The Age of Foodtech: Optimizing the Agri-Food Chain with Digital Technologies

Andrea Renda

1 Introduction: Digital Technologies as Enablers of Sustainable Development

Looking at current trends such as the resurgence of nationalism in politics, deteriorating rule of law in many countries, new protectionist stances and tariff wars in trade, short-termism in social policy and reiterated denial on climate change, the agreement reached in September 2015 by 193 countries on the Sustainable Development Goals (hereinafter, the SDGs) seems to belong to a very distant era in human history. Indeed, much has changed since then, with the United States reaching a record low in its commitment to SDGs, Brazil entering a new era of populist government and China struggling to show leadership on environmental, and even more social, achievements. In this relatively gloomy atmosphere, digital technologies are increasingly recognized as an essential contributor, if not the real lifeline, to achieve the 2030 goals. And the debate has gradually become broader, and deeper: while the possible contribution of digital technologies to the SDGs has initially been limited to the discussion of Goal 9 (industry, innovation, and infrastructure), there is now a well-established understanding that digital technology can help drive progress for all goals, and it might be essential to harness this potential to be able to reach the goals by 2030, as time is running out. Untapping this potential requires that policymakers integrate technology developments into a coherent policy framework for the achievement of the SDGs. This is not yet happening, in particular when it comes to emerging, disruptive and pervasive digital technologies that bear the highest

A. Renda (✉)
CEPS, Brussels, Belgium

College of Europe, Bruges, Belgium
e-mail: andrea.renda@ceps.eu

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potential for SDGs, such as blockchain and (more generally) distributed ledger technologies,[1] the Internet of Things, and Artificial Intelligence (hereinafter, AI).

This chapter looks at the current developments in digital technologies, as defined in Sect. 2 below, which also illustrates the prospective impact of technologies like AI, the Internet of Things, and blockchain on the agri-food chain. Section 3 discusses possible use cases in various parts of the value chain, with specific emphasis in particular on smart and precision farming, value chain integrity, personalized nutrition and the reduction and prevention of food waste. Importantly, the cooperation of the private sector is considered, alongside with the need for awareness-raising and education in order to empower users in the agri-food chain. Section 4 briefly concludes by projecting humanity into 2030 and discussing possible shifts in technology that may further disrupt the agri-food chain, for good.

2 Big Data, AI, IoT and Blockchain: The "new stack" and Its Impact on the Agri-Food Chain

The past few years have been characterized by the rise of a new wave of technological developments, which promise to revolutionize the digital economy, bringing it towards and era dominated by dramatically superior computing power and connectivity speeds; a skyrocketing number of cyber-physical objects connected to the Internet (the so-called Internet of Things, or IoT, powered by nano-technology and by 5G wireless broadband connectivity); and the pervasive spread of AI into almost all aspects of personal and professional life. This new stack will be composed of powerful hardware, including faster processors (mostly a combination of CPUs, GPUs and TPUs); distributed computing capacity through edge (or fog) computing; new, distributed and decentralized platforms such as blockchain, able to keep audit trails of transactions and other asset-backed values; and a pervasive presence of AI-enabled solutions, mostly in the form of data-hungry techniques such as smart analytics, deep learning and reinforcement learning (Renda 2018, 2019). Focusing on all layers of this emerging stack is extremely important when it comes to scaling up these technologies to the benefit of society: merely focusing on one element, such as AI or blockchain, would not harness the full potential of this emerging world.

Figure 1 portrays the technology stack. The Internet of Things (IoT) layer generates an unprecedented amount of data, requiring sensor technology, nano-tech, enhanced connectivity through 5G or satellite, and devices like drones or robots, able

[1] Distributed ledger technology (DLT) is a digital system for recording the transaction of assets in which the transactions and their details are recorded in multiple places at the same time. DLTs do not rely on centralized data storage or administration. Blockchain is a specific type of DLT in which a log of records is shared by means of blocks that form a chain. The blocks are closed by a type of cryptographic signature called a 'hash'; the next block begins with that same 'hash'.

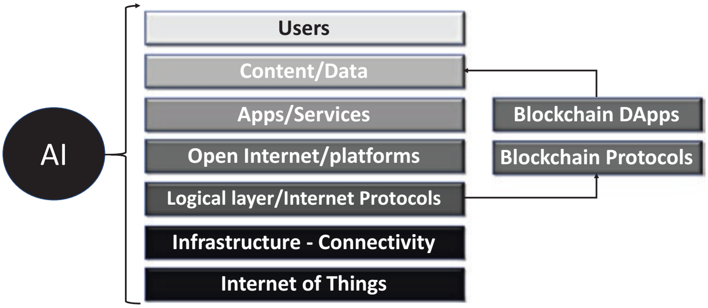

Fig. 1 The emerging digital technology stack. Source: Author's elaboration

to generate live data remotely.[2] Regardless of the way in which data are generated, stored and exchanges, the use of AI will be ubiquitous in most supply chains. At the top of the supply chain, end users very often constitute the weakest link, due to the need to equip them with adequate skills in using digital technologies (Renda 2019).

