Smart and Sustainable Food: What is ahead

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Abstract

Food systems are evolving to support sustainable food security. In this chapter, we aim at discussing the role that digital technologies play, especially those with the potential to provoke deep changes. The ongoing revolution in this field has given birth to the so-called Agrifood 4.0. Our interest lies also on the impact of digital technologies in the food chain, from production to consumption, especially the case of food loss and waste. In fact, the growing use of ICT in this field may generate game-changing effects, which can be positive or negative, affecting productivity, sustainability, and other aspects. We consider both present and future scenarios, looking at the potential of novel techniques - as for instance 3D printing of food, use of blockchain, and smart packaging - taking into account the sustainability criteria proposed by the Agenda 2030 of the UN to assess the changes on tasks and procedures all along the food chain.

Keywords: food systems, digital technologies, game changers, blockchain, SDG

1.0. Introduction: the socio-ecological problems of the agri-food sector

Since the mid-60s, there is a growing awareness that the industrial socioeconomic system, as it is set, is environmentally and socially unsustainable. After the Earth Summit in Rio de Janeiro in 1992, the concept of 'sustainable development' was outlined as a strategy to cope with socio-environmental problems related to modern society activities. From that date, sustainability is the main challenging issue of international politics. This concept includes three intertwined pillars: economic growth, environmental protection, and social equality. In short, the aim is to meet human needs in a fair way among social groups not compromising the ability of natural systems to provide the natural resources and ecosystem services on which societies depend. Sustainable development can be defined as the economic development that meets the needs of the present without compromising the ability of future generations to meet their own needs. To define concrete actions in terms of sustainable goals, large-scale initiatives were born at the international level, like the United Nations (UN) Millennium Development Goals in 2000, and more recently, the UN Sustainable Development Goals (SDGs) or 2030 Agenda, approved in 2015[1]. Recently, some scholars and international agencies identify a strong connection between the concept of sustainability (and SDGs) and the 'circular economy' (Geissdoerfer et al., 2017, Schroeder et al., 2019; Esposito et al., 2020). Circular economy means a closed-loop economic system aiming at the use, reuse, sharing, repair, refurbishment, and recycling of the resources. It has the potential to minimise the use of resource inputs and the creation of waste, pollution, and carbon emissions. In this frame, all by-products recovered from an industrial process should be considered as natural resources (e.g., compost) or for another industrial process (e.g., recycled iron as a secondary raw material).

In this scenario, the agri-food sector is involved in the SDGs initiative to prevent the environmental degradation, the climate change, the loss of natural resources, but also to increase the social equity on food accessibility, the economic benefits for smallholders and healthy diets to reduce diseases for under- or over-nutrition. As FAO reports (FAO 2011; FAO, 2019; FAO 2020), the agri-food sector presents a relevant problem along its chain production that can be considered as a good example of future food system challenges: in fact, around a third of edible goods per year is lost or wasted. Despite differences, this phenomenon is common

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[1] https://www.un.org/sustainabledevelopment/development-agenda.

among world areas. Nearly 35% of cereals, for example, are lost or wasted in industrialized countries, while in Sub-Saharan Africa and South and Southeast Asia the value is around 20%. In developing countries, it mainly occurs at post-harvest and processing levels, while in industrialized ones it happens especially at retail and consumer stages. The urgency to adopt solutions for this phenomenon is undoubtedly an ethical issue also because, according to the FAO et al. (2020), around 9% of person in the world suffers from undernourishment and severe food insecurity. However, Middle Africa and Eastern Africa countries record the worse food conditions (respectively, 29.2% and 26.9% of population suffers from poor nutrition). Still, it also represents a socioeconomic and environmental problem. First, food loss and waste worsen the ecological footprint of the industrial alimentary productions because it causes a too intensive use of land, water, chemicals, and energy required by food production. To feed the increasing world population (more than 9 billion people by 2050), the food system can be pushed to increase the ecological pressure of the alimentary production, thus increasing the climate change factors, contributing cause of floods, droughts, the extinction of pollinating insects, etc. These effects can further reduce food availability, security, and quality. Second, production costs and food prices tend to increase because of food loss or waste, causing the contraction of both the farmers' incomes and access to food for low-income social groups. Consequently, it can worse socioeconomic asymmetries between rural areas and cities, social groups and nations, possibly pushing for massive immigration, social tensions and other phenomena.

