global is subsequently presented based on the major points from the presentation given by one of FET`s co-founders.

3. Results

3.1 What are the key problem areas in the agri-food supply chain causing today`s food insecurity?

After years of decline, since 2014 the global number of people suffering from hunger continues to rise. In 2020 there are approximately 60 million more undernourished people than in 2014. Concurrently the global number of undernourished people is expected to exceed 840 million in 2030 (FAO, 2019). This means that SDG 2 (Zero Hunger) is not expected to be reached even remotely by 2030. Latest estimates suggest that 746 million people, or approximately 9.7 percent of the world population, had to endure serious levels of food insecurity in 2019. Since then, more than 1.25 billion people, have suffered from food insecurity at moderate levels. Moderate food insecurity translates to people not having regular access to sufficient and nutritious levels, even if they do not necessarily suffer from hunger. Translating into a total of 2 billion people, the worldwide predominance of severe and moderate levels of food insecurity was estimated to be 25.9 percent in 2019. These levels of total food insecurity have been consistently increasing since 2014, largely due to the increase in moderate food insecurity (FAO, 2020).

"Food security exhibits all five characteristics of so-called wicked problems." (Rittel and Webber 1973; Conklin 2006, as cited in Breeman, Dijkman, & Termeer, 2015). Breenan, Dijkman, and Termeer further build unto this:

> "First, in contrast to 'tame' policy problems, food security is ill-defined, which means that there is no definitive formulation of the problem. Different problem frames are being used, such as, for example, an agricultural production problem, an environmental problem, a development issue, a trading problem, a regional issue, a food sovereignty issue or as a nutrition problem." (Candel et al. 2014, as cited in Breeman, Dijkman, & Termeer, 2015). Second, as these issues are interwoven, the implementation of food security policies may lead to uncertain and unpredictable consequences (Rittel and Webber 1973; Head 2008, as cited Breeman, Dijkman, & Termeer, 2015). Third, as the relevant set of stakeholders keeps evolving, a potentially unlimited number of problems may have to be solved. The need to respond to such a fickle set of conflicting demands puts policy makers in difficult positions regarding their moral and democratic obligations. Fourth, food security being a multi-dimensional issue spans across various technical and policy disciplines such as agriculture, environment, health, energy, water management, and trade. Lastly, these categories of problems have no objective ultimate solution, but simply solutions that are considered "better" or "worse," and "good enough" or "not good enough". This suggests that frustrations, stalemates, fruitless interactions may be the result from such policy development. (Breeman, Dijkman, & Termeer, 2015).

Presently, food security is commonly conceptualized as resting on three pillars: availability, access, and utilization. These concepts are inherently hierarchical; availability is necessary but not adequate to ensure access, and is in turn, necessary but not adequate to ensure effective utilization (Barret, 2010). Availability inquires after the physical presence of the food. Access inquires after the ease at which households and individuals are able to procure the food. Utilization is an issue more prevalent in developed nations and asks whether consumers are making good use of the food they have and fosters greater attention to dietary quality and nutrition beneficial to the consumers health. It stands to reason then, that the key problem areas in the agri-food supply chain are intertwined with the pillars of availability, access, and utilization. Below, some of the prevalent issues are listed:

a) **food availability** (I.e., “having viable access to sufficient quantities of nutritious and affordable food”),

b) **food safety** (I.e., the production, handling, processing and storage of food in order to prevent foodborne illness)

c) **food access** (I.e., the affordability and spatial accessibility of food and its retailers)

d) **food utilization** (I.e., ensuring adequate nutrition in household through the effective use of food, ultimately reducing food waste)

> Even although globally, there is theoretically sufficient food for everybody, millions risk not having access to diverse and nutritious foods. Globally, enough food is being produced or in stock to meet dietary energy needs, but border closures, quarantines, market, supply chain and trade disruptions are restricting people’s physical access to sufficient, diverse and nutritious sources of food, especially in countries hit hard by the covid-19 pandemic or already affected by high levels of food insecurity. Particularly in respect of the pandemic we are for example seeing high value perishable commodities going to waste, as essential workers in food and agriculture are barred from crossing borders and food supply chains are being disrupted. Closure of informal markets may exacerbate unaffordability healthy diets. (FAO, 2020).

Below, the prevalent problems named above, are further expanded upon, and explained.

3.1.1 Problem 1: Limited availability of food due to conflicts and climate-related shocks

The reasons for the observed increase in food insecurity of the last few years are contributed to multiple causes. The recent rise of food insecurity can be linked to increase of global conflicts, which are often caused or intensified by climate-related disturbances. Economic slowdowns have been threatening the food security of poorer demographics even in more peaceful regions of the world. COVID-19 for example made farmers lose their markets, supply chains were disrupted, consumer demand has plummeted, and food safety monitoring, to the extent it was implemented to begin with, is being interrupted (UNDP, 2020).

3.1.2 Problem 2: Limited availability of food due to loss (and waste) of food

Food is also wasted or lost to varying degrees around the globe, across various stages of the food supply chain, and across all kinds of foods. As a result, food security is negatively affected and the world’s agricultural system has to produce additional food to compensate for the lost food (Lipinski, et al., 2013). Because of the nature of the question, the focus lies on the relationship between food loss, rather than food waste, and the food supply chain. Food loss typically occurs during the production, storage, processing, and distribution stage of the food supply chain (Lipinski, et al., 2013).

Figure 2 below gives a deeper insight in the food loss and waste in the various elements of the supply chain. During the production stage, on-farm food losses can occur before, during, and after harvesting; in some cases, crops may be left entirely unharvested in the field. The causes of food losses during the production stage are varied and often context specific. Pre-harvest conditions, such as weather conditions, seed variety, growing practices, pest infestations, and disease infections, often influence the degree of food loss once a seed has been sown (FAO, 2019). During the storage stage, food can be degraded by disease, fungus, and pests. During processing food loss may occur because of food being damaged or food being lost because of poor order forecasting and inefficient factory processes. And finally, during the distribution stage, food may be lost due to it not meeting social aesthetic demands or not being sold before the expiry date (Lipinski, et al., 2013). A study in Uganda revealed a positive correlation between infrastructural bottlenecks and food loss/insecurity. These bottlenecks included impassable roads, inadequate handling equipment, inappropriate storage facilities, and high cost of transport to collection centers (Ssennoga, Murugusi, & Oluka, 2019). Claims that these resulting food shortages could be minimized with the implementation of the right infrastructure (Ssennoga, Murugusi, & Oluka, 2019), further reiterates the typical stages where food loss, and as such food insecurity, occurs.

Production	Handling and Storage	Processing and Packaging	Distribution and Market	Consumption
DEFINITION				
During or immediately after harvesting on the farm	After produce leaves the farm for handling, storage, and transport	During industrial or domestic processing and/ or packaging	During distribution to markets, including losses at wholesale and retail markets	Losses in the home or business of the consumer, including restaurants/caterers
INCLUDES				
Fruits bruised during picking or threshing	Edible food eaten by pests	Milk spilled during pas-teurization and processing (e.g., cheese)	Edible produce sorted out due to quality	Edible products sorted out due to quality
Crops sorted out post-harvest for not meeting quality standards	Edible produce degraded by fungus or disease	Edible fruit or grains sorted out as not suitable for processing	Edible products expired before being purchased	Food purchased but not eaten
Crops left behind in fields due to poor mechanical harvesting or sharp drops in prices	Livestock death during transport to slaughter or not accepted for slaughter	Livestock trimming during slaughtering and industrial processing	Edible products spilled or damaged in market	Food cooked but not eaten
Fish discarded during fishing operations	Fish that are spilled or degraded after landing	Fish spilled or damaged during canning/smoking		

Figure 2 Food Loss and Waste among the Value Chain (Lipinski, et al., 2013)

To summarize, the key problem areas in the agri-food supply chain occur during the stages of production, handling and storage, and distribution. These problems seem mostly centered around whether the infrastructure (including stable and continuous cooling) is available and equipped to adequately support the actors in their operations, accidents caused due to human error, and unsatisfactory order forecasting possibly due to lack of communication between actors in the food supply chain.

3.1.3 Problem 3: Limited access to food

"Some people, particularly those in certain urban environments and especially those with low-income, may face greater barriers in accessing healthy and affordable food retailers, which may negatively affect diet and food security." (FAO, 2020). Referred to as self-provisioning capacity, the ability among farmers to produce and store enough food for themselves is the essential first step to the ensuring sustainable food access to the entire population (FAO, 2020).

Another aspect to consider in this context are food deserts, as explained by the Food Empowerment Project.

> Food deserts can be described as geographic areas where residents' access to affordable, healthy food options (especially fresh fruits and vegetables) is restricted or nonexistent due to the absence of grocery stores within convenient traveling distance. For instance, according to a report prepared for Congress by the Economic Research Service of the US Department of Agriculture, about 2.3 million people (or 2.2 percent of all US households) live more than one mile away from a supermarket and do not own a car. (Food Empowerment Project, 2021).
>
> In urban areas, access to public transportation may help residents overcome the difficulties posed by distance, but economic forces have driven grocery stores out of many cities in recent years, making them so few and far between that an individual's food shopping trip may require taking several buses or trains. In suburban and rural areas, public transportation is either very limited or unavailable, with supermarkets often many miles away from people's homes. The other defining characteristic of food deserts is socio-economic: that is, they are most commonly found in black and brown communities and low-income areas in for example the United States (where many people don't have cars). Studies have found that wealthy districts have three times as many supermarkets as poor ones do, that white neighborhoods contain an average of four times as many supermarkets as predominantly black ones do, and that grocery stores in African American communities are usually smaller with less selection. People's choices about what to eat are severely limited by the options available to them and what they can afford—and many food deserts contain an overabundance of fast-food chains selling cheap "meat" and dairy-based foods that are high in fat, sugar and salt. Processed foods (such as snack cakes, chips and soda) typically sold by corner delis, convenience stores and liquor stores are usually just as unhealthy. (Food Empowerment Project, 2021).