Although no real estimate of the combined impact of these technologies on the future economy exists, several studies have already been published on the economic impact of AI, as well as on the impact of IoT in specific sectors. For example, recent reports by Accenture/Frontier Economics, McKinsey and PWC conclude that AI will be a game changer for total factor productivity and growth, by gradually rising as a third pillar of production, together with labor and capital. PWC (2018) concluded that by 2030, global GDP will be 14% higher due to AI development and diffusion; the Accenture study (Purdy and Dougherty 2017) finds that growth rates will be doubled by 2035 thanks to AI. The latter study also shows an industry-by-industry breakdown, which includes agriculture, forestry and fisheries: this sector is expected to more than double its growth rate by 2030, from 1.3 to 3.4% on a yearly basis thanks to AI. Similarly, the Internet of Things is expected to massively contribute to future growth: by 2020 approximately 30 billion devices are expected to be connected to the Internet, and according to one recent forecast the number will soar to 125 billion in 2030 (IHS Markit 2018). ARM, a big semiconductor firm recently acquired by Softbank, predicted that there will be as many as one trillion connected devices in 2035 (Renda 2018). Finally, distributed ledger technologies are expected to complement these developments by solving several market failures along supply chains, as well as empowering end users in their consumption choices; some commentators go beyond these expectations, and foresee a revolutionary impact of blockchain in many sectors, including agriculture and food, as will be explained in Sect. 3 below.

[2] Data can be stored in various ways, including through remotely accessible, cloud-enabled solutions; through distributed databases; or through distributed ledger technologies such as blockchain. Some of these technologies are key enablers of value chain integrity, monitoring and trust, since they produce "audit trails" that enhance the verifiability of transactions and contractual performance across the value chain.

3 Key Changes in the Agri-Food Chain

Changes triggered by digital technology in the agri-food sector can be located along a number of areas, ranging from precision farming to the empowerment of small farmers, the promotion of supply chain integrity and traceability, better signaling of food quality to the end users, and support for the circular economy with more effective management of food waste (Bonanno and Busch 2015). Below, we briefly describe and discuss each of these changes.

3.1 Precision Farming: Promise and Perils of Smart Agriculture

A recent report by the World Economic Forum (2018) observed that smart agriculture has the potential to "fundamentally change agriculture even more than twentieth century mass farming methods did"; and these changes "may spread more rapidly than previous ones"; in particular, Artificial Intelligence could enable farms to become almost fully autonomous (WEF 2018). Farmers will be able to grow different crops symbiotically, using AI to spot or predict problems and to take appropriate corrective actions via robotics. For example, should a corn crop be seen to need a booster dose of nitrogen, an AI-enabled system could deliver the nutrients. AI-augmented farms could also automatically adjust crop quantities, based on supply and demand data. This kind of production could be more resilient to earth cycles.

A recent paper by Liakos et al. (2018) explores various uses of AI in agriculture. Here, what will really make the difference for productivity, growth and sustainability is the technology stack, not AI in and of itself. For example, by applying machine learning to sensor data, farm management systems can evolve into real time AI-enabled programs that provide rich recommendations and insights for farmer decision support and action. The key fields of application include: crop management, including applications on yield prediction, disease detection, weed detection, crop quality, and species recognition; livestock management, including applications on animal welfare and livestock production; water management; and soil management. More specifically:

- In crop management, there are several fields of application. They include most notably yield prediction, which impacts key activities such as yield mapping, yield estimation, matching crop supply with demand, and crop management to increase productivity. Use of AI also massively improves disease detection, particularly in the area of pest and disease control, where the use of machine learning allows much better targeting of agro-chemicals input in terms of time and place, thus avoiding the uniform spraying of pesticides; and breakthroughs in image processing and recognition can enable real-time control of plant infection, as well as real-time plant classification.

- Another well-developed area in which AI is dramatically changing agriculture is in the management of livestock, and in particular in protecting animal welfare and livestock production. For example, in the field of animal welfare, AI is helping in the monitoring and classification of behavior based on data from cameras and drones, the recognition of the impacts of dietary changes (in cattle), and even the automatic identification and classification of chewing patterns (in calves) thanks to data collected by optical sensors. In the area of livestock production, studies have led to the accurate prediction and estimation of farming parameters to optimize the economic efficiency of the production system. Researchers are increasingly able to avoid the use of Radio-frequency identification tags to recognize and monitor animals, and this removes a source of stress for the animal itself, at the same time reducing costs.
- Finally, AI can help agricultural firms also in water and soil management. On water, Machine Learning is being applied to the estimation of evapotranspiration, important for resource management in crop production; and to the design and the operation management of irrigation systems and the prediction of daily dew-point temperature. For what concerns soil management, machine learning leads to a more accurate estimation of soil drying, condition, temperature, and moisture content, at the same time dramatically reducing costs. Using high-definition images from airborne systems (e.g. drones), real-time estimates can be made during cultivation period by creating a field map and identifying areas where crops require water, fertilizer or pesticides, with consequent resource optimization.

