Digitalisation and Artificial Intelligence for sustainable food systems

Trends in Food Science and Technology

Marvin, Hans J.P.; Bouzembrak, Yamine; Fels-Klerx, H.J.; Kempenaar, Corné; Veerkamp, Roel et al

https://doi.org/10.1016/j.tifs.2022.01.020

Trends in Food Science & Technology 120 (2022) 344–348

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Digitalisation and Artificial Intelligence for sustainable food systems

Hans J.P. Marvin *, Yamine Bouzembrak, H.J. van der Fels-Klerx, Corné Kempenaar, Roel Veerkamp, Aneesh Chauhan, Sanne Stroosnijder, Jan Top, Görkem Simsek-Senel, Hans Vrolijk, Willem Jan Knibbe, Lu Zhang, Remko Boom, Bedir Tekinerdogan

Wageningen University and Research (WUR), Droevendaalsesteeg 4, Atlas, Building 104, Wageningen Campus, 6708 PB, Wageningen, the Netherlands

ARTICLE INFO

Keywords
Systems approach
Digital twins
Machine learning
Internet of things
Big Data

ABSTRACT

Background: The European Commission (EC) has launched the European Green Deal communication, setting out the path for a fundamental transformation of Europe. Key element in this policy is a fully sustainable food system outlined in the farm-to-fork strategy. Such strategy requires a systems approach in which all aspects related to the production and consumption of sufficient and healthy food are considered, including economic, environmental (climate, ecosystems) and social aspects.

Scope and approach: Here, we present the systems approach concept for food production, following the farm-to-fork principle as embraced by the EC, and elaborate on how digitalisation and Artificial Intelligence (AI) can solve the challenges that a sustainable food system imposes.

Key findings and conclusions: We present a number of research and innovation challenges and illustrate these by some specific examples. It is concluded that AI and digitalisation show great potential to support the transition towards a sustainable food system. This development will impact the roles and interactions of the actors in the entire value chain from farmers to consumers. Policy recommendations are made for a successful future implementation of AI in sustainable food production.

1. Background

The EC European Green Deal communication sets out the path for a fundamental transformation of Europe's economy and society. An integral part is to implement the United Nation's 2030 Agenda and the Sustainable Development Goals (UN, 2015), and other priorities announced in president von der Leyen's political guidelines (EC, 2019, pp. 1–22). The outlined policy seeks to maximise benefits for health, quality of life, resilience and competitiveness. A key element is the realisation of a fully sustainable food system, which is formulated by the FAO (Lowder et al., 2014) as, "*a sustainable food system delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised*". To realize the required transitions, a systems approach is needed in which all aspects related to the production and consumption of sufficient and healthy food are considered, including economic, environmental and social aspects. A systems approach considers a specific issue (e.g. application of biofuel as energy source) as one element within a larger set of aspects, having direct and indirect interactions with each other, and takes into account seemingly unrelated aspects as well (e.g. land available for food production). This implies that solving an issue in a particular sub-system should be approached with a 'holistic' perspective, taking into account possible interactions, trade-offs and feedback loops on other (in)directly interconnected sub-systems (EC, 2019, pp. 1–22).

2. Scope and Approach

Food is produced within a complex web of supply chain actors that interact with each other on a global scale. The performance of this food system is influenced by interrelated international and local developments. Many 'drivers' that affect the food supply chain have been identified, among them (i) the growing world population and changing diets, (ii) scarcities in resources needed for agricultural production (e.g. fertile land, fresh water, energy), (iii) climate change, (iv) diminishing biodiversity, (v) inadequate governance, and (vi) competing agricultural systems (GO-Science, 2011; Marvin et al., 2019).

The current food system is unable to fully adapt to these drivers, and is too wasteful, polluting and natural resource exhaustive. If current trends continue, the global food system will be unable to provide a

* Corresponding author.
E-mail address: hans.marvin@wur.nl (H.J.P. Marvin).

https://doi.org/10.1016/j.tifs.2022.01.020
Received 14 September 2021; Received in revised form 7 January 2022; Accepted 10 January 2022
Available online 13 January 2022

healthy, safe and nutritious diet to a burgeoning population within safe planetary boundaries (Raworth, 2017). To transit towards a sustainable food system that is able to achieve this goal, a systems approach is essential.