In the above-mentioned context, the food waste represents an example when dealing with unsustainability in relation to the agri-food system in the 'business as usual' model (FAO, 2017; Annosi et al. 2021), which contributes to destabilizing the socio-ecological assets of societies. Socio-cultural features of farmers (e.g., skills, knowledge, traditional farming methods), low financial capacity, limited cooperation among food producers, a not adequate connection between producers and consumers, lack of food information for customers, among others, are some of the reasons that contribute to the lost and waste alimentary goods, perpetrating unsustainable agricultural practices. This issue could be faced through an innovative way to produce, store, distribute and purchase alimentary goods. Agriculture is not only involved to reach the goals of zero hunger (SDG2) and responsible consumption and production (SDG12) but, directly and indirectly, it can contribute to all of SDGs (FAO 2018). For example, protecting natural resources or increasing productivity, employment and value addition in food systems are aspects linked with several SDGs. In short, transforming the international agri-food system contributes to face not only specific sectoral problems but also several other connected issues.

How to promote the agri-food change? Is it possible to accelerate such a change to better adapt to the incipient climate change and the growth of the world population? According to some studies and reports, this challenge can be supported by digital technologies (De Clercq et al., 2018; García Zaballos et al., 2019; Panetto et al., 2020; Annosi and Brunetta, 2020) that can promote the circular economy principles in this sector (Fassio et al., 2019; Del Borghi et al., 2020).

The rapid spread of digital technologies – e.g., blockchain, internet of things, artificial intelligence – is disruptively changing not only industrial sectors, slowly moving into the so-called 'Industry 4.0' stage, but also the agri-food system, igniting the 'Agrifood 4.0'. For example, the adoption of mobile technologies, remote sensing, and distributed computing are improving smallholders' access to information, inputs, market, finance and training, creating opportunities to integrate them in a digitally-driven agri-food system (OECD). Scholars stress that digitalization of agri-food chains transforms farm management of natural and economic resources throughout a highly optimized, individualized, intelligent, and anticipatory system (Lezoche et al., 2020). Driven by data, in a real-time and hyper-connected environment, food value chains become traceable and coordinated at the most detailed level, from production to delivery and consumption steps. Crops and animals can be accurately managed to their optimal prescriptions. Digitalization of the agri-food sector is going to create systems that are not only highly productive but also anticipatory and adaptable to changes, such as those caused by climate changes or consumer preferences. This, in turn, could lead to food security, profitability and sustainability (Miranda et al., 2019; El Bilali et al., 2020). In short, digitalization of the agri-food sector can potentially close the gap with the SDGs targets. It can also deliver social benefits (communication and inclusivity or rural communities) and economic rewards (agricultural productivity, cost efficiency, market opportunities) supporting sustainable environmental productions (optimized resource use and adapting – and partly fighting – climate). In this sense, digital tools can be game changers (e.g. IoT in rural areas (Bacco et al., 2020)), as to say an element (an entity, a rule, an activity) that generates a deep change in the ordinary routines (the 'game'), a significantly changes how the system operates, as well as its inputs, its outputs and its outcomes.

Several works have also focused on the different socio-economic contexts and on the limits and opportunities of digitalization of the agri-food sector emphasizing limits and opportunities of this ‘smart’ revolution (Deichmann et al., 2016; Kabbiri et al., 2018) observing that, despite some positive impacts of digitalization, often these are not relevant as expected due to the socio-economic barriers and cultural aspects that characterized farmers in the poorer countries. Works on rural Africa (Oliveira-Jr et al., 2020) or Middle East and North Africa region (Bahn et al., 2021) observe how digitalization can be a great chance for these areas. But to promote a fair and affective adoption, policies need to focus more on socio-territorial contexts where tools will be applied considering environmental and social challenges related to smart technologies in agri-food sector and rural communities.