More generally, the use of IoT in combination with various AI techniques is revolutionizing agriculture, and the process is unlikely to stop any time soon. Precision agriculture is expected to increasingly involve automated data collection and decision-making at the farm level, increasing the resource efficiency of the agriculture industry, lowering the use of water, and even more that of fertilizers and pesticides, with ensuing benefits to the ecosystem. Besides AI and IoT, smart agriculture will also entail significant deployment of robot labor, as well as synthetic biology and advanced materials. In the coming years, many of the mentioned technologies are expected to reach significant progress. Smart agriculture may evolve through a combination of remote sensing and observations (e.g. through drones and computer vision, as well as satellite images); and proximity sensing. For example, in soil testing remote sensing requires sensors to be built into airborne or satellite systems, whereas proximity sensing requires sensors in contact with soil or at a very close range: this helps in soil characterization based on the soil below the surface in a particular place.

3.2 Empowering Small Farmers

Smallholder farmers grow about roughly half of global food calorie production and 70% of the world's food supply on farms that are less than one hectare. They are critical to the global food system. One of the most often evoked dangers of the ongoing reindustrialization of agriculture is the gradual transition from small farms to large industrial conglomerates, which very often enjoy massive economies of scale and build large, global supply chains vertically integrating production with distribution. The need for substantial investment in technology and equipment already led to the prevalence of large industrial firms such as Monsanto, or Bayer in agricultural production during the past century. Today, the prospected merger between these two giant producers may leave small farmers in an even more disadvantageous position vis à vis these mega firms (Lianos and Katalevsky 2018). But this is not necessarily the only, or even the biggest, challenge faced by farmers in the next decade. As agriculture transforms itself into a new technological stack, the real value will be captured by those players that can get hold of the massive amount of data that will be generated by farms and, more generally, the agri-food supply chain.

This, however, does not necessarily have to occur, especially if policy choices are made in order to empower small farmers. The use of AI solutions and the attribution of data ownership, in particular, can benefit small farmers even more than the mobile revolution benefited trade in agricultural products in least developed countries.[3] One way to use these tools for smallholder farmers is to create probabilistic models for seasonal forecasting, by merging into one dataset several variables including soil nutrients, seed bed preparation, germination rate, irrigation, cultivation, minerals, microorganisms, pests, and disease.

Projects related to digital agriculture for small farmers are being developed in various parts of the world. In India, companies like Microsoft are helping by providing several solutions, from basic technological support (i.e. automated voice calls to inform farmers whether their cotton crops are at risk of a pest attack, based on weather conditions and crop stage) to providing governments with AI-powered price forecasts and informing farmers on the optimal sowing date based on large datasets.[4] In Africa, small farmers have the prospect of significantly profiting from index insurance thanks to advanced use of satellite imaging and remote sensing. This reduces their vulnerability due to climate-related risks, which typically strike farmers in the same area and at the same time, making most risk management approaches unfeasible. A project implemented in Senegal by the Weather Risk

[3] For example, the CGIAR Platform for Big Data in Agriculture employs biologists, agronomists, nutritionists, and policy analysts to use Big Data tools to create AI systems that can predict the potential outcomes of future scenarios for farmers. The ultimate goal is to seamlessly integrate real-world data from farms around the world into algorithms that generate critical insights that can then be shared back with farmers. The CGIAR Platform is already showing results of potential benefits for smallholder farmers, such as for the Colombian Rice Farmers Federation. After multiple seasons of challenging rain patterns, rice farmers in Colombia were struggling to know when to plant their crop. Depending on whether there was going to be above average or below average rainfall, farmers would need to decide whether to plant earlier or later in the season. If there was going to be too much rain, they might decide not to plant at all that season.

[4] To calculate the crop-sowing period, historic climate data spanning over 30 years—from 1986 to 2015—for the Devanakonda area in Andhra Pradesh was analysed using AI. To determine the optimal sowing period, the Moisture Adequacy Index (MAI) was calculated. https://www.business-standard.com/article/companies/microsoft-ai-helping-indian-farmers-increase-crop-yields-117121700222_1.html

Management Facility (WRMF) showed that the potential of these instruments is significant, but is also constrained by lack of high quality data and adequate skills in government and among farmers (IFAD 2017).

Similar projects have consistently concluded that data and skills are major obstacles to the empowerment of small farmers. Data can be used by farmers in many ways along the chain, and in particular for planning, monitoring and assessment, event management and intervention, and autonomous action through ICTs. It is therefore very important that projects are developed in order to tackle the specific challenges of each data use, in a way that is tailored to the needs of small farmers. This includes i.a. aggregating farmer data and services through joint action that empowers and gives voice to farmers; developing platforms and mechanisms that enable open data sharing; and reaching international agreements to facilitate data access, ownership and flows.

