Technology, digitalisation, and AI for sustainability.

An assessment of digitalisation for food system transitions

Gianluca Brunori, Manlio Bacco, and Silvia Rolandi

Abstract

This chapter discusses one of the most urgent and significant challenges we must face— the transition towards sustainable food systems. In this context, we discuss the role digital technologies may play, proposing the use of *socio-cyber-physical systems* as a paradigm, and extension of its Information and Communications Technology version, the *cyber-physical system.* Key digital technologies, with the potential of being game changers, are identified, as is their role in supporting a transition towards greater sustainability. Risks are identified and discussed related to the adoption of digital technologies in the food system, as well as policy conditions for digital technologies to operate in societies' interest. Recommendations are provided on the embodiment of socio-economic principles in the digitalisation process, in line with the socio-cyber-physical approach.

Keywords: digitalization, sustainability, food systems

Introduction: Sustainable food systems and digitalisation

Transition towards sustainable food systems is widely recognised as one of the most significant challenges facing the planet, and the urgency of such transformations is now irrefutable (Balafoutis et al., 2017). Research is considered a key driver for the transition. In this spirit, the European Commission's Standing Committee on Agricultural Research's (SCAR)—a body that coordinates the member states' research policies in the field of agriculture—launched its 5th foresight exercise with the aim of providing a frame of reference for national research strategies, EU-level partnerships, and joint programming initiatives. The experts were asked to explore the pathways to achieve a "safe and just operating space" for the primary systems in Europe. Three pathways—healthy and sustainable diets for all, circularity in food systems, and diversity—were identified through workshops, expert inputs, and deliberation. These pathways provide different entry points and key driving forces, and require integrated and coherent efforts by a wide range of actors.

The first transition pathway relates to what we eat: everyone should have access to healthy diets, and at the same time, diets should reflect the need to reduce the pressure on the environment (Van Wassenaer at al., 2021). This pathway implies a change in both food supply and demand. The second pathway relates to circular food economies, which aims at closing the material loops in all the subsystems of the food system, starting from primary production wherein circularity can be managed through ecosystem redesign and the mobilisation of functional biodiversity (Araújo et al., 2021). The third pathway relates to social and biological diversity to augment ecosystem services and foster more resilient systems. In this context, digitalisation has been highlighted as a key cross-cutting issue.

Given its game-changing role, digitalisation can be a driver of progress and prosperity; and, depending on its application, it can cause social inequalities and environmental degradation. Much will depend on the capacity to shape ICT technologies in view of the common good and to design appropriate legal, social, and economic frameworks to control its development. The chapter discusses the role that digitalization may play in each of these pathways. We provide an overview of the main concepts related to digitalisation, and then identify, for each pathway, current and future ICT applications that may support the process and their potential impact. Discussion and conclusions will follow.

The digital transformation: Main concepts

ICT technologies are the drivers of two distinct, albeit interconnected, processes: **digitisation** and **digitalisation**. We first explain the former. **Digitisation** is the transformation of analogical signals into digital information. Digitisation increases exponentially the capacity to store, retrieve, exchange, and integrate data, allowing the so-called **datafication**, which is the growing production of data to support decision making (Serazetdinova et al., 2019). The exponential reduction of the costs of computing has made it possible to translate physical information into a digital format, which has generated an unpreceded possibility of access to knowledge and information, raising at the same time issues of privacy and intellectual property.

In more recent years, the development of sensing technologies has allowed a new wave of datafication based on the automatic collection and storage of data with very limited human intervention. Among the most relevant sources of data, we can now count satellites, sensors, and the so-called 'Internet of Things' paradigm, mobile phones and apps, censuses and surveys, publications and documents, citizen science, administrative data, and finance data (Jensen & Campbell, 2019).

Digitisation allows the creation of digital representations of the physical world. The Internet allows the circulation of these representations that become part of the cybersphere, a world of informational objects. Through the cybersphere, humans can remotely act on the physical world. To better grasp this interconnectedness, the concept of 'cyber-physical system'(CPS) (Cyber Physical Systems Public Working Group, 2016), has been proposed. In a CPS, physical and cyber components are connected and communicate with each other to perform a given function (Bacco et al., 2020). Logically, CPSs can be described as composed by five layers: *sensing* (data collection through sensors), *data exchange* (through wired or wireless connection), *computing* (data storing and processing), *intelligence* (application with a given purpose), and possibly *actuation* (semi or fully automatic execution of actions). These systems allow "smart processes", as they can adopt flexible decisions and carry out fine-tuned operations based on data. CPSs can radically change the patterns of interaction among people. Communication at a distance allows new forms of sociality, new labour organisation patterns, new lifestyles: robots can replace or support human work; such automatic translation opens new possibilities for communication.