1.1 Smartness and sustainability

Most farming communities do not possess knowledge, skills, and financial resources to understand, adopt and use profitably and fairly new digital methods of food and livestock production (Srivastava, 2018). In the Global South, for example, farmers work in a not-friendly socioeconomic and political context (failure of states, weak banking institutions, high level of corruption, predatory behaviour of intermediaries, etc.) with low, but increasing, digital infrastructures and connectivity. At the same time, the digitization process also comes with controversial social, ethical, and normative issues. What data should be shared, with whom, how to guarantee data security, who owns data, which limits on data availability and data processing, who and how benefits of digitalization and who not, etc., are questions that call to set policies – and practices – to govern these troubles (Scholz et al., 2018). Nevertheless, (Srivastava, 2018) reports that farmers are particularly motivated to learn and to adopt digital technologies if they understand the benefits related to digital tools, such as: how to cope with natural adversities (e.g. drought, flood, pest attacks), how to improve harvest yield (e.g. optimal use of seeds, fertilizers, water), how to get financial gains (e.g. benefits of the government policies and banking institutions), and how to sell their products more profitably in the market. They are also sensible on sustainable issues and to the chance to reinforce the community's resilience against socio-environmental challenges, thanks to the adoption of digital solutions. In short, while digitization can be a strategy to address the relevant socio-environmental problems of the agri-food supply chains, like the food loss and food waste, there is also a need for appropriate policies that consider the barriers to its diffusion and potential negative impacts of it.

At the international level, a good example of sustainable agri-food policy comes from the European Union. In 2015, the EU contributed to the definition of the UN's 2030 Agenda, and in 2016, it adopted the Paris Agreement in advance with respect to other countries. At the end of 2019, with the EU Commission's communication for the European Green Deal[2], this interest in ecology issues turned into the commitment to transform the continent into the first climate-neutral economy by 2050. For this, some programs have been defined as the 'Farm to the Fork Strategy' (F2F Strategy)[3]. Through this initiative, the Commission aims to make the agri-food system fair, healthy, and environmentally friendly. The EU recognizes the need to redesign food system because of its ecological footprint (greenhouse emissions, overuse of natural resources, biodiversity loss), but also because of its negative health impacts and social inequalities (under- or over-nutrition, different access to food) and not fair economic returns especially for primary producers. The F2F strategy aims to design a food system resilient to crises, such as the pandemic one and climate change, and socio-ecological sustainable intervening in production, processing, distribution, and consumption steps. In this strategy, the prevention of food loss and waste is a pivotal point and stakeholders consultation aims to adopt action to promote the F2F in a more equitable way. In this strategy, sustainability issues are tied to new technologies and technoscience research.

The Common Agriculture Policy (CAP) proposed by the Commission in June 2018 aims at facilitating the investment support to improve resilience and to accelerate the green and digital transformation of the agri-food sector. These measures should promote better use of data to optimize inputs (e.g., sensors of the soil of plants help to optimize the use of pesticides, fertilizers, and water) and to adopt a more results-oriented business model. Some solutions are expected to enhance traceability systems to counteract frauds (like the digitized catch certificates to prevent illegal fish products). At the same time, other innovations could improve the accessibility of clear food information to make easy for consumers to choose food for healthy and sustainable diets (e.g., QR codes as a solution for smart packaging). Through the example of the EU F2F strategy, it

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[2] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. The European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

[3] https://ec.europa.eu/food/farm2fork_en

emerges how ‘smartness and sustainability’ are the axes on which agri-food policies are designed to cope with contemporary environmental and social challenges.

This chapter, therefore, intends to propose reasoning on the role of digital technologies in the agrifood sector, as well as some considerations on their possible impacts through examples. However, it is evident that digital opportunities and impacts are also related to the socio-economic and cultural context, and that policies have a pivotal role to address a just and socially sustainable adoption of smart solutions in the agrifood sector.

2.0. The Role of Digital Technologies

AgriFood 4.0 aims at achieving robust, resilient, and sustainable agri-food supply chains, among other objectives; such an objective is a challenging one, given the uncertainty and risks connected to the agricultural production (Lezoche et al., 2020). For instance, because of external complex factors that cannot be controlled, such as weather, market behaviours, and policies; some of those are hard to forecast as well, making it very difficult to react quickly to changing trends. Because of those factors, agricultural supply chains are often pressured to implement digital solutions to e.g. real-time monitoring the flows of materials, products, and associated data, so that reacting as soon as possible to changing factors should be easier than in the absence of digital tools. The possibility of faster reactions to changing conditions should be considered a driver of the *digital transformation* process, fed by digital data. Thus, supply chains are expected to transform into data-driven supply chains in the next future, changing the shape of the agricultural sector. Key features of this new concept are the *sensing*, *smart*, and *sustainable* features (Miranda et al., 2019), that should be considered as game-changing concepts. In the authors’ view, sensing is the capability to collect data as measurements of physical phenomena; smart refers to the ability to react to sensed data by implementing actions (*actuation*); sustainability embeds the idea of optimising both the use of materials during the production process (e.g. reducing the use of potentially dangerous substances, like chemicals in agriculture) and the characteristic of final products, in the sense that their social, economic, and environmental footprint can be measured and assessed. Sustainability can be used as a metric also during the design of new processes and products, not only as an ex-post one. In this way, compliance with pre-determined objectives is more likely to occur than in the case of corrective actions in an already running system designed without those objectives in mind. According to (Keoleian et al. 1994), several requirements are to be met for a process or a product to be defined as sustainably designed: 1. selection of low-impact materials; 2. minimal weight or volume of materials in products; 3. cleaner techniques in manufacturing; 4. reduction of the impact due to packaging and distribution; 5. reduction of the impact due to use and maintenance of products; 6. optimization of the lifecycle; 7. end-of-life management through reuse, remanufacturing, recycling, or safe disposal.