Within the systems approach, all factors interact continuously, such as through feedback loops, which is illustrated in Fig. 1 for the food supply chain. The systems approach is particularly needed in complex systems such as food supply chains, where multiple interactions occur between influencing factors through mechanisms which are not yet fully understood. Conceptual food systems approaches have been developed, taking into account all activities and their interrelationships within the food system, while also considering food security, and socio-economic and environmental indicators (Berkum et al., 2018; Lesschen et al., 2020). Hence, such approaches take a holistic view by broadening the traditional food supply chain or farming system to include the interactions within the food system and its socio-economic and biophysical environment. Such frameworks support the development of an integrated international policy on food security, nutrition security and international agri-business.

In our view, the Digital Strategy vision (EC, 2021) should be combined with the Green Deal vision to achieve a fully sustainable food system. Here, we present our vision of the systems approach in food production, following the farm-to-fork principle as embraced by the EC, and elaborate on how digital solutions and Artificial Intelligence (AI) can contribute to facing the challenges that this approach imposes (see Fig. 1). Examples demonstrating how such a systems approach can be implemented successfully using elements of the Digital Strategy, such as AI, have recently been shown for food fraud (Marvin et al., 2016) and food safety (Bouzembrak & Marvin, 2019; Marvin & Bouzembrak, 2020). The systems approach was also adopted by Wageningen University and Research (WUR) (WUR, 2021) several years ago. Moreover, the implementation of digitalisation, AI and the FAIR data (Findable, Accessible, Interoperable, Reusable) (Wilkinson et al., 2016) principles are being explored and adopted in each step of the food supply chain. These examples show the strength of data driven and digital approaches and warrant high investments in these technologies to address the challenges faced when developing a truly sustainable food system as foreseen in the Green Deal.

In the following sections, we will elaborate on the systems approach as illustrated in Fig. 1, present a number of challenges involved, and opportunities (Fig. 2), followed by specific examples, but recognizing that many others could be named such as horticulture, robotics, vertical farming, etc.

3. Key Findings and Conclusions

3.1. Farming (arable and livestock)

Productivity and resource use efficiency of Dutch agriculture is amongst the highest in the world. This is a result of a mixture of favourable production conditions, craftmanship, application of advanced technologies and mature agri-food chains (Viviano & Locatelli, 2017). Despite the enormous differences between farms and the consecutive stages of the supply chains, they all face the challenge to produce more and better, with less, having to deal with climate change, reduction of pesticide and fertilizer use while maintaining productivity and improving biodiversity.

An important driver towards sustainable food systems will be the digitalisation of farms and supply chains. Currently still in its infancy, we expect that data driven agriculture will mature in the coming decades, shaping the farms of the future. Also, equipment suppliers focus more and more on data driven activities. Farmers can have access to three categories of data intensive technologies to help address the aforementioned challenges, including Farm Management Information Systems (FMIS), precision farming, and agricultural automation & robotics (van Evert et al., 2017). Internet of Things (IoT) provides a wealth of solutions to gather data from any stage of the food supply chain using sophisticated sensors and devices that transmit the collected data to centralised data warehouses (Bouzembrak et al., 2019).

Farmers can use the data for (i) monitoring of the status of soils, climate, crops and farm animals using sensor systems, (ii) benchmarking of crop, animal and farm performances, (iii) accountability whereby the farm submits digital information to governments, chain partners and institutions, and vice versa, (iv) optimization of operational decisions in crop cultivation and storage, and v) prevent overproduction by improved forecasting of market demand.