The twenty-first century has been referred to as the *urban century*. More than half of humanity lives in cities (Boone & Modarres, 2006 as cited in Gartin, 2015). The majority of cities are unable to produce enough food to sustain their residents (Potchukuchi & Kaufman, 1999 as cited in Gartin, 2015). However, some cities are exploring the idea that urban agriculture can create a more resilient food system. Resilience of a food system implies that regardless of any external forces (e.g., climate change, hazard event, or economic crisis) to food production or supply systems, residents remain food secure until the system is restored (Grewal & Grewal, 2012 as cited in Gartin, 2015). Yet, some argue that the global food system is too interconnected with the local food systems and that no system can exist without some level of vulnerability to external forces (Evers, 1994; Plattner, 1985; Pottier, 1999 as cited in Gartin, 2015).

3.1.4 Problem 4: High costs, low affordability (and utilization) of healthy diets limiting access across different income groups.

The FAO distinguishes four main sets of drivers determining the cost of food (FAO, 2020):

1. "Cost drivers that relate to the production of diverse nutritious foods that contribute to healthy diets (insufficient diversification and low productivity; low levels of technology; pre-harvest and post-

harvest losses; seasonality and other climate risk factors; insufficient investment in R&D, limited access to knowledge and information)."

2. "Cost drivers that relate to the food supply chain beyond food production (inadequate food storage, handling, and preservation, especially of perishable foods; food losses beyond pre-harvest and post-harvest losses; poor road networks and limited transport capacity)."
3. "Cost drivers that relate to the food environment as well as consumer demand and behavior (population growth, urbanization, access to markets; food preferences and culture; consumer knowledge and behavior)."
4. "Cost drivers that relate to the political economy of food (including the unique impact of food and agricultural policies on the cost of nutritious foods; trade measures and government policies that favor energy-dense foods of minimal nutritional value over nutritious foods; public expenditure; unfavorable trade mechanisms and the impact of food and agriculture industry lobbying on the cost of nutritious foods)."

Further building on this, the FAO continues:

> Data on food availability at the country level show large discrepancies in the per capita availability of foods from different food groups across different country income groups. Low-income- and lower-middle-income countries rely heavily on staple foods like cereals, roots, tubers and plantains which in low-income countries represent nearly 60 percent of all food available in 2017. This percentage decreases gradually with country income groups, down to 22 percent in high-income countries. The cost of a healthy diet is 60 percent higher than the cost of the nutrient adequate diet, and almost 5 times the cost of an energy sufficient diet. It is estimated that based on average estimated incomes more than 3 billion people in the world could not afford a healthy diet in 2017. (FAO, 2020).

In order to maintain a healthy living, people require a varied and healthy diet. The FAO/WHO advice individuals to consume a minimum of 400 grams of fruits and vegetables a day. Although on average the global availability of fruits and vegetables increased, only in Asia and upper-middle-income nations was there a sufficient number of fruits and vegetables to meet this recommendation (FAO, 2020).

In terms of nutrition derived from animal products, its global contribution varies amongst the income groups of countries. As perhaps expected, high-income countries enjoyed higher concentrations of animal source foods in their diets (29%), compared to middle-income countries (20%), and low-income countries (11%) (FAO, 2020).

UNICEF reports, that less than 40 percent of infants and young children met the minimum of dietary diversity. Additionally, the prevalence of minimum dietary diversity was strongly influenced by their wealth status and whether they lived in urban or rural locations. Children living in urban households were on average 1.7 times more likely to eat foods from at least five out of eight food groups than children living in rural households (FAO, 2020). Furthermore, it was found that with increasing levels of food insecurity diet quality worsens, according to an analysis of dietary patterns.

3.1.5 Problem 5: Scarcity of resources (environmental, land, finance)

According to the FAO (FAO, 2020):

> Valuing the hidden costs (or negative externalities) associated with different diets could significantly modify the assessment of what is "affordable" from a broader societal perspective and

reveal how dietary choices affect other SDGs. Two hidden costs that are most critical relate to the health (SDG 3) and climate-related (SDG 13) consequences of the general dietary patterns and the food systems that support these. The health and environmental consequences of unbalanced and unhealthy diets translate into actual costs for individuals and society as a whole, such as increased medical costs and the costs of climate damage, among other environmental costs.

The health impacts associated with poor diet quality are significant. Diets of poor quality are a principal contributor to the multiple burdens of malnutrition – stunting, wasting, micronutrient deficiencies, overweight and obesity and both undernutrition early in life and overweight and obesity are significant risk factors for NCDs (non-communicable –or chronic- diseases). Unhealthy diets are also the leading risk factor for deaths from NCDs. In addition, increasing healthcare costs linked to increasing obesity rates are a trend across the world (FAO, 2020).

Five dietary patterns and their estimated costs relating to climate-change and health were evaluated by the FAO; one controlled diet, to represent current patterns in food consumption, and four different and diverse substitutes that included foods from diverse food groups and additionally involved sustainability considerations. An analysis by the FAO found that health costs would see a considerable decrease of USD 1.2 -1.3 trillion if the substitute diets patterns were adopted. Compared to the benchmark scenario set in 2030, this would mean an average reduction of 95 percent of diet-related health costs globally (FAO, 2020).

The production and consumption of food may not only have major impacts on the consumers health, but also has a large environmental and climate change related significance. Around 21 – 37 of total greenhouse gas (GHG) emissions, are direct consequence of the world's current dietary patterns and the food system upon which it is built, signifying that the current food system is a major contributor to climate change (FAO, 2020).

Data limitations related to land use, water use and energy, obstruct global cross-country comparisons of important environmental impacts. As such, most global and cross-country evaluation of these impacts focus on GHG emissions as data is more readily available. In an emissions-stabilization scenario in 2030, the diet-connected social costs of GHG emissions relate to modern consumptions patterns were estimated to be around USD 1.7 trillion. Further evaluation of the FAO analysis mentioned above, shows that an adoption of any of the four substitute diet patterns could lead to major reductions of the social costs, between USD 0.7 to USD 1.3 trillion, of GHG emissions (FAO, 2020).

It is accepted that the negative effects of climate change are projected to affect communities that have the lowest capacity to adapt yet have the highest need to increase production in order to secure food and nutrition security. Increases in climate extremes exacerbate the vulnerability of food insecure populations and anticipates increasing impacts on agriculture and food systems. In the future, the possibility of localized warming of more than 4°C (above pre-industrial levels) will severely compromise the ability of agriculture and ecosystems to deliver food and environmental services – even with adaptation – and this will pose significant risk to food and nutrition security (FAO, 2020).

Considering that food-insecure small-scale producers will be the most adversely affected by climate change, and it becomes obvious that policy and practice will need to move in their favor. One of the greatest challenges governments face is how to ensure increased investment in sustainable, productive, equitable and resilient agriculture, through climate finance and agriculture finance.

Below in table 1, a summary was compiled of the various problems per key area which can be distinguished in respect of the main areas relating to food security, as discussed before.

Table 1 Food Security Challenges & Sub-Problems

MAIN FOOD SECURITY CHALLENGES	***SUB-PROBLEMS***
Limited availability & increasing demand	*Food waste & loss* *Too low production* *Limitations in making available agriculture lands* *Production/demand where-when-what not coordinated* *Non-diversified production (wrong incentives and focus)* *10 bln people in 2050* *56% of the world population currently are urbanized (Buchholz, 2020)*
Limited access	*Limited market access for farmer* *Limited market access for consumer* *Limited control on required diversity/on-demand availability* *Trade barriers* *Natural disasters, war, Covid-19*
Limited affordability	*Poverty* *Unemployment* *Trade tariffs* *Subsidies* *Too high prices (for the poor or certain income groups)* *Cost-increasing middlemen in supply chain* *Farmer receives too low price* *In transparency parties in supply chain and terms*
No proof of safe origin-process/healthy food	*Increasing regulations* *No proof of regulatory-compliant process-products* *In transparency production, handling, storage, transport throughout entire supply chain* *Unreliable data, lack of trust, lack of standards*
Climate change & shocks	*30% GHR related to livestock agriculture* *Reducing resources (land, financial means)* *SDG demands (2030): health & wellbeing (SDG 3), zero hunger (SDG 2)*

3.2 What kind of DLT and DLT associated technologies (in an applied context) currently exist, or are under development, that could be applied to solve the distinguished problem areas?

Before going into the details of the various DLT and DLT-associated technologies in paragraph 3.2.5, the relevant problems and specifics to potentially be solved or addressed with these technologies will be introduced below in paragraphs 3.2.1-3.2.4.