Data analysis strategies represent key tools of the underlining *digital transformation* process. Given the very high volume, velocity, and variety (3V) of digital data that supply chains will provide, Big Data techniques are to be considered one of the first assets. In fact, such a huge amount of data is not manageable with common tools, thus calling for new strategies, such as those studied and put forward by Big Data methods. For instance, Europe produces more than 700 million tons of agricultural waste per year, according to 2005's analyses (Pawelczyk, 2005); the amount of data produced by tracking it would be as huge as the amount of waste itself. As said above, the ability to follow those flows through sensing techniques is at the very basis of actions to measure and track the phenomenon of interest, such as waste; once data can be collected, corrective actions can be undertaken. Consider another case, the so-called *sustainable intensification* of agriculture: on the one hand, intensification means more waste due to the use of more resources, thus undesirable; on the other hand, intensification is needed in the presence of decreasing availability of land, and/or a growing population, thus increasingly necessary. The question is: can digital transformation bring any benefits? Can novel strategies or trade-offs be identified whether huge amounts of data are available? Answering is not straightforward, but Decision Support Tools (DSSs) are the class of services and applications that attracted the most interest in such scenarios because they allow decisions to be supported by data. More generally, if the whole supply chain were to be *sensed*, meaning that data would be available at every step, a digital image of the supply chain would be available. In the case of high-quality data able to properly represent the key features of a supply chain, new scenarios will open, based on a combination of simulation, optimization, and data analytics techniques: a *digital twin* of a supply chain (Ivanov et al., 2019). Digital twins are a game changer as put forward in Industry 4.0 strategies, which can be understood as digital replicas of systems. In more words, if physical entities and events can be digitalized through sensing techniques, the generated data can be used to generate a digital image of those entities and events, which is as dynamic as them. Thus, the interconnection of physical and digital worlds gives birth to novel concepts - the so-called cyber-physical systems - producing new tools. What makes them functioning is the data collected from the physical world, then elaborated into information to support decision making. The quality of the achievable decision-making support strongly depends on data and their features like completeness, validity, timely availability, and correctness. Looking at the supply chain as a cyber-physical system, for instance at the case of agricultural production (Dumitrache et al., 2017), the cyber part is its novel face, and with it the services and applications running on top of it, such as a dynamic allocation (or reallocation) of e.g. production and delivering. In other words, while DSSs can reinforce decision making through the use of data, digital twins open the exploration of new scenarios through a simulation-like process, allowing to understand the effects of decisions -- at least to a certain extent, and based on the premise of being able to model the supply chain -- before actually implementing them in reality. A core requirement is the availability of a model (or a set of models) describing a supply chain; subject to this, a digital twin can fully operate. Anyway, such a requirement is a hard-to-satisfy one, calling again for the introduction of novel techniques to meet it. So, as Big Data can be understood as the enabler of advanced analysis in the presence of 3V data collected through wide-scale sensing, Artificial Intelligence (AI) can provide the needed capability for modelling purposes in the presence of large and complex phenomena, such as the food chain. Two main tasks can be described for an AI powering a digital twin: the derivation of a model of the phenomenon under observation (if not already available), and the actuation of actions to modify the state of the system towards the desired objective. The second task can be performed only once the inner mechanisms (model) of the supply chain are known. In Baryannis et al., (2019), the authors consider the potential of AI in risk management to mitigate the impact of any events on the supply chain or part of it, as for instance the aforementioned external factors that are difficult to be prevented. According to the authors, for a risk management approach to be considered as *artificially intelligent*, two requirements must be satisfied: autonomy, and the capability to operate in partially unknown conditions. The former means that the AI-powered strategy is able to undertake a successful course of action on its own, and the latter means that the autonomy requirement is met also in the presence of new conditions, i.e. not seen before by the intelligent agent. The thorough overview presented by the authors highlights that this field requires additional exploration because of the limited ability of the surveyed tools to operate autonomously when applied to supply chains; some tools are even unable to properly support the decision-making process, or at least it is really unclear how due to the lack of empirical evidence. Lots of work is still necessary to close the gap between available tools and their applicability to real systems.