One key issue in this respect is data ownership (Craglia 2018). This creates at once problems of data protection, security, ownership and imbalances in bargaining positions of small farmers vis à vis service providers, as well as larger players along the value chain such as large agri-food corporations and distribution giants. At the EU level, a Code of Conduct on Agricultural Data Sharing by Contractual Arrangement was launched by a coalition of associations from the EU agri-food chain in April 2018 to facilitate data management in the agri-food chain, and attribute ownership to farmers. The Code provides that the right to determine who can access and use the data is attributed to the data originator, i.e. the individual or entity who created/collected the data either by technical means or by himself or who has commissioned data providers for this purpose. This initiative echoes similar self-regulatory schemes such as the American Farm Bureau's Privacy and Security Principles for Farm Data and New Zealand's Farm Data Code of Practice.[5] Sanderson et al. (2018) analyze these schemes and conclude that strong governance will be needed, including independence in evaluating and monitoring their effectiveness and impacts on players along the value chain. In particular, the problems identified are extreme complexity of agri-food data contracts, lack of awareness on the side of producers of what can be done with their data, as well as the terms of data licenses that they are entering.

More generally, there seems to be growing awareness of the need to support small farmers with more than simple data ownership, which already helps them in retaining control of their data. In particular, awareness of the practical, ethical implication of the data-driven age are needed. For example, already in 2001 the Club of Bologna presented a "Code of ethics for the agricultural machinery—manufacturing sector", and is now working to extend to the AI age its principles and value of integrity, compliance, fair competition, conservation of natural resources, ecological standards, fair and equal treatment of people (employees), health and safety, labor standards, social justice, high quality of products as well as documentation of development and products (Balsari et al. 2018).

[5] Farm Data Accreditation Ltd, New Zealand Farm Data Code of Practice, ver 1.1, Cl 4. American Farm Bureau Federation, Privacy and Security Principles for Farm Data, https://www.fb.org/issues/technology/data-privacy/privacy-and-security-principles-for-farm-data/

3.3 Using Blockchain to Re-intermediate the Agri-Food Supply Chain

Originally emerged as the underlying architecture of Bitcoin in Satoshi Nakamoto's seminal contributions, blockchain has quickly become much bigger than the most famous crypto-currency; and is now considered as a very promising solution for generating trust and transparency in many industrial settings, including the agri-food chain. Blockchains, and more generally Distributed Ledger Technologies (DLTs), have the potential to integrate supply chain transactions in real-time, as well as identify and audit the origin of goods in every link of the chain. When applied to the agri-food supply chain, critical product information such as origin and expiration dates, batch numbers, processing data, storage temperatures, and shipping details get digitized and entered into the blockchain at every step along the chain. Using smart-phones to read QR codes to get details on the source of meat, including an animal's date of birth, usage of antibiotics, vaccinations, livestock harvest, dispatch and shipping can easily be traced. Increasingly, companies are now developing infrastructure to leverage blockchain to make supply chains more robust, efficient, and traceable.

In early 2017, food giants like Wal-Mart, Nestlé, and Unilever (among others) collaborated with tech companies to apply blockchains to global agri-food supply chains. A recent report by Forbes highlighted that while by conventional methods Walmart took more than 6 days to trace the exact farm location of mangoes being distributed in its stores, using blockchain the same task can be completed in under 3 s.[6] Projects being developed by startups like FreshSurety, AgriDigital, HarvestMark, FoodLogiQ and Ripe.io all move in the direction of increasing the transparency and traceability of the value chain. A mapping of these projects (Ge et al. 2017) concluded that the key areas of application include: the registration of holdings, animal, plant and transactions; the tracking and tracing of products with credence attributes (i.e., qualities that are not directly observable by users or end consumers, on which see Sect. 3.4 below); true pricing, which aims to convey information on the externalities of food production; transfer of import & export certificates; inclusive development by ensuring access of smallholders to better market and better payments or financing possibilities (e.g., FairFood, AgriLedger); creating opportunities of automating business processes triggered by a conditioned transaction.

More generally, the use of DLTs can help reduce transaction costs in all those cases in which global value chains rely on a complex nexus of contractual agreements. The emergence of global value chains significantly affected the original dilemma of corporations on whether to revert to a more pluralistic, or a more proprietary business model. As observed by academics like Ronald Coase (1937) in his seminal work on the nature of the firm, the decision whether to bear transaction costs related to market transactions, or the administrative costs related to the setting

[6] https://www.forbes.com/sites/rogeraitken/2017/08/22/ibm-forges-blockchain-collaboration-with-nestle-walmart-for-global-food-safety/#3e9c1b843d36

up of more hierarchical structures such as firms, determines the heterogeneity of governance structures observable today. A more *nuanced* view was offered by Ian Macneil and later Oliver Williamson (1979), who distinguished possible governance arrangements as falling into more short-term market transactions ("classical contracting"), more long-term recurrent transactions based on repeated performance ("neoclassical contracting"), and more structured schemes that form quasi-integrated relationships, often coupled with dispute resolution schemes and deeper governance arrangements ("relational contracting"). These schemes, along value chains, already presented some risks for the parties, including the emergence of superior bargaining power and abuses of economic dependency, but also contractual risks of non-performance by players located in jurisdictions with faulty rule of law.