3.2.1 Food supply chains & food system

Our global food system is very complex. The same applies to global food value chains which are generally constructed with several independent organizations and may include multiple growers or cooperatives, independent processors, brand owners and retailers ((Schiefer, Reiche, & Deiters, 2013). Indirect service providers such as third-party logistics providers, food safety inspection and audit firms, certification bodies and analytical science laboratories are also involved (Schiefer, Reiche, & Deiters, 2013). There are lots of countries, products, stakeholders, and parties involved with lots of different languages, thousands of different regulations, and technologies as well as a potential hurdle to use technologies by, for example small holders, to take into regard. The promising side in respect of potential technology solutions is the exponentially growing global smartphone penetration rate which amounted in 2020 to 44.9% of all people on the globe, including developing countries (Statista, 2020). There are different regulations and different interpretations of transparency, meaning transparency may be seen as a threat in some countries. There is the assumption that transparency is good and wanted in the West, and that everyone sees it as such but unfortunately this does not apply in some regimes around the world (Keogh, 2020).

At a basic level, a food system can be regarded as a collection of parts (such as the food supply chain), and the relationships between these parts, see figure 3. It must also have at least one function or purpose. This distinguishes a system from just a collection of parts (IFSTAL, 2017).

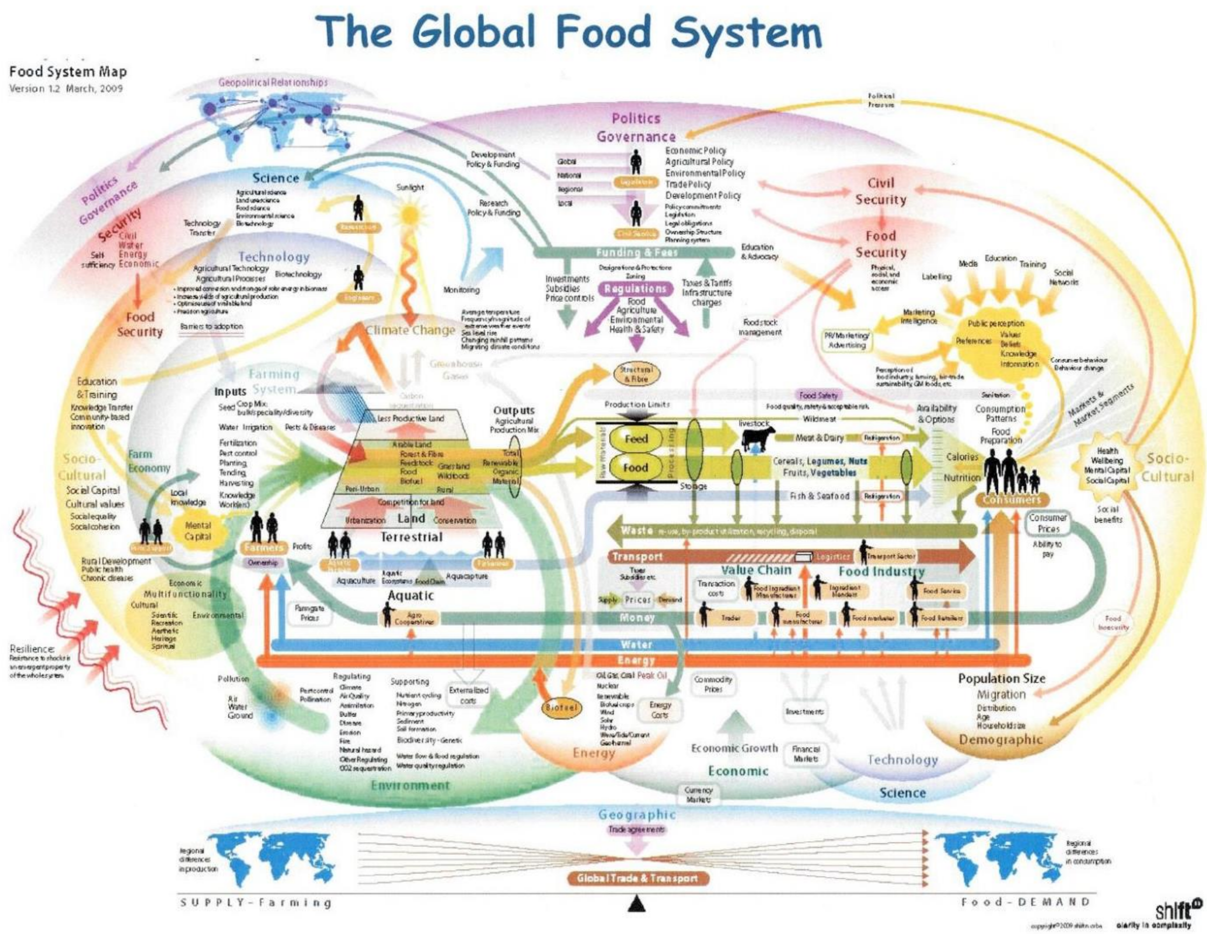

Figure 3 Global Food Systems Map (Nicholson, Stephens, Jones, & Kopainsky, 2019)

"There are essentially three challenges that can be distilled from trying to map or act on the food system: 1) incomplete knowledge, 2) the limitations of human cognition, and 3) limited capacity to act" (IFSTAL, 2017).

3.2.2 Transparency

Gerard Hofstede gives the following definition of transparency: "the extent to which all of a network`s stakeholders have a shared understanding of and access to product-related information that they request without lost information, noise, delay or distortion" (Keogh, 2020). Shared understanding brings up aspects like GS1 standards (i.e. a common language to identify, capture and share supply chain data) and the ability to agree on uniformly accepted product names. This brings up questions such whether to distinguish between master data and transactional data, what data are consumers interested in, and will there be different levels of accessibility to the data? Research shows that providing too much unrequested information can also scare consumers and make them respond negatively (Keogh, 2020).

Noise, delay, or distortion of data can be caused by a lot of things, for example lack of a shared understanding, but also lack of interoperability, a lack of standards and marketing-related additional information that is added but not relevant to the product, e.g., gluten-free tomatoes.

Hofstede states “if information is the lifeblood of an organization, then it is transparency that enables it to flow” (Keogh, 2020). Even in the case of relatively simple product such as an apple, it is important to let the consumers know the apple’s origins, whether it was genetically modified, if pesticides were used, etc.

The driver for transparency from a business perspective is competitiveness. This will determine what a company wants to share and what it wants to keep as a secret. On top of this comes of course regulation, which is another driver of disclosure and a driver of transparency.

On the two extreme sides of the disclosing and transparency scale there is a need to distinguish companies like Coca Cola, who will not want to disclose its secret recipe. Besides R&D, companies will also want to keep their suppliers, customers, costs and margins secret. On the other extreme side of the scale there are companies that embrace radical transparency. These companies have decided that they are going to share all their suppliers, their costs and margins. This is however, a unique scenario.

> Hofstede talks about three levels of transparency: 1) history-based transparency, 2) operations-based transparency, and 3) strategy-based transparency. History-based transparency can be compared to looking in a rear-view mirror. It is looking at what has happened upstream in the supply chain. Operations-based transparency is achieved when information is shared from a business-to-business (b2b) perspective. With strategy-based transparency the focus is on the future, and one is sharing bi-directional information which could include info on market entry, new products, co-developments, joint ventures, licensing and even things like the recipes and formulas and so on. This would only occur in a extremely close strategic relationship. (Keogh, 2020).

There are abuses and over-uses of transparency. Some corporations use transparency claims to cultivate the impression of full disclosure and consumers have come recognize and distrust these claims, sometimes unjustly. Having researched forty-five different eco-labels` sustainability rating and only one of these had a clear balance between transparency, neutrality/governance safeguards, expertise and explanations of the data, Graham Bullock speaks about the fact that 56 percent of Americans still do not trust companies' green claims. (Keogh, 2020).

3.2.3 Trust

Russo gave a multidisciplinary definition of trust as “a psychological state comprising of the intention to accept a vulnerability based upon positive expectations of the intentions or behaviors of another” (Keogh, 2020). A food supply chain will have different maturity levels when it comes to trust. There are different levels of maturity in supply chains which take time to develop, meaning sharing too much information prematurely, can put one at risk. When there is only limited trust only basic simple information will be shared out of fear of the severe risk of information. It takes time and investment to develop trust from basic trust to relationship trust and eventually collaborative trust.

According to Hofstede trust is both an antecedent of transparency and also an outcome (Keogh, 2020). In other words, people are trusting by nature, and accept risk within society and in all the things that they do. Trust is both an antecedent of transparency, and subsequently transparency can further enhance trust if it is clear, truthful, and honest. However, unfortunately, firms do not always behave ethically, as is exemplified with significant problems like food fraud food, adulteration, and other issues in the supply chain, such as product safety issues and quality issues. This is where analytical science comes in to restore trusts in firms.

Data provenance and scientific provenance are two very different things. Consequently, on transparency itself it is about sincerity, clarity, it is about honesty, credibility of the data and accuracy. Natural sciences (laboratory test confirmations, DNA tests and such) are the only way to prove with certainty that a product is what it says it is and where it is actually from.

Key here is to understand that whatever supporting technology one uses to gather and give access to data, the essence is on the quality and (verifiable) objective (and subjective) reliability of the data. Immutably linking any data on a blockchain for example only may have value if the data reliability is assured.

The Adelman Trust Barometer is a trust parameter developed and used over the last 20 years. It is a breakdown of aspects of trust in b2b and it also looks at governments, NGOs, media and industry which makes Adelman Trust Barometer one of tools that helps with achieving GS1. Related to GS1, the UK executed a project called a data crunch. They found between the four top manufacturers and the four top retailers, about one percent were consistent on their data and detected between 500 and 700 million pounds of inefficiencies over a five-year period that would have been passed on to consumers. This again indicates the importance to have data synchronization within the country and the ability to identify the difference between master data, transactional data and event data. Additionally, the authoritative source versus the custodian source needs to be identified (Keogh, 2020). These aspects are not very well understood by most industry players today but organizations such GS1 can be assist in helping organizations to understand the notion of the data creator being the authoritative source and the data users are consumers whether their systems are other platforms being the custodian and how to keep that all in sync (GS1, 2020).