2.1 Blockchains for supply chains

As discussed in the previous section, supply chains are subject to unknown and sometimes quickly-changing conditions, making it difficult for operators to react fast in the presence of changes. The larger the scale of the supply chain, the more hard-to-predict and hard-to-counteract events may occur. In this view, *sensing* and *smart* features have been presented before as desirable ones in supply chains because of the possibility to gather data at each step of the supply chain (*sensing*) and to implement actions on the chain (*smart*), both as new actions and as reactions to occurring events. A soft goal that a supply chain must satisfy is increasing *sustainability*, meaning that the impacts of materials, products, and processes must be as reduced as possible. In order to collect actionable data from the food chain, traceability is a core requirement. Centralised, or even standalone information systems collecting and storing data related to food chains exist today, but the collected data is partial, often not in the form of open data available to all the involved stakeholders. More trustable, comprehensive, and reliable solutions are needed, and closed-data solutions cannot be the answer, thus calling for distributed and decentralized solutions with different degrees of access to data according to the specific actor, providing actionable information to measure and assess the sustainability according to regulations and any other metrics in use. Information about timely provenance of goods and services must be available in a secure, clear, and trustable manner: the blockchain can be a very useful digital tool in this regard (Saberi et al., 2019).

In short, the blockchain, a specialization of the distributed ledger paradigm, is a database in which each data block is linked to the next one. No data block can be altered in a retroactive manner because this would cause the following blocks to be invalidated, thus immediately highlighting the illicit action. A distributed ledger is a distributed database, which means that a copy of it can be hold by each participant, and, according to the specific implementation, the rights of each participant on the ledger can vary, ranging from permissioned solutions (only authorized participants can perform actions on it) to permissionless ones (all participants can perform actions on it). Another distinction is on the access to the contained in it because the ledger can be public (anyone can have a copy of it and read data) or private (only authorized participants). The combination of these basic solutions provide flexibility: for instance, the digital ledger used by Carrefour[4] to trace some of its products is a permissioned ledger, based on the use of the IBM Food Trust[5] commercial solution. Carrefour's partners have access to the ledger to add new transactions, i.e., new data about the products later resold by Carrefour (Manhaeve, 2019). Anyway, external actors (e.g. customers) cannot have a copy of the Carrefour ledger, but only access its data through QR codes available on the product packaging, getting information through a web page that opens once the QR code has been decoded. Details on the transaction are accessible from the web interface, like the timestamp, the block header, and the transaction ID; in other words, clear references to the block in the ledger where the data are actually stored, and when data have been added. Anyway, the whole system behaves similarly to a classical database for external actors because they cannot have a copy of the whole ledger, thus somewhat contradicting the original purpose of a digital ledger but safeguarding commercial interests. From the Carrefour's partners viewpoint, the use of a ledger means that the activities are better standardized (i.e., how and where data are to be input, which types of data are to be provided), thus better aligning the way all the actors operate. It is easier for control and certification authorities to be added as authorized entities to the use of the digital ledger, thus facilitating their work and improving both the thoroughness of the verifications and the quality of final products through the identification of anomalies made evident by data. Digital ledgers offer additional features which may prove useful in several contexts, as for the instance *smart contracts*, which can be described as self-executing functionalities residing within the blockchain to facilitate, verify, or enforce the negotiation or performance of a contract (Christidis & Devetsikiotis, 2016). Smart contracts are procedures stored in the ledger, with a unique address (as all other data), and can be triggered by addressing a transaction to it: according to the data included in the transaction, the functionality is executed. The example provided in (Christidis & Devetsikiotis, 2016) helps in clarifying the exact functionality: user A is interested in exchanging X against Y with a pre-defined exchange rate (e.g., one X every five Y). Thus, when user A wants to trade X, he deposits e.g. three units of X into custody (the deposit of the smart contract), waiting for someone wanting to exchange them according to the aforementioned rate. Say that user B is interested in it, thus calling the transaction and offering ten