At the same time, different social patterns can give CPSs different shapes: the social, the cyber, and the physical domains co-evolve. These changes are captured by the concept of digitalisation. **Digitalisation** departs from the potentialities created by digitisation and regards the transformation of socio-economic-ecological systems in relation to it. The process of digitalisation cannot be captured by the concept of CPSs, where the social component is external to the system. For this reason, we have proposed the concept of **socio-cyber-physical system** (SCPS), which allows technological systems to be described as components of a broader set of relations and interdependencies. The SCPS concept emphasises the two-way relationship between the social and the technological processes, stressing that different social patterns may shape different technological patterns and vice versa. This reciprocity has important implications on innovation policies, as SCPSs approaches stress how to avoid technological determinism and propose an approach that subordinates the technology development to the identification and analysis of social problems, and thus to solutions that adapt technology according to the specific ecological, social, and organisational contexts (Rijswijk et al., 2021).

The impacts of digitalisation on the food system

Digitalisation has already changed the food system, but the technological developments in this field enable us to envision greater and deeper changes. The impact of digitalisation on the food system is briefly analysed in relation to its main actors and activities.

Digitalisation and farming

The impact of digitalisation on the future of farming is of increasing interest, as it promises to bring benefits to farmers. **Productivity gains** can be obtained through better insights into production variables and dynamics, informed decision-making based on insights and scenario analyses, and increased labour productivity. Accurate monitoring and optimisation of processes can bring higher quality and waste reduction. Digitisation can improve **access to markets,** and thus afford **economic gains**, by improving product quality and available information to customers, and by alleviating excessive dependency on intermediaries. Digitalisation can also improve the **quality of work,** relieving farmers from heavy or unpleasant tasks, and can improve the communication with administrations. **Benefits to the environment** are also envisioned as digitisation improves the efficiency of the use of external inputs and the monitoring of the impact of agricultural practices on GHG emissions and other environmental indicators (García-Llorente et al., 2018; Garske et al., 2021; Nikolaou et al., 2020). However, biases toward specific agricultural paradigms (specialisation, large-scale) embodied in technologies are problematic, as well as economic barriers to access (high initial investments to adopt the technologies), and technological ecosystems that may encounter inadequate infrastructure or supports for new technologies to work.

Digitalisation and Agricultural Knowledge and Innovation Systems

Agricultural Knowledge and Innovation Systems (AKIS) are about knowledge management: AI, big data, and cloud computing will make the organisation of traditional AKIS obsolete. The mix of face-to-face and remote interaction will be radically reorganised, and the function of face-to-face activities will be much different from the past. Farmers will be able to access information autonomously through specialised sites and increased peer-to-peer communication, and advisors will move from information brokering to data analysis. These services will be growing online, aimed at increasing the value of direct experience and generating trust. As data management will be more relevant for farmers, extension services, and cooperatives, it will change the functions of these food system actors into data managers, analysts, and brokers (Cobby, 2020). Machinery and input suppliers are already "connected" to farmers, and new digital services will be proposed. In terms of risks, lack of ICT skills will create new divides (Akyazi et al., 2020). Another risk that may be related to a technological bias is that extension services may choose to support the technologies that are more digitised. Dismissing traditional services may prompt a further disconnection from the AKIS of farmers lacking the skills to interact with digital services.

Digitalisation and the other actors of the food value chain

Data availability allows the reduction of "information friction" between actors of the value chain. Increased availability of data and of computing capacity will improve the processes of traceability, protecting the identity of products along the chain, reducing the costs of certification, and improving its accuracy. Improved one-to-one or one-to-many communication allows disintermediation from traditional intermediaries, which will reshape the value chain patterns. New business models supported by platforms show that farmers can have direct access to distant markets and to consumers (Sam et al., 2021). Improvement in logistics due to automation and data management will foster new organisational patterns. 3D printing will allow a spatial reorganisation of the food industry, allowing diffused manufacturing, but also create a divide between 3D printed and 'authentic' food (Lipton, 2017). In this new scenario, technology design will be shaped by the actors who have more power in the value chain; actors with greater capacity to collect and analyse data will wield more power. Weak regulation over data property will generate new enclosures and new monopolies and farms left outside the value chains will undergo marginalisation. Unregulated access to sensitive data— such as polluting emissions or quality of soils—may generate inaccurate information and endanger actors' reputations.