3.2.4 Food traceability

According to the European Commission, food traceability is "the ability to track any and all food, feed, or substance that will be consumed, through all stages of production, processing and distribution." (European Commission, 2007). Because of growing food safety issues, both perceived and real, food safety and availability assurance systems in both developing and developed countries are becoming more stringent and demanding (Henson & Caswell, 1999). For consumers, traceability satisfies their safety needs in terms of health and well-being, and their expectations in terms of information. For authorities, traceability constitutes a means of risk prevention, proof of compliance and a means of localization in case of food crises (Montet & Dey, 2018). The above implies that an accurate and reliable trustworthy traceability system resulting in increased transparency in the entire food supply chain would not only be beneficial to individual companies but be valuable to all involved stakeholders.

The tracing of food products, along with their expiry dates and batch numbers, would be made possible by assigning the products unique digital identifiers such as QR codes and RFIDs (Radio Frequency IDentification). This could not only prevent food loss but would also allow consumers to calculate the ecological footprint of their food and ultimately guide the distribution of food (Antonucci, et al., 2019). Currently, a system called AgriBlockIoT does just that, guaranteeing transparent and auditable asset traceability. Using IoT devices to collect data along the supply line, AgriBlockIoT uses blockchain technology and smart contracts to create a decentralized food traceability system (Caro, Ali, Vecchio, & Giaffreda, 2018). Systems such as these have the potential to serve as examples for how food traceability systems will function in the future.

One of the most important sectors in the world for economic development is the agri-food industry. Despite representing a major percent of total manufacturing value in most nations and its importance to the GDP of these countries, the sector still faces challenges ranging from climate and environmental protection to meeting the growing demand of food and new legislation. To meet these new challenges agri-food industries have been greatly shaped by the technological operations in the manufacturing sector named ‘Industry 4.0; the fourth industrial revolution` that is focused on supplying tools, methods and machinery based on the use of ICTs through the digitalization of processes and services in conjunction with the active advancement of the Internet of Things (Miranda, Ponce, Molina, & Wright, 2019).

Although most of the agriculture and food (agri-food) supply chains solely track and store orders, recently there have been developments in a system utilizing Internet of Things (IoT) technologies and Distributed Ledger Technologies (DLT), such as blockchain, to create openly accessible systems allowing for transparent tracing and tracking of food products throughout the entire supply chain. This system however, is not without its inherent faults and issues (Caro, Ali, Vecchio, & Giaffreda, 2018). Sensors can collect information in a variety of different ways, for example, from measuring the temperature of the barn of a livestock farm or tracking the location of food that is being delivered to more complex tasks such as identifying and transmitting the presence of physical entities with biosensors (Astill, et al., 2019).

3.2.5 Technologies

Distributed Ledger Technologies

> Distributed Ledger Technologies have been receiving growing attention in recent years as an innovative method of storing and updating data between organizations. A distributed ledger is a digital ledger that is different from centralized systems and ledger systems in two distinct ways. First, information is stored on a network of machines, with changes of the ledger being reflected simultaneously for all holders of the ledger. Second, the information is authenticated by a cryptographic signature. Together, these systems provide a transparent and verifiable record of transactions. (Deshpande, Stewart, Lepetit, & Gunashekar, 2017).

In its very essence DLT is a database that exists across several locations or among multiple participants (as opposed to the currently mostly used centralized databases that live in a fixed location and essentially have a single point of failure). A distributed ledger is decentralized to eliminate the need for a central authority or intermediary to process, validate or authenticate transactions. Enterprises use distributed ledger technology to process, validate or authenticate transactions or other types of data exchanges. Typically, these records are only ever stored in the ledger when consensus has been reached by the parties involved through validation. All files in the distributed ledger are subsequently timestamped and given a unique cryptographic signature. All of the participants on the distributed ledger can view all of the records in question (transparency and accessibility). The technology provides a verifiable and auditable history of all information stored on that particular dataset.

At its core DLT are data structures to record transactions and a set of functions to manipulate them, with the main goal to allow users who do not necessarily trust each other to interact without the need of a third party (El Ioini & Pahl, 2018). This puts an inherent limitation on the scope of the afore mentioned key problems that DLT alone can solve. With the purpose of DLT in mind, problems best solved by increasing the transparency within the supply chain and thus ideally increasing trust and synergy between the actors, such as proof a safe and healthy food would be best suited for the implementation of various DLTs.

Blockchain

Blockchain is perhaps the most recognized form of DLT, to the point where DLT and blockchain are used synonymously in various literature sources. A blockchain represents a complete ledger of a transaction history consisting of data sets which are further composed of chains of data package, also known as blocks, see figure 4 below. This blockchain is subsequently extended by each additional block added. This block is called the genesis block. Each (data) block is marked with a 32-byte cryptographic identifier called a hash Since these hash values are unique, fraud can easily be detected as changes to a block would immediately change the respective hash values. By a consensus mechanism, a block can be added to the chain if the majority of nodes within the network (validators) agree on the validity of the block itself. This mechanism ensures that new transactions are stored in a block for a certain time before its added to the ledger. After this, the information on the blockchain can no longer be changed (Nofer, Gomber, & Schiereck, 2017), and blockchain therefore ensures immutability of the information.

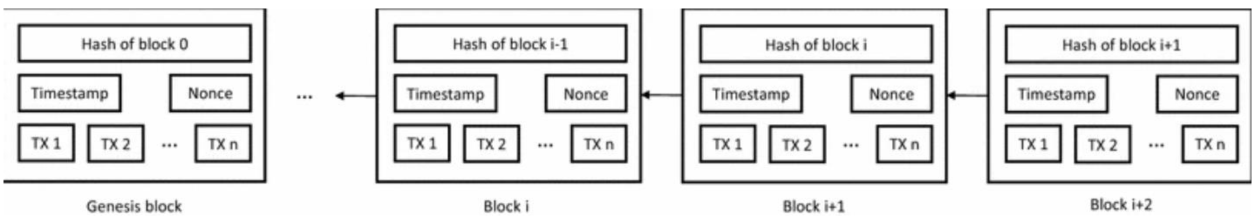

Figure 4 Example of a Blockchain (Nofer, Gomber, & Schiereck, 2017)

In general, there are three types of blockchain platforms: permissionless, permissioned, and private. Permissionless blockchains are open platforms that allow everyone to access and submit transactions, such as is the case with cryptocurrencies like Bitcoin or Ethereum (El Ioini & Pahl, 2018). Through an incentivization method, transactions are legitimized by 'miners' allowing for the identity of participants to be withheld and unidentified. Permissioned blockchains are platforms managed by a multitude of organizations where network participants are known, and a degree of control is in place. Private blockchains are managed by one organization with full control over the network. Permissioned and private ledgers do not require 'proof of work' to validate transactions and as such do not require an incentivization system. These ledgers are of interest to businesses as they can be distributed for closed communities that have overlapping but competing interests or can be held private for institutions that have the same interests (Deshpande, Stewart, Lepetit, & Gunashekar, 2017).

As explained above, blockchain as a concept is a great way to increase transparency within the supply chain, however, it is not a system that is foolproof. This is exemplified by the concept of scientific provenance versus data provenance. Data provenance is the description of a piece of data and the data processes by which it came to the database. Scientific provenance is information that is retrieved and can be verified through a scientific method. For example, in a case study where Walmart used blockchain to retrace a batch of mangoes in relation to a product safety recall, through data provenance traced the mangoes back to Mexico. However, when they looked deeper into the mangos scientifically, they discovered that the mangos actually originated from Brazil. This a case of data provenance versus scientific provenance and is one of the dangers that can occur when one solely relies on blockchain (Keogh, 2020). Another argument against the effectiveness of blockchains is the difficulty segregating the types of information that can be accessed once access is granted. This is a source of fear for some businesses, as their trade secrets and information could be shared unintentionally with competitors or partners in the same network (OECD, 2019).

Smart Contracts

The concept of smart contracts was already introduced in 1994 by Nick Szabo, who defined it as "a computerized transaction protocol that executes the term of a contract", which implies that smart contracts predate the idea of blockchain although smart contracts became well-known in the context of blockchain (e.g., Ethereum in 2015). The contractual clauses (e.g., collateral bonding delineation of property right, etc.) should be encoded and embedded in the required hard- and software. This minimizes the requirement of any trusted third party for communication using contracts and simultaneously protects the system against malicious attacks. When blockchain was introduced, smart contracts quickly became integrated as it allowed smart contracts to be kept secure with the involvement of a third party. Smart contracts have a platitude of uses to industries such as healthcare and the financial system, however, they are applicable in the supply chain too. When smart contracts are integrated with blockchain technology, smart conditions are developed that are executed every time a transaction occurs and then verified and validated by the nodes in the network (Mohanta, Panda, & Jena, 2018). The strength of smart contracts is also its weakness however. Since transactions in open blockchains are irreversible, an error in the smart contract cannot simply be updated but rather a whole new smart contract has to be issued (OECD, 2019).