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[4] See details at: https://www.carrefour.com/en/group/food-transition/food-blockchain

[5] See details at: https://www.ibm.com/blockchain/solutions/food-trust

units of Y: the exchange occurs (two units of X are exchanged with ten units of Y), and user A can decide whether getting back the remaining unit of X, or leave it available for other exchanges. Apart from the technicalities, this example of a smart contract is conceptually equivalent to a transaction occurring on an online platform: a user buys object X that is on sale, paying it with Y units of the currency in use. Another example can be related to assets tracking: a container and its content must be delivered from the production site (A) to the destination site (B) by using a courier. The courier arrives at A, calls the smart contract implementing the 'pickup' functionality, and a digital document certifying the pickup is generated and stored in the ledger. The same occurs at the destination side B, where the 'deliver' functionality is available: once triggered, the exchange between the courier and the receiver is performed, and digital proof of it is stored in the ledger. In order for the digital ledger to be able to scale up rapidly, distributed solutions are required; in fact, centralized solutions will generally underperform, especially in the case of a large volume of data and transactions to be performed. Going back to the case of a supply chain, only distributed solutions are feasible, meaning that more copies of the same ledger are used in a peer-to-peer fashion, providing a robust solution. Furthermore, such a solution is more transparent because each transaction has a publicly auditable proof. Such proof can establish e.g. data or product ownership without the need for a central authority.

2.2 Novel packaging techniques for food

As blockchain can support sustainability by collecting data, other tools can be used in different points of the supply chain. For instance, packaging solutions, as protection of the inside products, are common objects for all customers. Their purpose is also to communicate information about the product, to ease the transportation phase providing containment, and in some cases to offer additional possibilities, such as heating in a microwave. Traditional packaging is being slowly substituted by novel solutions, able to interact with the product inside to e.g. prolong its shelf life (*active packaging*), to provide more detailed information capturing e.g. ripeness of the product through sensing (*intelligent packaging*), or to track and trace plus monitoring the product during its life (*smart packaging*. Novel packaging solutions can be seen as a further extension of the paradigm of Internet of Things (IoT), which sees common objects transforming into connected ones, able to provide data to other entities on e.g. their status, or the status of the products inside in the case of food. The use of new materials and of small and low-cost chips is at the very basis of novel packaging. For instance, antimicrobial packaging (Zhong et al., 2020) and Radio Frequency Identification (RFID) transmitters can be used to prolong the shelf life and to track and trace the location of a product, contributing to creating an image of a supply chain, item by item. Those data can be stored into digital ledgers, and smart contracts can be automatically triggered in the presence of specific events. Repositories of smart contracts are flourishing on the Internet, and ready-to-use solutions for supply chains can be found (e.g., the SCTS system[6] based on the open-source Ethereum implementation).

Attaching solutions like QR codes or RFID tags to physical assets transform those into connected and smart objects. What kind of services can be designed and offered once such a practice will be more widespread? According to (Li et al., 2017), in the case of pre-packaged food, the phases of assembling (food with its package), disassembling (the food from its package), and the transaction phase (e.g. delivery) can be thoroughly tracked. Evaluation and warning services can be put in place, the former as a means for customers to easily provide feedback on products, and the latter to quickly spread urgent information related to e.g., unsafe products.

2.3 The potential of 3D printing for future food

3D printing, or additive manufacturing, has already shown lots of potential in several scenarios. In the case of food, the simplification of supply chains is possible (Liu et al., 2017). This means that manufacturing activities will move closer to customers, thus reducing the volume of delivery services, packaging, distribution, and related costs. Furthermore, new sources of food can be added to the existing ones, such as insects, plants fibers, and by-products. In this way, the list of ingredients to be used in food recipes can grow exponentially. Several potential applications of 3D printing to the food sector can be identified (Yang et al., 2017). Considering the nutrition aspect, food can be personalized or rethought in order to appear as desirable as e.g. chocolate, but with a clear nutritional objective in mind; for instance, taking into account people's lifestyle and appetites, or incorporating nutrient-dense ingredients. Novel shapes, textures, flavors can be created, and fresh food can be prepared. Today, 3D bioprinting techniques are used by e.g., KFC to create chicken meat without involving animals in the process. The so-called bio-meat removes the need for additives, according to KFC, reducing the overall environmental impact.