Combining data from different sources (e.g. open data like earth observation data, data from on-farm sensor networks, accountancy data

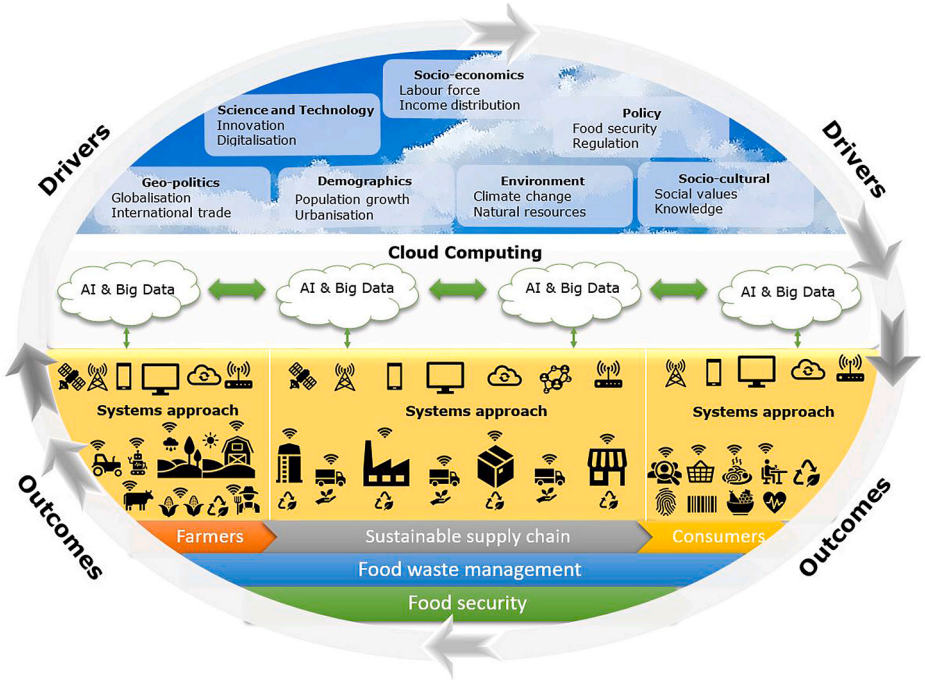

Fig. 1. *Schematically representation of the systems approach in which digitalisation and AI support the development of a sustainable food supply. All the objects and the actors in the supply chain are connected using IoT, it can include anything from a farmer smartphone to tractors, robots and different type of sensors used in the farm (e.g. temperature, light, precipitation, location, etc.). The communication medium can be Bluetooth, RFID, WIFI, or 4G, which facilitates communication with other machines or human and the computing resources (e.g. smartphone, computer, cloud computing, edge computing). In addition, circularity and sustainability are taken into consideration in all the steps of the food supply chain.*

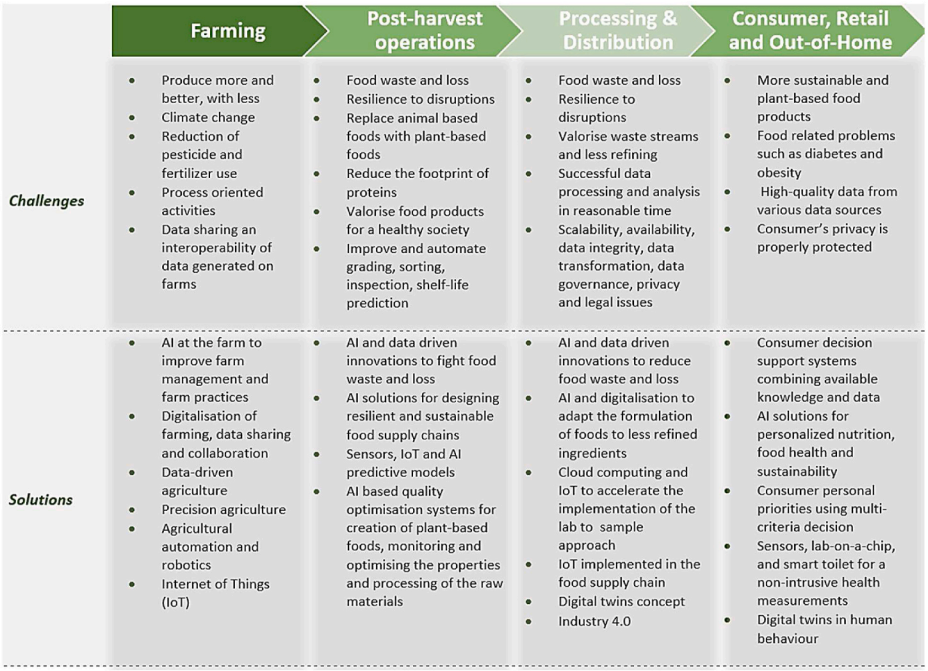

Fig. 2. Summary of the challenges, and the solutions that digitalisation and AI can bring from farm-to-fork.