Sensors

With the advancement of technology, new methods and tools are being developed to promote transparency in the supply chain. One such technology is the emergence of new sensors, allowing for new ways of data collection. These sensors are capable of collecting, storing, and analyzing data, and can be physically placed throughout and attached to all stages of the food production chain. Such sensors can collect information in a variety of different ways, for example, from measuring the temperature of the barn of a livestock farm or tracking the location of food that is being delivered to more complex tasks such as identifying and transmitting the presence of physical entities with biosensors (Astill, et al., 2019). These sensors can be managed, and their data can be accessed via the Internet of Things or IoT.

3.2.6 Suitability of DLT to solve food security related issues

In order to assess the suitability and applicability of DLT to solve food security related issues, below are a number of key factors that have to be considered.

Pros

Distributed Ledger Technologies can offer a wide range of advantages that are beneficial to agri-food supply chains, i.e.:

1. Trust is one of the things that can be expected from blockchain deployments as well as improved data governance. The promised benefits are improved transparency and security on information and improved sharing and trust of the data improved operational performance (Keogh, 2020).

2. Disintermediation as a result of the nodes being able to network directly without the need for a third party. This encompasses the capability to set up direct transactions of data, digitized data such as a cryptocurrency, or real-world assets such as land (Deshpande, Stewart, Lepetit, & Gunashekar, 2017). This applies also to food transactions and pre-orders.
3. The sharing of data and ease of access allow for new potential which can be attained by aiding the storage and access capabilities of various sorts of data for participants (Deshpande, Stewart, Lepetit, & Gunashekar, 2017).
4. DLTs provide the underlying mechanisms for smart contracts and enabling smart auditing capabilities (Deshpande, Stewart, Lepetit, & Gunashekar, 2017).

Cons

1. The utility of DLTs is not defined by the technology but by the context in which they are deployed. Blockchains as such are beneficial when applied to digital solutions such as cryptocurrencies but it is not the end all solution to all problems. A coherent encompassing application and solution have to be developed first, where DLTs can play a supporting role (Keogh, 2020).
2. DLTs are by nature quite energy intensive. With changes being made to multiple ledgers simultaneously, DLTs will require significantly more energy than centralized ledgers. This is more of a problem to permissionless ledgers than permissioned ledgers, since permissioned ledgers can be more easily managed and planned (Deshpande, Stewart, Lepetit, & Gunashekar, 2017). Of the two distinguished validation and mining systems that currently exist, i.e. proof-of-work and proof-of-stake system the proof-of-work system (as always used in permissionless ledgers currently for example) is more energy-intensive whereas more validators/nodes are involved).
3. Uncertainty around regulation hinders the implementation of DLTs. The understanding of how DLTs operate to the wider regulatory environment is a key element in the promotion of widespread use of DLTs (Deshpande, Stewart, Lepetit, & Gunashekar, 2017). Financial regulations are relevant particularly for cryptocurrencies and decentralized finance (DeFi) and payment solutions using DLTs.
4. AI technology is claimed in some cases to provide a faster and cheaper solution than blockchain. For example, Provision Analytics claims having measured its app against blockchain and claims that its solution is 4,666x faster and much less expensive (Keogh, 2020).

Recommendations

1. One of the clearly defined collaboration needs in solving some of the established food security challenges is centered around finding a data management solution to food security related issues. The UN Statistics Division launched a guide about data management needs and the SDGs (specifically focusing on data interoperability). They highlight the needs for effective data governance, standardized data languages and accessibility of data (Morales & Orrell, 2018).
2. High-integrity and good character firms need to start looking at GS1 standards which are critical to help solve the data problem. There are a few technology complexities that need to be discussed. Firstly, democratization refers to getting the technology out to more users, focusing on decentralization and disintermediation, taking out the middleman and, convergence of technologies. Another topic to consider is that when the world moves towards Society 5.0 there is the risk of mass surveillance and privacy breaches (Keogh, 2020).
3. Transparency and trust inherently have little to do with technology but more so with a firm's culture and needs to be embraced by the organization and its leadership as a whole. Organizational leaders

need to explain what transparency is in the context of their organization and what information is private, what information are corporate secrets, what information is allowed to be shared with their business partners and why, what information is shared with consumers, their know-how, etc. These are important considerations that have to be made before a firm even considers adopting DLTs.

3.3 What could the integral solution for a reliable supply chain of produce in the future in which DLT and DLT-associated technologies are embedded look like?

3.3.1 Overview of problem-solution aspects to be taken into regard

Table 2 below gives an overall overview of the main issues, sub problems versus the main solutions to the food security challenge. This overview serves as a checklist for consideration in thinking through systemic change solutions covering as many of those problems listed.

Table 2 Food Security Challenge Overview

MAIN ISSUE	***SUB-PROBLEMS***	***MAIN SOLUTION***	***MORE DETAILED SOLUTION***
Limited availability & increasing demand	*Food waste & loss* *Too low production* *Production/demand where-when-what not coordinated* *Non-diversified production (wrong incentives and focus)* *10 bln people in 2050* *56% of the world population currently are urbanized (Buchholz, 2020)*	*Reduce waste & post-harvest loss* *adequate food storage, good road infrastructure and good food preservation capacity* *Development and design of new technologies and regulatory frameworks, in addition to raising awareness, in a multi-stakeholder approach to food-waste reduction. (The Economist Intelligence Unit, 2018)* *Increase production/yield by (smallholder) farmers (demand-linked)* *Connect demand of customers (via retailer/platform) to farmers* *Increase productivity, yield (+ tackle environmental externalities)*	*Train/certify farmers (in cooperations) process, supplies, RWE compliance with all global regulations* *IoT/QR track & tracing from farm to fork (ongoing)*
Limited access	*Limited market access for farmer* *Limited market access for consumer*	*More local production and access points* *Digital global marketplace (better*	*Digital global assurance and marketplace platform connecting retail directly with farmer (through handling sales/*

MAIN ISSUE	**SUB-PROBLEMS**	**MAIN SOLUTION**	**MORE DETAILED SOLUTION**
	Limited control on required diversity/on-demand availability *Trade barriers* *Natural disasters, wars, Covid-19*	*access for farmers and retail – for the benefit of the consumer)* *Food, agriculture, trade policies (FAO, 2020)* *Physical access to food markets*	*distribution support centers)*
Limited affordability	• *Poverty* • *Unemployment* • *Trade tariffs* • *Subsidies* • *Too high price* • *Cost-increasing middlemen in supply chain* • *Farmer receives low price* • *In transparency parties in supply chain and terms*	• *Fair pay to smallholder farmers* • *Cut (most of) the middlemen* • *Food, agriculture, trade policies (FAO, 2020)* • *Increase productivity, diversification* • *Remove non-tariff trade measures*	*Social Economic Return program (toward food security related SDGs)*
No (availability/proof of) safe/healthy food	*No proof of regulatory-compliant products* *In transparency production, processing, distribution throughout entire supply chain* *Malnutrition: undernutrition and obesity*	• *Apply tax/tariff banners* • *Policies* • *Qualified products (proof of composition/production-handling, regulatory compliance, track-trace farm to fork)* • *Organized and controlled cool chain* • *Help introduce more plant-based proteins into the food system (The Economist Intelligence Unit, 2018)*	*IoT and blockchain enabled (track-trace farm to fork)*
Climate change & shocks	*30% GHR related to livestock agriculture* *Reducing resources*	*Local sustainable agriculture, processing & handling*	*Include regenerative farming principles, water and fertilizer*

MAIN ISSUE	***SUB-PROBLEMS***	***MAIN SOLUTION***	***MORE DETAILED SOLUTION***
	SDG demands (2030): health, zero hunger, no poverty		*management, in farmer education plan* *Involve national governments (investing and Social Return program)*

Important conclusions and recommendations from Keogh (Keogh, 2020) which are to be considered in addition to the above list are:

- Transparency and trust have to be matured at the same time (build trust and integrity in the supply chain).
- Technology does not replace natural science.
- Do not lead with technology and figure out what the problem is (technology is a tool, not an objective).
- Data and information quality are critical to success.
- GS1 standards are essential.
- Industry-wide proprietary platforms are not the solution.
- Standards-based interoperability is key.
- Current regulations are part of the problem so the one up one down concept as a minimum in traceability regulations is outdated and it is holding us back today.

And finally, the Fifth Assessment Report (AR5) of the International Panel on Climate Change (IPCC) lists a number of additional aspects and changes to consider transitioning towards sustainable food security (Pachauri, et al., 2014):

- **Remove subsidies**. The analysis of externalities must be improved, so that all perverse subsidies to agriculture that lead to unsustainable practices can be removed. Subsidies often tend to go to the large producers.
- **Improve farmers` access to finance**. Innovative mechanisms of getting finance need to be developed, especially private finance, from global and national institutions to farmers; mechanisms that both cut down on transaction costs and ensure more equitable and pro-poor outcomes. By making access to finance inclusive, scale and improved equity can be achieved.
- **Use practical farmer knowledge and science.** Learning by doing and co-generation of knowledge are key approaches to climate change adaptation; farmers need to be in the driving seat; but nonetheless recognize the need for breakthrough science (e.g. raising the temperature limits of various crops).
- **Focus on nutrition-related incentives to boost crop diversity.** Value chain approaches and productivity-focused research often led to reduced diversity of cropping, farming and landscape systems; incentives need to be created to maintain diversity given its crucial role in adaptation. Bringing household nutrition into community-based decision-making processes helps the understanding of the importance of dietary and thus crop diversity. Further nutrition-related incentives need to be developed.
- **Encourage farmer innovations by farmer field schools and other hands-on innovations.** Bringing ministries and communities together is critical but fostering farmer field and business schools, and other such approaches can deliver the final mile.