This trend towards the hybridization of contractual relationships on the value chain was later affected by several other factors, including the ongoing globalization of exchanges, which exacerbated contractual risks and information asymmetries. This is even more problematic since not only the authenticity, but also the so-called "credence qualities" of many goods and services are increasingly important in guiding consumer demand: for example, the fact that goods have been produced in compliance with workers' rights in all phases of the production chain; that food has been locally sourced; or that all players along a supply chain are compliant with environmental standards are often decisive elements in guiding consumers' willingness to pay: the lack of verifiability and clarity on these aspects of goods and services can lead to problems such as adverse selection (so-called "market for lemons"); and moral hazard, which further reduces the quality of available products, since competing on quality is not a winning strategy.

Can DLTs remedy some of these problems? In principle yes, as testified by the fact that several companies and intermediaries are developing ambitious projects to improve the integrity and efficiency of complex supply chains. A notable example is the Tradelens project recently launched by IBM and Maersk, which applies blockchain to the world's global supply chain, through shipping solutions designed to promote more efficient and secure global trade.[7] The project triggered competition by alternative, equally big platforms (e.g. GSBN, powered by Oracle in cooperation with Evergreen Marine, CMA CGM, Cosco Shipping, and Yang Ming, representing about one-third of total global container ship capacity). These schemes, however, face significant governance challenges.[8]

[7] https://newsroom.ibm.com/2018-08-09-Maersk-and-IBM-Introduce-TradeLens-Blockchain-Shipping-Solution. As many as 94 organizations are actively involved or have agreed to participate on the TradeLens platform built on open standards, including more than 20 port and terminal operators across the globe, global container carriers, customs authorities in five countries, custom brokers, cargo owners, freight forwarders, transportation and logistics companies.

[8] According to some commentators, the fact that Maersk owns a stake of the TradeLens and the intellectual property associated with the joint venture creates conflicting interests in the governance of the platform, in particular when it comes to attracting members that are also competing with platform owners. Commitment to profit-sharing and an open IP policy would probably remedy current problems. https://www.forbes.com/sites/andreatinianow/2018/10/30/how-maersks-bad-business-model-is-breaking-its-blockchain/#476280234f4d

Lessons learnt from the first steps of Blockchain/DLT applications in the agri-food supply chain suggest that the potential is great, but the impact so far still very small. Most of current investment focuses on supply chain integrity and traceability, as well as on financial transactions. Moreover, it must always be recalled that DLT applications for the supply chain cannot entirely solve the problem of informational asymmetries, lack of verifiability of credence qualities and opaque supply chains. Blockchains/DLTs only record transactions: they do not entail the creation of any "Internet of Value", contrary to what some commentators argued. This means that while they offer key advantages in terms of verifiability and traceability of information related to products as appended to the ledger, they cannot guarantee that the information introduced in the system is not false.[9]

Furthermore, what is commonly called blockchain in the supply chain world is effectively a permissioned DLT, in which several parties agree to share a ledger and act as validating nodes for it. Rather than dis-intermediating the supply chain, and thus remove costly intermediaries, these applications effectively re-intermediate the supply chain, with large potential efficiency gains, but no permissionless environment. In other words, these applications are technology-enabled variants of relational contracts, which potentially achieve coordination in settings that are characterized by collective action problems: they are far from the permissionless, fully decentralized architecture described by Nakamoto (2008). This also means that they economize on redundancy and synchronization in the name of full scalability: depending on the technical specifications, these systems may scale up more easily than a fully decentralized blockchain. This feature will be particularly important as the number of nodes in these networks increases, and even skyrockets thanks to the emergence of IoT-enabled solutions.

3.4 Empowering Consumers: Quality Signals and AI-Assisted Technologies

Towards the end of the agri-food supply chain, digital technologies can have a substantial impact on the way individual consumers manage and approach their consumption behavior and decisions. This is, again, due to a combination of technologies

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[9] A good example of past attempts to increase verifiability through globally shared commitments to certify the origin and distribution of products was the Kimberley process, established in 2002 to break the link between diamonds and armed conflict. The scheme engaged participants from governments, civil society, and the private sector to eliminate the trade in "conflict diamonds," or rough diamonds used by rebel groups to finance conflict with an aim toward overthrowing legitimate governments. Compliance was monitored with certificate data, statistics, and annual reports, among other types of information: but these monitoring efforts were largely unsuccessful: fraudulent certificates soon emerged in Angola, Congo, Ghana, and Malaysia. Could blockchain solve these problems? Only partly: for example, a startup called Everledger created a blockchain application that tracks assets over the course of their lifetimes, and claims to be able to drastically reduce the estimated USD45bn lost every year due to insurance fraud. In reality, blockchain and DLTs can help solve some of the associated problems (e.g. checking certificate numbers to avoid fraud by spotting duplicative certificates), but the problem of trust among the players in the supply chain shifts "upstream", to the moment in which a given transaction is appended to the ledger.