like invoices and data from food chain platforms) concerning one farm is still a challenge. However, technical designs to do so do exist (FISpace, 2021; IoF2020, 2021) and some monitoring systems are moving in that direction (Poppe & Vrolijk, 2018). The farm-to-fork strategy proposes to extend the Farm Accountancy Data Network to a Farm Sustainability Network. The feasibility of collecting sustainability data has been tested and proven in a pilot in 9 EU member states (Vrolijk et al., 2016). Increasing data needs make it necessary to use digitalisation to collect these data in more efficient ways. AI techniques and robotic accounting will help to integrate, process and analyse data in more efficient and new ways. Linking economic and environmental data provides the opportunity to evaluate the cost effectiveness of policy measures and the ability of farmers to innovate at farm level.

3.2. *Post-harvest operations, processing and distribution*

Given the global nature of our food system, post-harvest operations, food processing and distribution logistics are central to its successful functioning. However, due to the linear nature of these industries as well as persisting inefficiencies, they are wasteful (FAO, 2019; FUSIONS, 2016) and not resilient to disruptions, while the majority of nutrients such as proteins that we harvest do not end up on our plates (Alexander et al., 2017). AI and data driven innovations offer a significant opportunity to address these challenges (Lezoche et al., 2020; Top & Wigham, 2016; Wolfert et al., 2017).

The need of the hour in the current food supply chains is resilience to disruptions and uncertainties caused by pandemics, political conflicts, natural disasters and policy changes. In particular, *lean* and *efficient* global food supply chains must also consider resilience and risk management, but our supply chains also need to become more flexible with regard to the type and quality of the raw materials that can be provided. AI based techniques, combining data from multiple sources, can play a significant role in providing predictive risk analysis as well as prescriptive decision-support (Lezoche et al., 2020; Papadopoulos et al., 2017). Eventually, such approaches may also be used for adaptation, when changes overstretch the possibilities of resilience.

AI is already playing an important role in preventing food from being wasted at retailers by offering dynamic pricing based on remaining shelf life (Burman et al., 2021, pp. 132–143; Chen et al., 2018). It can also effectively map and match products near the expiry date directly to consumers who can save the food from begin wasted. Sensors and AI can be used to help refine such models further by predicting actual product quality and shelf-life instead of a fixed date of expiration or in traceability system to ensure food safety throughout the supply chain (Jin et al., 2020). Imaging technology and AI is also helping fight food waste in the food service industry. Dynamic pricing decisions by the artificial agents, however, are usually invisible to humans which also leads to social and ethical concerns regarding algorithmic responsibility and accountability (Martin, 2019; Seele et al., 2021).

Handling big data issues are challenging and time consuming, and require a large computational infrastructure. Although cloud computing has been adopted by many organizations as a solution, research on Big Data in food chain using cloud computing technology remains in its infancy. In the food chain, several research challenges such as scalability, availability, data integrity, data transformation, data governance, privacy and legal issues have not been fully addressed yet. Furthermore, cloud computing might accelerate the implementation of the "*lab to sample approach*" in which food safety data is generated on-site by portable devices and/or on-site sensors (IoT), transferred to a central cloud based data e-infrastructure, processed and analysed on-line. The results are directly sent back to the operator allowing onsite decisions on compliance with food safety legislation. Such an approach will reduce the costs and enhance the efficiency of food safety control since only suspected samples will be taken to the laboratory, where they will be analysed by highly skilled laboratory personnel employing sophisticated equipment. In case IoT can be applied, a potential food safety risk will be detected early allowing quick actions to mitigate the risks. IoT in food safety and quality control is already being explored mainly by Chinese research teams (Bouzembrak et al., 2019).