3.3.2 Systemic solution approach

A joint report by various institutions such as the FAO, UNICEF and WHO, suggests the following factors to be considered in developing a systemic solution approach:

> To achieve the dietary patterns for healthy diets that include sustainability considerations, large transformative changes in food systems will be needed at all levels. Given the large diversity of current food systems and wide discrepancies in food security and nutrition status across and within countries, there is no one-size-fits-all solution for countries to move from the status quo to achieving healthy diets and create synergies to reduce their environmental footprints. Assessing the context-specific barriers, managing (and sometimes enduring) short-term and long-term trade-offs, and exploiting synergies is critical.
>
> For countries where the food system not only provides food, but also drives the rural economy, it will be important to consider the impact of shifting to healthy diet patterns in terms of the livelihoods of smallholder farmers and the rural poor as well. In these cases, care must be taken to mitigate the negative impact on incomes and livelihoods as food systems transform to deliver affordable healthy diets.
>
> Many lower-income countries, where populations already suffer nutrient deficiencies, may need to increase their carbon footprint in order to first meet recommended dietary needs and nutrition targets, including those on undernutrition. On the other hand, other countries, especially upper-middle-income and high-income countries, where diet patterns exceed optimal energy requirements, and where people consume more animal source foods than required, will need to make major changes in their dietary practices and food environments as well as system-wide changes in food production and trade (FAO, IFAD, UNICEF, WFP and WHO, 2020).

Additionally, in both developing and developed countries the development of a sustainably embedded food system, both regionally and locally, rely on essential factors such as social well-being, environmental integrity, economic resilience, and governance. Policy makers are now faced with the mending these issues in developing a system that promotes the sustainability of production, processing, transportation, retail, consumption of food (Carsjens, 2020).

Carsjens continues (Carsjens, 2020):

> Economic resilience, environmental integrity, social well-being and governance of food systems is vital to the development of sustainable territorially embedded local and regional food systems both in developed and in developing countries. Improving the sustainability of and the consequent production of waste is an emerging challenge for policy makers and planners at all levels of geographical scale.

3.3.3 What could the integral solution for a reliable supply of produce in which DLT and DLT-associated technologies are potentially look like?

3.3.3.1 Food insecurity measurement

In order to measure progress towards accomplishing or improving food security a reliable and globally standardized measurement system of areas of progress and issues needs to be included in a systemic solution. The greatest advances in the measurement of food insecurity, and thus also in respect of food insecurity reductions, will come from the following three developments (Duan, Zhang, Gong, Brown, & Li, 2020):

First, a global network of sentinel sites using a standardized core survey protocol for regular, repeated household- and individual-level monitoring would enable us to track the co-evolution of multiple food security indicators with targetable individual, household, and community characteristics across continents and to rigorously monitor and evaluate the impacts of various policy and project interventions. The recent review of social sciences within the CGIAR calls for this, modeled in part on the National Science Foundation's Long-Term Ecological Research network. Second, if the predictive accuracy of different indicators in forecasting future food security states was better known, data collection could be more cost-effectively concentrated on measures of which tar-getable actions can be most reliably programmed. This would help overcome the breadth-versus-depth trade-offs that presently limit the availability of suitable time series data at the individual and household level. Finally, just as poverty research is moving beyond static, snapshot measures to dynamic mobility ones, especially with respect to critical behavioral thresholds, so must the food security research community begin developing measures based on longitudinal data that capture the risk of food insecurity that respondents routinely voice in perceptions-based measures (CGIAR, 2017).

3.3.2.1 GreenZone

Recently the opportunity presented itself to interview one of the co-founders of a new private business project called GreenZone of FET Global in Switzerland. FET (Food-Ethics-Transparency) Global has been working on a smart global multi-stakeholder systemic food security solution for several years now (involving tens of thousands of farmers including smallholders, local franchisee consultants and local certified key country distributor full-service centers, a large global so-called food TIC company (testing, inspecting, certification) as well as 35,000 retailers). FET is in the process of digitizing its solution in a global digital platform with substantial additional features and services. See figure 5 for a visualization. The essence of FETs systemic solution consists of:

1. Having gathered all global, local and retail regulations and standards that exist throughout every single step in the food supply chain from farm to trade, having translated these (and continuously updating them) into a database of measuring points resulting into self-assessment tool for farmers and standard operation procedures which together with local expert consultants (franchisees) are instructed and taught, implemented and monitored during all steps of the growing and breeding processes by the farmers of all 5 agricultural food groups. The farm, processers, distributors, and logistics will be certified, the (production) process is certified, and the product produced by the certified farm is qualified. Ongoing audits by TIC companies and scientific checks by laboratories are continuously taking place at all levels, which will also have a huge impact on the data quality and objective reliability of the food quality and data.

2. Various certified franchise Key Country Distributors per country are appointed who will serve as full-service centers (storage, handling, processing, distribution, invoicing, sales support) from farm to trade (retail or market).

3. Currently, FET is fully digitizing its solution which is being transformed into a digital qualified food assurance and market platform as described in the below figure, called the GreenZone.

4. A fully standardized franchise model by FET Global in each country will ensure fast scalability of the GreenZone Platform and concept

5. Furthermore, a percentage of each GreenZone transaction fee and turnover will be used by FET for social economic return (SER) projects to support the further acceleration and increase of food security as to be determined and executed together with local, regional and global authorities and NGOs (e.g., infrastructure, further awareness and economic empowerment programs of smallholders or population).

Figure 5 FET GreenZone Plan (FET, 2020)

The figures and ideas presented in this report are published with the consent of FET Global. The full storyline (process, procedures compliance, the whereabouts of produce including regular laboratory research and DNA checks) of each product from seed to trade (retail or market) will be directly linked to each product and are accessible via the QR code, which will be linked to various sensors in the IoT systems, which in its turn are all directly connected to the GreenZone Platform. Each stakeholder and client of the GreenZone Platform will have the agreed access rights to the GreenZone and its respective own personal dashboard. The various certified Key Country Distributors (KCDs) (FET franchisees) will pay the consultants, the farmers` education, and the farmers` certification costs to join the GreenZone Platform. The farms will interact with the GreenZone Platform via their smart tablets received from the KCD or via their smartphones (as ongoingly instructed and supported by the local consultants).

Certified farmers will accomplish higher yields and higher prices for their produce (depending on the produce quality category achieved, A, B or C). The standard operational processes result into environmental optimized growing processes with less waste, and less loss throughout the supply chain. Furthermore, the GreenZone Platform brings demand and produce offers together, which effectively gives retailers global access to farmers all over the world who are included in the GreenZone Platform. This also implies that pre-orders can be given globally to farmers which were previously out of reach for retailers which will enable different financial and economic models in the food security system. The KCDs will be managing the full supply chain and actions in respect of all produce from farm to market. The combination of having a proven concept which is being digitized in a global digital platform, working with strong strategic partners, local governments and local certified franchisees allows FETs GreenZone Platform concept to scale and expand fast.

The tech stack of the GreenZone platform will include cybersecure database and digital identification technologies (for farms, KCDs and foremost products with their QR-code), smart contracts, digital automatic payment systems, combined with blockchain technology. Certified and countless approved sensors/Internet of Things technology will be used by the KCD and the various players throughout the supply chain from KCD to trade to support the verifiable high-trust story line of each product from seed to trade (as managed under liability towards FET by the franchising KCDs).

To complete the full picture, below in figure 6 and 7, a summary is shown of the full description of “the GreenZone effect”, which is also aligned to the narrative and criteria of the relevant SDGs.

FETs GreenZone solution =

wise production + wise distribution + global digital qualified food assurance & transaction platform + scalable collaborations

GREENZONE SOLUTION	DETAILS OF SOLUTION	GREENZONE EFFECT	GREENZONE EFFECT IN SDGS
Wise agri-food production	**Farm does a structured self assessment (SAS)** on his gap analysis to establish required training and changes in environmentally-responsible, best production methods, supplies used (incl. water, fertilizers etc), processes (is-should) to ensure full regulatory and best practice compliance. When compliant and certified, farmer can qualify for 3 quality criteria A, B and C (with increasing requirements (e.g. EU compliant) and increasing price levels). **Local independent expert consultants (franchisees)** support, train and support with crop selection, diversity etc. (paid by KCDs). Audit processes also performed by consultants (in strict governance process)	• Middlemen cut out of the distribution chain / minimized marketing-sales costs (reduce cost) • Shorter delivery times between farm and retail/market (higher quality, healthier, safer) • Reduction of food waste and loss • Standardized supply chain for all 5 agri-food groups • Pro-active production planning and ordering • Farm has expanded markets access, sales assurance, full service center support by KCDs and consultant • Citizen has access to qualified safe and healthy products from certified farmers and KCDs with a reliable full track and tracing and storyline to each product	**BETTER AVAILABILITY AND ACCESS TO AFFORDABLE SUSTAINABLE SAFE AND HEALTHY AGRI-FOOD** **Driver of prosperity** • Higher productivity & yield farmers through innovation • Improvement of controlled transport infrastructure via multiple KCDs and their global KCDs in the network • Expanded markets and expanded market access for farmers, better access for citizens • Reduction of food loss and waste **Preserving resources** • Regenerative farming • Minimisation of water, energy, fertilisers, • Focus on maximization of local-local deliveries/coordination **Safe and healthy food** • Certified and audited farms • Qualified and audited products (Cat. A, B, C) • Certified and audited KCDs • Regular lab tests of products at the farm
Wise agri-food distribution	Select full-service KCDs, certify them in accordance with SOP. KCDs to provide all handling, sales and distribution services from farm to trade. Before being accepted KCD is certified/trained by local independent expert consultants. Audit processes also performed by consultants (in strict independent governance process).		