in the "agri-food stack", including connectivity, IoT, blockchain and AI. One good example is the use of blockchain to enable more transparent and reliable decision-making by end users when deciding which food to purchase and consume. As already mentioned in the previous section, the use of blockchain can solve some of the problems associated with so-called "credence qualities" in food, which can otherwise create problems of adverse selection. Since opacity and lack of trust in the value chain can limit the trustworthiness and observability of quality attributes of food, consumers end up choosing cheaper products as they do not trust the signals provided by their distributor. With blockchain, end users could trace the origin of food by themselves (if supported with adequate data), and may then decide to place more value on quality signals. This can address the issue of high-quality food being otherwise excluded from the market (as in Akerlof's market for lemons), thus restoring the allocative efficiency potential of market exchange, as well as incentives to invest in quality on the side of producers and distributors. This is even truer now that Walmart's original proofs of concept with IBM on mangoes and pork have been scaled up to a large coalition of retailers and producers, including Kroger, Wegmans, Tyson, Driscolls, Nestle, Unilever, Danone, McCormick, and Dole (Yiannas 2018). More recently, in November 2018, Auchan, the world's 13th largest food retailer, announced the implementation of TE-FOOD's blockchain based farm-to-table food traceability solution in France, with further international roll-outs expected to follow in Italy, Spain, Portugal and Senegal.[10] Outside the United States, French retail giant Carrefour has taken similar steps to Walmart by integrating IBM's tailored blockchain data system known as Food Trust with a view of improving food safety.

Needless to say, the implementation of blockchain technology for traceability and integrity in the agri-food supply chain also has important consequences for the SDGs, and in particular to avoid the spread of diseases such as, i.a. the recent Romain lettuce e.coli outbreak in the US and Canada.[11] In particular, blockchain can assist in tracing the cause of the outbreak to a specific distributor, farm or grower in the supply chain. This prevents blanket warnings which affect everyone even when the cause is limited to a particular origin. This positive effect is also one of the reasons why food safety regulators have started to consider using the technology on a large scale. In October 2018, the US Food Standards Agency announced the successful completion of a blockchain trial to track beef from the slaughterhouse to the end consumer. The expansion of the use of DLTs in agri-food is by now considered to be likely, and promising: however, the governance attributes of existing projects are constantly evolving, and the need for a distributed, if not decentralized structure is often evoked as the only way to avoid that the re-intermediated sector falls into the hands of large corporations, creating problems of competition and also reducing the possibility for public authorities to fully observe the data being stored on the chain.

[10] This follows an extended pilot in Vietnam, where more than 6000 companies are using it, including leading international food conglomerates like AEON, CP Group, Lotte Mart, Big C, Japfa, and CJ. https://www.foodingredientsfirst.com/news/globalized-blockchain-auchan-implements-food-traceability-technology-on-international-scale.html

[11] https://thespoon.tech/after-more-romaine-recalls-is-blockchain-the-missing-link-in-preventing-outbreaks/

Besides blockchain, also AI can empower end users in many ways. These range from purely technological solutions to behavioral assistance in consumption decisions. For example, a new dataset of common grocery store items was recently developed by Klasson et al. (2018), using a smartphone camera and photographing 5125 images of various items in the fruit and vegetable and refrigerated dairy/juice sections of 18 different grocery stores. The dataset contains 81 fine-grained products which are each accompanied with an iconic image of the item and a product description including origin country, the estimated weight and nutrient values of the item from a grocery store website. Such system can reportedly help visually impaired people when they shop in grocery stores, and can complement existing visual assistive technology, which is confined to grocery items with barcodes. More generally, still on the technical side, image recognition and computer vision can enable more trust in remote shopping, where enhanced ability to recognize the conditions and quality of the food being purchased is needed. If coupled with remote sensing through IoT in the future, these systems can improve on the experience of purchasing food directly in the store, at the same time distancing consumers from their direct, hands-on experience.

Besides purely technical solutions, there is reason to expect that the real revolution brought about by AI in the short term will be on personalized services in nutrition. Food giants like Nestle are now launching ambitious programs to boost personalized diet advice through AI, coupled with new technological breakthroughs such as instant DNA testing. In Japan, this already led more than 100,000 users of the "Nestle Wellness Ambassador" program send pictures of their food via the popular Line app that then recommends lifestyle changes and specially formulated supplements. This requires the use of voice assistants powered by natural language processing and machine learning, and ends up into so-called "mass customization of food", such as the creation of personalized tea capsules based on individual characteristics and preferences.[12] As the understanding of human dietary needs improvement in the coming decades, these services will become commonplace, with significant impact on SDGs related to health, hunger and malnutrition. For example, the absence of balanced food and nutrition security leads to health problems such as diabetes, obesity, and malnutrition. Personalized approaches can be effective since responses to dietary intervention vary across the population, according to variables such as genetics, age, gender, lifestyle, environmental exposure, gut microbiome, epigenetics, metabolism nutrition derived from diet, and foods.