The food processing industry is engaged in the integration of new technologies that will have impact on value creation, work organization, and the downstream services of the companies. Experts are referring to a complete paradigm shift in manufacturing, towards the smart factory and industry 4.0, which is marked by a technical integration of Cyber-Physical-Systems in manufacturing and logistics processes as well as the use of the IoT and services in industrial processes (Bartodziej, 2017;

Bauernhansl, 2014; Braun et al., 2018).

Also the food processing industry is taking on its role in building responsible supply chains. AI is being adopted rapidly in the processes of product design, lab and pilot experimentation, supply logistics and marketing (Ghoreishi & Happonen, 2020). For instance, the concept of the Digital Twin as a virtual, real-time equivalent of a production line or entire plan is now being explored in many ways in order to be able to increase effectiveness, efficiency and product quality (WUR, 2021a). The digital twin concept offers a real-time pairing of a physical process to its virtual counterpart, which can provide transformative insights on the functioning of current systems as well as provide virtual platform for experimentation. WUR researchers are developing digital twins in several areas such as virtual tomato crops, food diet and Digital Future Farm (WUR, 2021c).

3.3. Consumer, retail and out-of-home

Traditionally, education and general product information are supposed to help the consumer in making the 'right' choices. The farm-to-fork strategy puts an emphasis on product labels to steer consumers towards healthy and sustainable food choices. One step forward is to move to consumer decision support, combining available knowledge and data. With new information technology, recommendations can be made specific, context-dependent and personal. In particular the field of personalized dietary advice is gaining much attention. '*Personalized nutrition uses individual-specific information, founded in evidence-based science, to promote dietary behaviour change that may result in measurable health benefits*' (Adams et al., 2020). Thousands of recommender apps are available in app stores but many of them have not yet brought the expected impact as they do not cover and combine the full range of knowledge and data (Franco et al., 2016).

Proper consumer decision support systems, either for health, environment or other purposes (or a combination of all those in one), require continuous input of high-quality data from various disciplines and multiple sources. This includes data on food products, ingredients and meals, the status and preferences of the consumer, context, situation and dietary habits.

3.4. Political economy of digitalisation

As is evident from developments in other sectors than food systems, digitization opens up possibilities for large concentrations of market volumes, and even to the monopolization of markets. For instance, online offerings of shopping, data storage, search engines, and social communities tend to concentrate in a very few companies world-wide, absent legal limitations to their market coverages. Apparently, neoliberal government policies (not directly inclined to pose market restrictions) and digital connectivity (enabling a swift pervasion of world-wide markets) tend to reinforce each other. It is interesting to consider how these forces will affect food systems. On the one hand, food being a physical entity, there will be limits to markets becoming entirely digital. On the other hand, information sharing is crucial in adapting to market opportunities and since information is largely digital, this may well open up very similar possibilities of market concentration in food systems. It is not covered in the present paper, but we are convinced that the political economy of food systems in an increasingly digital world deserves further research.

4. Conclusions

It is evident that AI and digitalisation show great potential to support the transition towards sustainable food systems that are in balance with society as a whole. This development will impact the roles and interactions of the actors throughout the entire value chain from farmers to consumers. Adoption and integration of the technologies will vary per sector and region. Because of its increasing data production it will be accompanied by a continuous debate on data ownership, privacy and transparency. The position of farmers in relation to the supply chain is the weakest link in the farm-to-fork data space. To solve the bottlenecks, already policy recommendations have been developed in this area (e.g. European Interoperability Framework (EIF) for governance,[1] Data Collection and Data Modelling recommendations of EFSA (EFSA et al., 2020), AIDA-AGRI Public Hearing on AI, Agriculture and Food Security (EP, 2021)). We further posit the following policy recommendations:

- Farmers have to work with a patchwork of ICT tools, often delivering poorly interoperable data, making it virtually impossible to bring together data generated on their farms in a useable, trusted, transparent, robust and in control way.[2] To solve the bottlenecks, we recommend to make public-private agreements on architectural principles of technical and organizational nature. These agreements are the basis for realizing a better farmers position in the desired farm-to-fork data space. When the desired data space becomes available, new opportunities will arise in the field of farm and chain optimization, new services and monitoring of social goals, including those of EU CAP. When researcher can have access to real-time object-specific farming data, they can develop decision support with AI for topics of interest to farmers and society (e.g. optimization of yields and quality of agricultural products, resource use efficiency, circularity, nature-inclusiveness and climate adaptation), in this way contributing to more sustainable farming.
- Data access and data ownership sometimes appear as mutually exclusive; solutions to judiciously combine both are crucial for progress of AI in society, including solutions to safeguard privacy and prevent information leakage.
- Cybersecurity follows immediately as being conditional to progress, in order to prevent criminal and even terrorist activities, which threaten citizens and society as a whole. It requires advanced policing in addition to public and private awareness of the risks.
- Vendor lock-in easily follows after aggressive marketing strategies but then threatens progress by suffocating innovations. Solutions, like open standards, do exist but require strong (regulator, government) support for implementation.
- Adoption of AI requires competences to handle the occasionally increased complexity of the new processes. Support for developing this expertise will have to be organized in order to prevent a societal divide between those who follow and adopt, and those who don't.
- Trust and transparency will play a prominent role in building responsible and resilient supply chain networks. Targeted approaches have the potential to provide such solutions and can dramatically transform current supply chains. Further, increased transparency can be achieved by development of integrated data management solutions with sensor and observational data on individual food products across different segments of the supply chain, mapping the food product's history (circumstantial and descriptive information).
- Develop FAIR based methodologies to link data that takes into consideration all requirements (e.g. security, governance, sensitivity) (Duncan et al., 2019) data owners may have and the phenomenal growth in machine to machine (M2M) connections.

Acknowledgment

We acknowledge comments and suggestions from the Dutch Ministry of Agriculture, Nature, and Food Quality (LNV) on an earlier draft, and Dr Gijs Kleter for critical reading the manuscript.Commitments from the Dutch Ministry of Agriculture, Nature, and Food Quality (LNV) contributing to the knowledge base in this domain is greatly

[1] https://ec.europa.eu/isa2/eif_en.
[2] https://ec.europa.eu/isa2/eif_en.

appreciated.

References

Adams, S. H., Anthony, J. C., Carvajal, R., Chae, L., Khoo, C. S. H., Latulippe, M. E., Matusheski, N. V., McClung, H. L., Rozga, M., Schmid, C. H., Wopereis, S., & Yan, W. (2020). Perspective: Guiding principles for the implementation of personalized nutrition approaches that benefit health and function. *Advances in nutrition (Bethesda, Md, 11*, 25–34.

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D., & Rounsevell, M. D. A. (2017). Losses, inefficiencies and waste in the global food system. *Agricultural Systems, 153*, 190–200.

EFSA, Alvarez-Pinera, J., Bager, F., Bystrický, M., Rasmussen, S. D., Foster, D., Fuchs, K., Gilsenan, M., Grahek-Ogden, D., Jozwiak, Á., Moez, S., Neagu, M., O'Dea, E., Perrella, A., Richardson, J., Scharfenberg, E., Sokolic, D., Stack, M., Vermeersch, K., & Wienk, K. (2020). *Report of the advisory forum task force on data collection and data modelling. 17* p. 1901E). EFSA Supporting Publications.

Bartodziej, C. J. (2017). Introduction. In C. J. Bartodziej (Ed.), *The concept industry 4.0 : An empirical analysis of technologies and applications in production logistics* (pp. 1–6). Wiesbaden: Springer Fachmedien Wiesbaden.

Bauernhansl, T. (2014). Die Vierte Industrielle Revolution – der Weg in ein wertschaffendes Produktionsparadigma. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser (Eds.), *Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung · Technologien · Migration* (pp. 5–35). Wiesbaden: Springer Fachmedien Wiesbaden.