Figure 6 FETs GreenZone Solution (FET, 2020)

FETs GreenZone solution =

wise production + wise distribution + global digital qualified food assurance & transaction platform + scalable collaborations

GreenZone Solution	Details of Solution	GreenZone Effect	GreenZone Effect in SDGs
GreenZone global digital platform	• Key touch points of all-most stringent- local, global, retail regulations are included in SAS and certification procedures and criteria. These are integrated in every single detail and step of the Standard Operational Procedures (SOP) a farmer and KCD need to follow. • DNA scanning at farm • Farmer completes SAS, SOP details, product and crop codes via ipad to the GreenZone Platform (trained by consultant), proof of compliance and story linked to each product • Same for KCDs • QR tagging at KCD • Certification and Audits proof of signoff of products, farms and KCDs • IoT sensors in KCD linked to product QR to track-trace • Smart contracts place and pay food orders, pay platform fee • All data on track-trace from farm to trade hashed on blockchain (immutability)	• Full product & product journey life story tagged to each product • QR track-tracing of each product from farm to trade • Full regulatory (local, global, retail) and best practices compliance assurance of product and process full supply chain visible. • match supply-demand/trade, pre-ordering, • assessments, certification and education of farmers and KCDs • system produces full billing and lifestory information • Full pivot-table dashboard for each stakeholder	**BETTER AVAILABILITY AND ACCESS TO AFFORDABLE SUSTAINABLE SAFE AND HEALTHY QUALIFIED FULLY IMMUTABLY TRACED AGRI-FOOD FROM FARM TO TRADE**
Scalable collaborations towards food ecosystem	In each country: • Select, train, engage local expert consultants • Select, train, certify local KCDs • Collaborate with food TIC companies for certification in each country • Connect local and global retailers, market places • Work with country authorities and stakeholders Globally: • Connect all country GreenZone parties • Work with country authorities and stakeholders	• Proof of concept in country 1 to be duplicated in each country. • Expanding qualified products for local and global markets • Expanding network • Expanding database	New regulations and policies can easily be integrated continuously in the GreenZone Platform and its SOPs

Figure 7 FETs GreenZone Solution (FET, 2020)

To reiterate once again, FET`s GreenZone Platform provides an example of a far-reaching multistakeholder systemic solution to increase the reliability of the supply chain and increase food security, where DLTs are embedded into the system.

The multi-stakeholder approach of the GreenZone Platform results into a sustainable solution of almost all listed problems in paragraph 3.3.1. (as repeated below in table 3 in addition), which justifies calling the GreenZone Platform a solution towards a potential systemic solution for the food insecurity problem with DLTs usefully being embedded in this solution.

Table 3 Food Security Challenge Overview

MAIN ISSUE	***SUB-PROBLEMS***	***MAIN SOLUTION***	***MORE DETAILED SOLUTION***
Limited availability & increasing demand	*Food waste & loss Too low production Production/demand where-when-what not coordinated Non-diversified production (wrong incentives and focus) 10 bln people in 2050 56% of the world population currently are urbanized (Buchholz, 2020)*	*Reduce waste & post-harvest loss adequate food storage, good road infrastructure and good food preservation capacity Development and design of new technologies and regulatory frameworks, in addition to raising awareness, in a multi-stakeholder approach to food-waste reduction. (The Economist Intelligence Unit, 2018) Increase production/yield by (smallholder) farmers (demand-linked) Connect demand of customers (via retailer/platform) to farmers Increase productivity, yield (+ tackle environmental externalities)*	*Train/certify farmers (in co-operations) process, supplies, RWE compliance with all global regulations IoT/QR track & tracing from farm to fork (ongoing)*
Limited access	*Limited market access for farmer Limited market access for consumer Limited control on required diversity/on-demand availability Trade barriers Natural disasters, wars, Covid-19*	*More local production and access points Digital global marketplace (better access for farmers and retail – for the benefit of the consumer) Food, agriculture, trade policies (FAO, 2020)(GreenZone is flexible to adapt to any new regulation or standard)*	*Digital global assurance and marketplace platform connecting retail directly with farmer (through handling sales/ distribution support centers)*

MAIN ISSUE	***SUB-PROBLEMS***	***MAIN SOLUTION***	***MORE DETAILED SOLUTION***
		Physical access to more food markets	
Limited affordability	• *Poverty* • *Unemployment* • *Trade tariffs* • *Subsidies* • *Too high price* • *Cost-increasing middlemen in supply chain* • *Farmer receives low price* • *Intransparent parties in supply chain and terms*	• *Fair pay to smallholder farmers* • *Cut (most of) the middlemen* • *Food, agriculture, trade policies (FAO, 2020)* • *Increase productivity, diversification* • *Remove non-tariff trade measures (not included in GreenZone)*	*Social Economic Return program*
No (availability/proof of) safe/healthy food	*No proof of regulatory-compliant products* *Intransparent production, handling, transport throughout entire supply chain* *Malnutrition: undernutrition and obesity*	• *Apply tax/tariff banners (not included in GreenZone)* • *Policies (GreenZone is flexible to integrate any new policy)* • *Qualified products (proof of composition/production-handling, regulatory compliance, track-trace farm to fork)* • *Organized and controlled cool chain* • *"Help introduce more qualified plant-based proteins into the food system" (The Economist Intelligence Unit, 2018)*	*IoT and blockchain enabled (track-trace farm to fork)*
Climate change & shocks	*30% GHR related to livestock agriculture* *Reducing resources* *SDG demands (2030): health, zero hunger, no poverty*	*Local sustainable agriculture, processing & handling*	*Include regenerative farming principles, water and fertilizer management, in farmer education plan* *Involve national governments (investing*

MAIN ISSUE	***SUB-PROBLEMS***	***MAIN SOLUTION***	***MORE DETAILED SOLUTION***
			and Social Return program)
Keogh recommendations *(Keogh, 2020)*		• *Mature transparency and trust in parallel* • *Data and information quality are critical* • *Standards are essential* • *Standards-based interoperability* • *Full transparency from seed to fork*	
AR5 report recommendations *(Pachauri, et al., 2014)*		• *Improve farmers` access to financing.* • *Use practical farmer knowledge and science* • *Focus on nutrition-related incentives to boost crop diversity* • *Encourage farmer innovations by farmer field schools and other hands-on innovations* • *Support markets & value chains for low-income producers and consumers*	

4. Discussion of results

The objective of this research report was, using literature review, to determine the extent to which the agri-food supply chain could be made more secure (and thus improve food security) through the integration of DLTs in the food supply chain within the next ten years. From the various sources used in this report, the general use of DLTs and their application in securing the food supply chain has been illuminated.

Food insecurity in the agri-food supply chain is mainly caused by four factors: limited food availability, food unsafety, limited food access, and limited food utilization. These are the four generally accepted key problem areas that have to be ensured in order to solve the issue of food insecurity (Barret, 2010). Thus, an integration of DLTs that is effective in reducing food insecurity must, at least in part, solve one or more of the key problem areas. This is an important realization since any development or innovation in DLTs that is not able to fulfill this base requirement can immediately be written off as an irrelevant technology to the purpose of this research and allows for the creation of initial criteria in selecting relevant DLTs.

With food being a basic requirement of survival, related literature has been written about it for decades and as such, there was no shortage of information to be found on the topic. Since the chapter is based on reliable literature review and well-established concepts, this section serves as a satisfactory base and transition into the next chapter.

DLTs and DLT-associated technologies such as blockchain, smart contracts, and sensors were selected as relevant technologies that were best suited to be applied in solving the previously named problem areas. These technologies have the potential to increase trust between the actors of the chain by increasing traceability and transparency in data and transactions (Deshpande, Stewart, Lepetit, & Gunashekar, 2017), and as such an ideal system that integrates DLTs incorporates these three technologies.

The scope of DLTs inherently limits the specific issues the technology can solve in terms of food security. In researching DLTs in literature, some issues were encountered. For example, due to the relative immaturity of this new technology, the terms of DLTs are not yet clearly defined. Several literature sources use DLT and blockchain interchangeably, even though when delving deeper it became clear that although the terms are related, they are in fact not one and the same. Small disagreements of term definitions made it more difficult to follow the various arguments, and undoubtedly influenced the interpretation of the technology, and thus potentially the reliability of the results. Additionally, it should be mentioned that the topic of DLTs is so detailed and complex that it deserves its own research report. However, for the sake of comprehensiveness, only the information concerning DLTs relevant to this report has been written down and explained.

In terms of a potential reliable solution with embedded DLTs, the company FET Global has created a solution for a seemingly reliable food assurance solution with embedded DLTs called the GreenZone Platform. This system relies on the collection, representation of and compliance with all local and global retail regulations throughout every step in the agri-food supply chain. These regulations and standards are translated into a database of measuring points which are then turned into a self-assessment tool (SAS) for farmers, education and certification programs and standard operation procedures (SOP). These are thereupon implemented and monitored in the digital GreenZone platform, and the products are tracked and traced with the use of amongst others DLTs (FET, 2020). However, FET is not the only one developing such a food track and tracing system; FET`s uniqueness is in combining this system with the SAS, SOPs and resulting measuring points from a myriad of regulations, the GreenZone Platform and its franchising system, which altogether is intended to be a systemic solution. AgriblockIoT for example, also aims at using Blockchain and various IoT technologies they propose to create a system that guarantees auditable and transparent traceability throughout the whole supply chain (Caro, Ali, Vecchio, & Giaffreda, 2018). The fact that various institutions are attempting to create a DLT reliant system speaks for the effectiveness of this technology may have on increasing food security in the current food supply chains, thus painting a picture of the potential future of the food supply chains as technology progresses.