The combination of user data, DNA and genetic testing and analysis, big data, computer vision, data on environment, healthcare records, data from wearables and implanted devices and advanced AI solutions can generate enormous advantages, but also important risks, for humanity.[13] For example, closely monitoring conversations on social media, companies can use AI to analyze consumer data and identify sentiments or behavior that are crucial not only in building positive experiences but also in the development and design of new product lines. Herranz et al. (2018) study food

[12] https://www.independent.co.uk/news/science/nestle-dna-artificial-intelligence-health-personalised-diet-japan-nutrition-a8519626.html

[13] https://www.frontiersin.org/articles/10.3389/fnut.2018.00117/full#B7

analysis powered by AI and focus i.a. on recommender systems, which require collecting feedback and user preferences, and in particular, taking health and nutritional aspects in the recommendation. As demonstrated in large randomized controlled trials on personalized nutrition such as Food4Me, such systems can be extremely effective in promoting healthy diets; but can also easily nudge users towards specific food consumption, enabling a new, more season of granular, extremely effective AI-enabled marketing, which can even compromise human agency and self-determination (Verma et al. 2018).

3.5 Optimizing the Prevention, Collection and Management of Food Waste

According to the United Nations, 815 million people lack access to the food necessary to lead a healthy lifestyle today, 98% of which live in developing countries and 75% in rural areas. In stark contrast with this figure, one third of the food produced in the world for human consumption (approximately or 1.3 billion metric tons) gets lost or wasted every year. Digital technologies can help overcome this mismatch in many ways: importantly, they can help the world overcome hunger without having to increase output by 70% (a figure often quoted by experts) (Fig. 2).

Much of the global food waste is due to inconsistencies in the supply chain: inventories are not recorded, suppliers are not informed, and quality is not taken into account. This is a relatively uncontroversial use case for DLTs, subject to our considerations in Sect. 3.2 above. DLTs can, for example, help in the implementation of "cold chains", i.e. temperature-controlled supply chains, which ensure that distance traveled by food does not inadvertently lead to damaged goods.[14] Blockchain can also help in more downstream phases of the food waste cycle, by helping reallocate leftovers. This is what companies like Goodr in Atlanta do to arrange the distribution of leftovers from restaurants to local charities through an app. Estonian company Delicia is using blockchain to create a global, decentralized platform for retailers like grocery and convenience stores to sell food that is nearing expiration to local buyers like restaurants or consumers. These services can easily be coupled with AI-enabled dynamic pricing: companies like Wasteless help retailers to dynamically price and sell products based on their freshness; the automatic tracking of unsold inventory allows effective decisions leading to the most optimal financial outcomes and less food waste (e.g. Spoiler Alert). Coupled with IoT, blockchain can do even more: for example, a startup named Blue Ocean is attempting to deploy a radical business model that would leverage identity verification systems, algorithms, IoT, smart sensors, and blockchain to develop a system in which connected smart

[14] Id. With blockchain, vendors can remotely record a wide variety of predetermined measurements, including storage temperature, at each juncture in the supply chain. If temperature at point B varies dramatically from the temperature at point A and C, product managers can extrapolate this data to pinpoint problem areas and allocate resources accordingly.

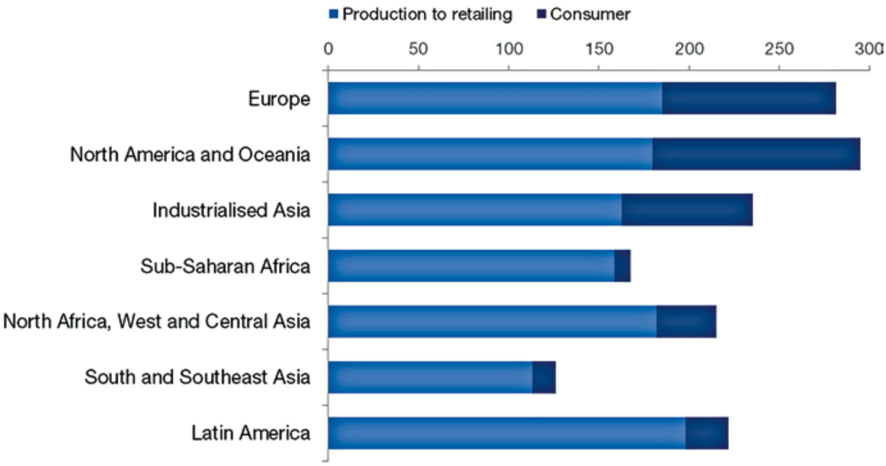

Fig. 2 Food waste by region. Source: The Food and Agriculture Organization of the United Nations (FAO)

bins identify who, when, what and how participants within the ecosystem are behaving. This, in turn, allows the system to immediately reward users for placing food leftovers in the recycling trash bin.[15]

Outside the blockchain universe, the use of AI, mostly in the form of machine learning, to reduce food waste is growing rapidly. For example, Hitachi partners with hospitals to use AI to monitor food waste, improving meal preparation while also relieving the burden on nurses to check these leftovers. The system works by using a camera mounted on a trolley that collects trays, taking pictures of the leftovers. Hitachi systems can recognize patterns in the leftovers that humans otherwise could not see. Similarly, startups like Winnow (a food waste meter technology for restaurants) and Kitro (smart bin that can identify, manage and monitor the sources and quantities of food waste) are developing solutions that combine data collection and sensing with AI. AI-enabled algorithms are being used also to improve food inspections using images taken by a mobile phone (AgShift), hyperspectral images (Impact Vision) and sensor data.