Berkum, S.v., Dengerink, J., & Ruben, R. (2018). *The food systems approach: Sustainable solutions for a sufficient supply of healthy food*. The Hague: Wageningen Economic Research.

Bouzembrak, Y., Klüche, M., Gavai, A., & Marvin, H. J. P. (2019). Internet of Things in food safety: Literature review and a bibliometric analysis. *Trends in Food Science & Technology, 94*, 54–64.

Bouzembrak, Y., & Marvin, H. J. P. (2019). Impact of drivers of change, including climatic factors, on the occurrence of chemical food safety hazards in fruits and vegetables: A bayesian network approach. *Food Control, 97*, 67–76.

Braun, A.-T., Colangelo, E., & Steckel, T. (2018). Farming in the era of industrie 4.0. *Procedia CIRP, 72*, 979–984.

Burman, V., Vashishtha, R. K., Kumar, R., & Ramanan, S. (2021). *Deep reinforcement learning for dynamic pricing of perishable products*. Cham: Springer International Publishing.

Chen, W., Liu, H., & Xu, D. (2018). Dynamic pricing strategies for perishable product in a competitive multi-agent retailers market. *The Journal of Artificial Societies and Social Simulation, 21*, 12.

Duncan, S. E., Reinhard, R., Williams, R. C., Ramsey, F., Thomason, W., Lee, K., Dudek, N., Mostaghimi, S., Colbert, E., & Murch, R. (2019). Cyberbiosecurity: A new perspective on protecting U.S. Food and agricultural system. *Frontiers in Bioengineering and Biotechnology, 7*.

EC. (2019). *A Union that strives for more My agenda for Europe; POLITICAL GUIDELINES FOR THE NEXT EUROPEAN COMMISSION 2019-2024*. EC. https://ec.europa.eu/info/sites/default/files/political-guidelines-next-commission_en_0.pdf.

EC. (2021). The European digital strategy. EC https://ec.europa.eu/digital-single-market/en/content/european-digital-strategy, 2021.

EP. (2021). *AIDA working paper on 'AI, agriculture and food security'. Special committee on artificial intelligence in a digital age*. European Parlement.

van Evert, F. K., Fountas, S., Jakovetic, D., Crnojevic, V., Travlos, I., & Kempenaar, C. (2017). Big Data for weed control and crop protection. *Weed Research, 57*, 218–233.

FAO. (2019). The state of food and agriculture. Moving forward on food loss and waste reduction. http://www.fao.org/3/CA6030EN/ca6030en.pdf.

FISpace. (2021). FIspace a business-to-business (B2B) collaboration platform. https://www.fispace.eu/, 2021.

Franco, R. Z., Fallaize, R., Lovegrove, J. A., & Hwang, F. (2016). Popular nutrition-related mobile apps: A feature assessment. *JMIR Mhealth Uhealth, 4*, e85.

FUSIONS. (2016). Food waste quantification manual to monitor food waste amounts and progression. Deliverable Number: D1.7 https://www.eu-fusions.org/phocadownload/Publications/FUSIONS%20Food%20Waste%20Quantification%20Manual.pdf. D. N. D1.7 (Ed.), (pp. 1-165).

Ghoreishi, M., & Happonen, A. (2020). New promises AI brings into circular economy accelerated product design: A review on supporting literature. In *E3S web conf.* (Vol. 158), Article 06002.

GO-Science. (2011). *Foresight. The future of food and farming. Final project report*. London: The Government Office for Science. Published in 2011. pp. 211. Available at: http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/11-546-future-of-food-and-farming-report.pdf. Animal Genetic Resources/Ressources, 48, 127-127.

IoF2020. (2021). IoF2020 Eu project. https://www.iof2020.eu/communication-materials/iof2020-booklet-2019-highres.pdf. In (pp. 1-71).

Jin, C., Bouzembrak, Y., Zhou, J., Liang, Q., van den Bulk, L. M., Gavai, A., Liu, N., van den Heuvel, L. J., Hoenderdaal, W., & Marvin, H. J. P. (2020). Big Data in food safety- A review. *Current Opinion in Food Science, 36*, 24–32.