3D printing of food is still in a very exploratory area, thus it is difficult to forecast its acceptance from people and the impacts it may have on the food systems.

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[6] https://devpost.com/software/scts

Affordable 3D printing machines are available on the market, but those systems are not designed for food production yet, which may still need several years of research before being ready for mass production. Anyway, some future scenarios may be of interest for 3D printed food, as for instance the case of hospitals or people with special needs: food with a controlled composition can represent both a therapy and a feasible way, from an economical point of view, for large structures to print/produce large quantity of meals satisfying specific needs. Texture-appropriate food can be of support in similar contexts, encountering larger acceptance.

3.0 Impacts and solutions

The use of a blockchain in the food sector is a recent phenomenon with the potential to address several issues that have always affected the food chain system, from farm to fork, such as food safety, loss of food, traceability, consumers trust (Kamilaris et al., 2019; Sylvester, 2019; Bumblauskas et al., 2020). From farm to fork means the inclusion of all those passages from production to consumption involving several subjects such as producers, food operators, insurance companies, public authorities, certification bodies and most of all consumers (Kamilaris et al., 2019). It is referred to as a chain because each ring of it corresponds to a different and sometimes complex phase, which can be shorter if the products are sold as fresh ones and without certifications, or longer in the case products are processed, certified and internationally traded (longest extension). In the following paragraphs, the chain is firstly going to be considered as a single ring containing others within a specific section such as agri-food or animal breeding, and secondly as the entire chain from production to consumption, mentioning the correspondent impacts and focusing on those cases impacting on food waste.

When referring to the agri-food production phase and animal breeding several digital technologies can be combined such as IoT, AI, RFID (Kayikci et al., 2020) in order to provide detailed data into a blockchain. It means that all different productions phases can be inserted in the chain, tracked and consequently monitored by the producer or breeder in the first instance, and by a controller in case of certification (e.g. organic) or all those subjects that carry an interest to get information about that specific phase within the food chain when needed. In facts, there could be information that is automatically gathered in the blockchain (e.g. information about the quantity of milk produced by a cow and the feed consumption indicating health conditions), while others have to be inserted by the producer (e.g. the certification of the utilized seeds – grain production). The activities carried out are traceable ones, meaning that there can be several positive impacts: social benefits for the producers or breeders that could devote less time (in case of automation) on administrative issues; better and safer products with a consequent impact on people health; societal as trust increase both among food operators or food operators and consumers (Sylvester, 2019; Kayikci et al., 2020); economical as the income increase generated by the gained trust or the possibility for a faster and automated control in case of a certification authorization, with the consequent administrative burden reduction (in terms of costs and dedicated time) (Kamilaris et al., 2019); environmental such as food waste reduction. At the same time, from the literature analysis, in particular concerning blockchain, negative aspects emerge, such as, among others, reduced accessibility to the blockchain utilization caused by the costs of the equipment or digital illiteracy of SMEs and privacy issues (Kamilaris et al., 2019; Feng et al., 2020; Köhler et al. 2020; Kamilaris et al. 2021; Liu et al., 2021).

At the consumer level, there is the possibility of a higher level of safety for food because it would be possible to recall food products in the case of foodborne illnesses (Kamilaris et al., 2019). At the same time, food fraud could diminish because the controls are easier, thus generating positive impacts for consumers in terms of wellbeing, and in terms of brands integrity for the industrial sector (Chang et al., 2020). Considering the economic sustainability, food operators could have impacts in the activity management field through an automated contractual phase (Kayikci et al., 2020) and a possible increase in selling due to renewed consumers' trust, being able to get information about a product and to control that none of the food chain processes has been altered; facilitate financial transactions in developing countries (Kamilaris et al., 2019). There are also negative social impacts when considering that the use of the technology might be costly and consequently not accessible, even causing for some actors to be excluded because not complying with the use of the blockchain.

From the environmental viewpoint, the blockchain can reduce food waste and loss because of enhanced traceability. In fact, food loos and waste can occur in several passages of the sector chain and in particular: production, postharvest, processing (food losses) and distribution, consumption (food waste) (Kummu et al., 2012; Mao et al., 2018; Kayikci et al., 2020). The loss of food can be described as lost production (lost while growing it or harvesting within the farm); postharvest loss is the one due to improper storage or transportation conditions (between the farm and distribution); processing loss occurs during the transformation of the products; finally, distribution loss is generated in the markets or grocery stores because the food is not properly stored or remains unsold for too long (Kummu et al., 2012; Kayikci et al., 2020). Reducing or eliminating the food loss and waste can help in implementing the UN SDGs, because of the immediate benefits both in terms of food security and of waste of resources; in particular, SDGs 2 (Zero Hunger); 7 (Affordable and clean energy) and 12 (Responsible consumption and production); 13 (Climate action); 17 (partnership for the goals) (FAO 2018) are those impacted.