4 Concluding Remarks: Using Policy and Spending Programs to Nurture FoodTech

FoodTech, intended as the use of disruptive digital technologies along the agri-food chain, features an outstanding potential to contribute to the SDGs, and in particular to help combat and eradicate hunger without a massive increase in food production.

[15] https://e27.co/ai-waste-management-startup-blueocean-20181011/

Foodtech could be usefully combined with holistic approaches to the management of the agri-food chain (such as agro-ecology, see Wezel et al. 2009), which incorporate also the social and environmental dimensions. This chapter reviewed emerging applications of technologies like IoT, DLTs and AI at various phases of the agri-food chain, focusing in particular on smart and precision farming, value chain integrity, personalized nutrition and the reduction and prevention of food waste. In all these use cases, the potential appears egregious, but a strong role of policy and public investment seems to be needed in order to avoid equally significant risks.

First, it is important that the focus of governments is not limited to one single technology, but to the whole stack. There are two main reasons for this: on the one hand, it is the combination of technologies like remote and proximity sensing, big data analytics, 5G, blockchain and AI that seems to be generating the most high-impact innovation; on the other hand, the potential of every single technology depends on the relative advancements of complementary technologies in the stack, and without sufficient attention to all complementors a number of bottlenecks could emerge, thereby limiting the overall potential of FoodTech. Government spending on research and innovation, as well as policies aimed at incentivizing private investment will be needed to ensure a harmonious development of the FoodTech ecosystem.

Second, very often the weakest players along the value chain are unable to make the most of the data revolution. Small farmers have limited knowledge of how to use their data, and consumers can easily be nudged into sub-optimal, profit-motivated advice by suppliers. Awareness-raising, training and smart policy choices are thus complementary actions that governments may consider in order to ensure that data ownership belongs to farmers and users, and that both categories are adequately assisted and informed when participating in the FoodTech ecosystem. Recent actions, such as self-regulatory schemes on data sharing in agriculture, should then be adequately monitored and enforced, and complemented by information provision and training initiatives.

Third, blockchain/DLT technologies need to be subject to dedicated policies. The governance of emerging initiatives based on distributed ledger technology are far from the public, permissionless architecture featured by Bitcoin or Ethereum, which exhibit significant scalability problems along with very positive dis-intermediation and decentralization potential. Existing initiatives aimed at securing value chain integrity and food traceability should be carefully monitored in terms of their concentrated governance and possible re-intermediation effects, before they are fully supported in terms of policy. Otherwise, problems such as manipulation of information, imbalances of contractual power along the value chain and lack of trust among players in the ecosystem would simply be replicated in different form. Even the creation of national or international federated ledgers (e.g. the Australian National Blockchain, the Spanish Alastria and the nascent EU blockchain platform) should come with enhanced attention for the underlying government and technology: very little is known today on the likely evolution of platforms such as Ethereum and Hyperledger, and large conglomerates like Tradelens have already experience internal consensus problems.

Fourth, the use of AI in agriculture is already leading to important results in terms of optimization of processes, prediction of events, detection of diseases, and user empowerment through personalized nutrition. However, in line with what occurs in AI applications in other sectors, there is a need to establish shared ethical and legal standards to avoid that AI use impinges on user self-determination and agency, as well as privacy and integrity, leading to cases of discrimination, hyper-nudging, and intrusive use of personally identifiable information. The emergence of "mass customization" in FoodTech thus constitutes both a big opportunity, and a big risk. Government policy is needed to ensure that a predictable legal environment emerges with respect to the use of AI, both in B2B and B2C settings. In many countries AI strategies are emerging to this end: the European Commission High Level Expert Group on AI published ethical guidelines on Trustworthy AI in April 2019 (Renda 2019).

Fifth, FoodTech heavily depends on the availability of high quality data infrastructure and digital skills. Therefore, any solution that relies on digital technologies will need to be inclusive, otherwise the risk will be to widen the digital divide, excluding entire categories of users and geographical areas from the benefits they will provide. Very often, governments are attracted to digital technology without realizing how divisive and discriminatory its deployment can be, if these technologies are not adequately supported. Recent initiatives, such as Finland's decision to offer AI training courses for free to its citizens, go in the direction of ensuring inclusive development of digital technologies; these should be coupled with ad hoc policies to ensure the availability of high quality data, including through open data policies in government.

Finally, and more generally, FoodTech is a very important contributor to future government and global governance objectives, but it is not the only one. It is important to realize how to make FoodTech compatible with all SDGs, including environmental and social objectives. For example, automation of jobs and the carbon footprint of data centers very often challenge the achievement of important SDGs such as limited or zero carbon footprint (SDGs 7 and 13); inclusive growth, full and productive employment, and decent work for all (SDG 8); quality education (SDG 4); and the promotion of women empowerment (SDG 5). In this respect, proposals to steer AI development in a direction that is fully consistent with SDGs appear to be more likely to achieve this form of policy coherence than proposals merely based on GDP and competitiveness.

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