The writing of this chapter was heavily influenced and inspired by FET Global`s presentation of their current operations and innovative operations. However, although it does inject a certain amount of bias, this focus on FETs activities is not necessarily a negative thing. FETs arguments and solutions are in line with the conclusions and arguments made throughout the rest of the report and backed up by the literature review, meaning that in terms of narrative the overall significance of FETs solution is one that is relevant to report as a whole. At the same time however, because FET is so heavily incorporated in the solution to this question it may seem like FET is the only integral solution, and although FET does provide a great real-life case study, it is not the only solution.

5. Conclusions & Recommendations

5.1 Objective of the research

The United Nations` Food and Agriculture Organization (FAO) defines food security as "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life." (FAO, 2020).

The World Health Organization officially recognizes "that foodborne diseases significantly affect people's health and well-being and have economic consequences for individuals, families, communities, businesses, and countries" (WHO, 2002) and outbreaks of foodborne diseases have the potential to damage the economy and overall public health, capable of damaging a nations tourism and trade, leading to a loss of earnings and increased unemployment (Aung & Chang, 2014).

Additionally, malnutrition is taking a heavy toll across developing and developed nations. More than two billion adults, adolescents and children are now obese or overweight. The consequences are severe for public health, for national wealth, and for individuals' and communities' quality of life.

Today there is more than enough food being produced to feed every last one of us. Yet, with the world population expected to reach ten billion by 2050, the demand for food security and increased production is rising (Tomlinson, 2013). There is a large need to create resilient, productive, and sustainable food systems that are able to provide safe and nutritious food. On way firms are attempting to achieve this goal is by improving the current traceability system or by designing new food traceability systems.

Digital innovations such as the Internet of Things or Distributed Ledger Technologies stand at the forefront of this new revolution.

Consequently, the objective of this report is to answer the overarching research question of *to what extent can today`s agri-food supply chain be made more secure within the next ten years by integrating distributed ledger technologies?*

5.2 What are the key problem areas in the agri-food supply chain causing today`s food insecurity?

In short, food insecurity can be attributed to four factors: **food availability** (I.e., "having viable access to sufficient quantities of nutritious and affordable food"), **food safety** (I.e., "the production, handling, processing and storage of food in order to prevent foodborne illness"), **food access** (I.e., the affordability and spatial accessibility of food and its retailers), and **food utilization** (I.e., ensuring adequate nutrition in household through the effective use of food, ultimately reducing food waste).

Furthermore, these four factors can be further divided into six main general scenarios: 1) the limited availability of food due to conflicts and climate-related shocks, 2) the limited availability of food due to loss of food, 3) limited access to food, 4) high costs, low affordability (and utilization) of healthy diets limiting access across different country income groups, 5) scarcity of resources (environmental, land, finance), and 6) the lack of global policies and standards (FAO, 2020).

5.3 What kind of DLT and DLT-associated technologies (in an applied context) currently exist, or are under development, that could be applied to solve the distinguished key problem areas?

Distributed Ledger Technologies (DLT) are simply put data structures designed to record transactions, combined with a set of functions to manipulate them, with the main goal to allow users who do not necessarily trust each other to interact without the need of a third party (El Ioini & Pahl, 2018). This puts an inherent limitation on the scope of the aforementioned key problems that DLT alone can solve. With the purpose of DLT in mind, problems best solved by increasing the transparency within the supply chain and thus ideally increasing trust and synergy between the actors, such as proof a safe and healthy food would be best suited for the implementation of various DLTs.

However, although DLTs do bring a varied amount of benefits with them, they do come with their own share of issues. On the one hand, DLTs provide improved transparency and security on information, allowing to be verified without the need of an intermediary. As a result, trust between the actors is increased. On the other hand, however, there are various negatives surrounding DLTs. Uncertainty surrounding regulations around the technology hinders a greater adoption of the technology (e.g., data, identity, privacy, financial). In addition to DLTs being relatively energy-intensive, there are also claims that certain AI technologies are able to compete with DLTs but are faster and cheaper.

Considering these points, three technologies were ultimately selected that were thought to be best suited to solve the distinguished key problem areas when used in conjunction:

a. **Blockchain**. A blockchain represents a complete decentralized ledger of a transaction history. It is also the most well recognized and adopted form of DLT, and thus has vast software opportunities surrounding it.

b. **Smart Contracts**. Smart contracts predate the conception of DLTs and are in essence computerized transaction protocols that execute the terms of a contract. When integrated with DLTs such as blockchain, smart contracts allow for development of smart conditions which are automatically executed by the software before every transaction (OECD, 2019).

c. **Sensors**. Sensors are capable of collecting, storing, and analyzing data, and can be placed throughout all stages of the food production chain. Such sensors can collect information in a variety of different ways, for example, from measuring the temperature of the barn of a livestock farm or tracking the location of food that is being delivered to more complex tasks such as identifying and transmitting the presence of physical entities with biosensors (Astill, et al., 2019). These sensors can be managed, and their data can be accessed via the internet (which is also called the Internet of Things or IoT).

5.4 What could the integral solution for a reliable supply of produce in which DLT and DLT-associated technologies are potentially look like?

Solving the food security causes named in paragraph 5.2 is not something that is feasible solely with the implementation of DLTs. However, a system that implements these technologies in its design has the potential to in a unique manner, if not solve, at least improve these issues.

Currently a company in Switzerland called FET Global (note: FET stands for Food-Ethics-Transparency) is trying to do just that. Under its GreenZone digital platform, the essence of FETs systemic solution consists of having gathered and processed all global, local, and retail regulations and standards that exist throughout every single step in the food supply chain from farm to trade. These regulations have been translated (and are continuously updated) into a database of measuring points resulting into a self-assessment tool (SAS), continuous training programs for farmers and standard operation procedures (SOP), which together with local expert consultants (franchisees) are instructed and taught to the farmers. At this point in time, FET is in the process of fully digitizing its solution which is being transformed into a digital qualified food assurance and market platform called the GreenZone Platform. The SAS, SOP, certifications, and food tracing throughout the entire supply chain from seed to trade are then implemented, ensured and monitored via the aforementioned DLTs and DLT associated technologies. This will lead to dashboards and storylines for each single product of all 5 agricultural food groups during the entire supply chain from seed to trade. The farm, the consultant and the key country distributors will be certified, and the product produced by the certified farm is a tagged qualified product. Ongoing audits by TIC companies and laboratories are continuously taking place at all levels, which will have a huge impact also on the data quality and reliability of the food quality and data. Multiple certified franchise Key Country Distributors per country are appointed who will serve as full-service centers (storage, handling, processing, distribution, invoicing, sales support) from farm to trade (retail or market) which cuts out several middlemen, shortens the supply chain, reduces risks for food loss and costs. The GreenZone platform thus directly connects farmers with an extended market which the farmers through the full-service support of the local KCDs and local consultants will be able to serve with secure food through the GreenZone platform. The SER (social economic return) program of FET Global, in addition, provides for further acceleration potential to achieve food security for all by contributing a fixed percentage of its turnover to SER projects and infrastructure towards food security which will be defined, selected, and executed in close collaboration with local and global authorities and stakeholders.

FETs GreenZone Platform is just one example of what a possible food security solution where DLTs are used advantageously and implemented systemically, can look like. And it may offer template or indication how similar systems in the future will develop.

5.5 To what extent can today`s agri-food supply chain be made more secure within the next ten years by integrating distributed ledger technologies?

As is hopefully made apparent by the answering of the previous three sub questions, DLTs on itself are not the sole answer to increasing food security. What DLTs can do however, is increase traceability and transparency assurance within the supply chain and between the actors, thus increasing trust and ideally the quality assurance of the food that is purchased by the end consumer.

It is only when integrated into a larger system, that DLTs truly will be able to shine. By giving new digitized systems the guarantee that transactions logged are truly proven transparent and immutable, new innovative systemic solutions will have an easier time being integrated into the food system if proven successful, since the data which is openly available to the involved parties is validated by DLTs.

5.6 Relevance of Results

The results obtained by this report are relevant to the extent of the specific connection between DLTs and their capabilities of increasing food security. The technology is of DLTs is not compared or evaluated against competing technologies to whether there are more suitable technologies better suited to increase food security. As such, this report should not be viewed as the singular or even optimal solution to the issue of food insecurity that food system suffers from.

5.7 Recommendations

The results of this report may be used as preliminary or supporting research when investigating on how to integrate DLTs or similar technologies in a system that combats the issue of food insecurity, or a project in a similar vein of thinking. In essence this report serves to inspire further research on the topics of DLTs and/or food security. It is recommended that in the short term, a practical experiment where a system like FETs is carried out on a small scale to assess first-hand the initial costs and benefits that a system with integrated DLTs brings with it. In the longer term, after the initial practical experiment, it is recommended that another literary review is done on DLTs, as the industry and the technologies are progressing rapidly, and significant developments may have been made between then and now.

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