3.1 Tech-based solutions for food waste and loss

In this section, we show a sample of available solutions exploiting data coming from the food chain to reduce food loss and waste. A key case study is the pilot programme run by Walmart in China to coverage the pig market, based on the use of the IBM Food Trust commercial solution (Kamath, 2018). The blockchain is based on the use of the Hyperledger Fabric implementation, with a modular architecture. Walmart collaborated with the government for piloting such a test. Each animal is tagged with an RFID chip, capturing its movements through cameras in the farms. Also, during the shipping phase of the meat, sensors are used to capture data verifying the compliance with regulations for safe conditions, and Walmart can trace the position of trucks during their travels. All the data are stored in the blockchain, and a QR code can be used to read information about each product package. Other solutions that are becoming popular in the market are those based on a more collaborative approach and exploiting simpler yet effective systems, such as online platforms and mobile applications. Through those, people, food producers and food resellers can offer surplus or close to date food to different types of consumers. A summary is provided in Table 1.

Table 1: solutions for the circular economy (own elaboration)

Type of solution	**Name of the solution**	**Case study**	**Technology**	**Coverage of the supply chain**	**Food loss and waste**
Blockchain-based	IBM Food Trust	Walmart pigs chain in China	Hyperledger Fabric permission-based collecting data from RFID tags on animals and from sensors all along the delivery process	The whole process can be tracked, from the birth of the pigs to the customers	The pilot has demonstrated the capacity to document post-cumulative losses due to inefficiencies in the process
Online coordination platform	Foodmesh	Canada-wide food recovery network	Online marketplace	Distressed, close to date and overstocked products	The program is successfully running having recovered more than 2 million kilograms of food
Online coordination platform	Olio	Connection among neighbours and among businesses and people	Mobile application to browse, add, and pickup food. Online	Surplus products or close to date ones (even non-food)	The initiative claims almost 1 million members and almost 1.5 million portions of food shared

Online coordination platform	FoodCloud	Born for the Irish market, slowly expanding globally	Mobile application linked to a cloud platform where markets / producers can offer surplus food to charities	Surplus food	More than 45.000 charities are supported through this programme
Online coordination platform	Too good to go	UK based, slowly expanding globally	Mobile application backed by a cloud-based system	Surplus or close to date food that can be bought by clients at very cheap prices	More than 2.5 million portions of food sold through the platform

Conclusion, Opportunities and Future Challenges

In this chapter, we focused on the agri-food sector, especially on the food chain. The aim is in providing a better understanding of how digital technologies can support such a crucial yet complex system, which is slowly transforming into a global cyber-physical system. Initiatives like the EU Farm to Fork recognizes the role that technology can play in this regard and pushes for increasing use of systems able to collect data all along the chain to identify and resolve inefficiencies. We discussed how core features like sensing, smart, and sustainability are to be considered central in this regard, promoting the collection of data at every step, storing them in distributed systems like distributed ledgers, thus opening to the use of analytics to provide support to those in charge of regulating the food system. Furthermore, initial steps are being made in the direction of digital twins of food chains to explore novel and more efficient strategies. Even if uncertainty and risks cannot be fully counteracted using digital solutions, yet more robust, resilient, and sustainable agri-food supply chains can be achieved, able to react to sudden variations in trends. From the point of view of environmental sustainability, the impacts of digital technologies are yet to be assessed as well in this field because of their recent introduction. It is argued whether digital technologies may improve the overall footprint because the environmental impact of technologies must be considered along with the impact of food production. Large efforts are being poured into making more energy-efficient both technologies and food production, and in collecting relevant data to measure and assess their environmental footprint. Another theme is related to socio-economic impacts of digital technologies, which may worse socioeconomic asymmetries, as discussed in this chapter. Discussions on this theme have not yet reached satisfying conclusions. For this reason, it seems useful to inquiry the current role of digital technologies in the agri-food sector, the way how they are game changers, able to face future sector challenges, and their plausible impacts.

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