Lesschen, J. P., Reijs, J., Vellinga, T., Verhagen, J., Kros, H., de Vries, M., Jongeneel, R., Slier, T., Gonzalez Martinez, A., Vermeij, I., & Daatselaar, C. (2020). *Scenariostudie perspectief voor ontwikkelrichtingen Nederlandse landbouw in 2050*. Wageningen: Wageningen Environmental Research.

Lezoche, M., Hernandez, J. E., Alemany Díaz, M.d. M. E., Panetto, H., & Kacprzyk, J. (2020). Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. *Computers in Industry, 117*, 103187.

Lowder, S. K., Skoet, J., & Singh, S. (2014). What do we really know about the number and distribution of farms and family farms in the world?. In *ESA working papers* (Vol. 14)Food and Agriculture Organization of the United Nations (FAO). www.fao.org/family-farming/detail/en/c/281544/.

Martin, K. (2019). Ethical implications and accountability of algorithms. *Journal of Business Ethics, 160*, 835–850.

Marvin, H., & Bouzembrak, Y. (2020). A system approach towards prediction of food safety hazards: Impact of climate and agrichemical use on the occurrence of food safety hazards. *Agricultural Systems, 178*, 102760.

Marvin, H., Bouzembrak, Y., Janssen, E. M., van der Fels- Klerx, H. J., van Asselt, E. D., & Kleter, G. A. (2016). A holistic approach to food safety risks: Food fraud as an example. *Food Research International, 89*, 463–470.

Marvin, H., Bouzembrak, Y., van Asselt, E., Meijer, N., Kleter, G., Lorentzen, G., & Johansen, L.-H. (2019). Applicability of a food chain analysis on aquaculture of Atlantic salmon to identify and monitor vulnerabilities and drivers of change for the identification of emerging risks. *EFSA Supporting Publications, 16*, 1619E.

Papadopoulos, T., Gunasekaran, A., Dubey, R., Altay, N., Childe, S. J., & Fosso-Wamba, S. (2017). The role of Big Data in explaining disaster resilience in supply chains for sustainability. *Journal of Cleaner Production, 142*, 1108–1118.

Poppe, K., & Vrolijk, H. (2018). Microdata: A critical source for policy evaluation. *EuroChoices, 17*, 28–35.

Raworth, K. (2017). *Doughnut economics : Seven ways to think like a 21st century economist*.

Seele, P., Dierksmeier, C., Hofstetter, R., & Schultz, M. D. (2021). Mapping the ethicality of algorithmic pricing: A review of dynamic and personalized pricing. *Journal of Business Ethics, 170*, 697–719.

Top, J., & Wigham, M. (2016). The role of e-science in agriculture. In *Agricultural knowledge and innovation systems towards the future- aForesight paper* (Vol. 5, pp. 45–75).

UN. (2015). Transforming our world: The 2030 Agenda for sustainable development. https://sustainabledevelopment.un.org/post2015/transformingourworld.

Viviano, F., & Locatelli, L. (2017). *This tiny country feeds the world*. National Geographic magazine. September 2017 https://www.nationalgeographic.com/magazine/article/holland-agriculture-sustainable-farming.

Vrolijk, H. C. J., Poppe, K. J., & Keszthelyi, S. (2016). Collecting sustainability data in different organisational settings of the European Farm Accountancy Data Network. *Studies in Agricultural Economics, 118*, 138–144.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., … Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data, 3*, 160018.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming – a review. *Agricultural Systems, 153*, 69–80.

WUR. (2021a). Digital twins, Wagenigen University and research degital twin projects. https://www.wur.nl/en/Research-Results/Research-programmes/Research-investment-programmes/Digital-Twins.htm, 2021.

WUR. (2021b). Wegenigen University and research. website, 2021 https://www.wur.nl/en.htm.

WUR. (2021c). WUR is working on Digital Twins for tomatoes, food and farming, 2021 https://www.wur.nl/en/newsarticle/WUR-is-working-on-Digital-Twins-for-tomatoes-food-and-farming.htm.