Digitalisation and consumers

Digitalisation has given consumers access to an enormous amount of information about products, increasing their power of choice. Information about the product increases responsibility of both producers and users, as information links the choice to its consequences. Labelling and certification, nutritional parameters, and environmental footprints will accompany the product, allowing an assessment of its sustainability and healthiness. Information to consumers will constitute another field of competition between firms. Risks may be related to information overload, trusting wrong sources of information, lack of skills to interpret the data, and the deliberate pollution of information sources. Firms may carefully select the information to be disclosed, thus potentially increasing the level of confusion or the risk of inaccurate claims.

Digitalisation and rurality

Digitalisation reconfigures spatial patterns (settlements, mobility, resource flows, communication), disrupts goods and services provision, and opens new opportunities for natural resources and ecosystem services management. In theory, digitalisation has the potential to reduce distance and isolation in rural areas; in practice, market-led digitalisation may enlarge the gulf between rural and urban areas. To reverse this trend and enable rural areas to harvest such opportunities, a strong effort to rethink the role, resources, and importance of rural areas is needed.

Digitalisation and public administrations

Digitisation offers a multiplicity of tools to policymakers. Improved communication among farmers and administrations will reduce the transaction costs and the power of intermediaries. Better information about production processes will allow public administrations to grant "licences to operate" in a more accurate way. Environmental monitoring may activate performance-based policies (Bikomeye et al., 2021). Monitoring systems for food storage will improve food safety. Data sharing about risks will improve the capacity to respond to crises. Technology will allow the development of "nudging systems" for consumers toward healthy and sustainable diets. Again, inaccurate disclosure of information may create panic, bias, and may undermine the reputation of some actors. Lack of trust in the public administration may hamper data sharing, and excessive nudging could spark a sense of diminishing freedom.

Transitions to sustainable food systems: The role of digitalisation

The role that digitalisation may play in the transition to sustainable food systems will depend on the shape that SCPSs take. Defining transition pathways would include identifying technology pathways.

Pathway 1: Healthy and sustainable diets for all

The first pathway, "healthy and sustainable diets for all" starts from the observation that current diets are both unsustainable and unhealthy. Change in diets will require a change in both demand and supply (Sadhukhan et al. 2020). The transition to sustainable diets will also depend on the capacity to shape the food environment, a set of physical and symbolic conditions that affect consumers choice (Bronson, 2020). Change of dietary patterns—on average, reduction of food intake and increase in plant-based food—will stimulate producers to provide food with higher nutritional density and lower pressure on the ecosystem (McClements, 2020). Alternative sources of proteins will be available and diversification will increase the food variety.

[INSERT FIGURE 1 HERE]

Figure 1: Impacts on food systems. Source: The work of the authors.

Reshaping demand and behaviour

Digitisation offers a variety of solutions for sustainable dietary patterns (Smetana, 2019). Access to nutrition-related information can be made accessible and apps connected to wearables can provide personalised recommendations. Improved traceability will give consumers information about the impact of what they eat, fostering more sustainable patterns. The growing role of e-commerce will allow retailers to 'nudge' consumers, with sustainable solutions being more visible.

Reshaping supply and systems

Digitisation will make it possible—through data provided through several sources—to measure the carrying capacity of agro-ecosystems, and therefore to set levels for sustainable yields per region. Inputs could be distributed in proportion to both environmental and crop needs. Good agricultural practices will be documented, and related information can be communicated to consumers. Environmental certification will accompany food products. Improved access to knowledge and tailored decision support systems can support farmers in their practices (Tsolakis et al., 2021). Food safety can be improved through sensors, smart packaging, blockchain, or other technologies that hold the potential to increase trust and coordination between actors of the chain.

Supporting sustainable trade policies

Trade links together distant social and ecological systems. Sustainable trade occurs when this interaction does not harm the capacity of the systems to provide benefits for the future generations. Increasing evidence shows that a considerable share of international trade is not sustainable, and the increasing availability and accuracy of this information generates a clash between the principle of free trade and sustainability principles. The Lulucf regulation[1] is a key example of policies influencing practice, with telecoupling enabling interaction at a distance.

Digitisation will allow a generalised use of footprinting, which will improve the awareness of the true cost of food and support policy making with substantial evidence (Rincon-Patino & Corrales, 2018). Available information about the impact of distant production processes will inform actors across food systems about problems in, or impacts from, certain patterns of consumption and trade, and will increase the level of responsibility of firms, consumers, and policy makers.

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[1]The LULUCF Regulation implements the agreement between EU leaders in October 2014 that all sectors should contribute to the EU's 2030 emission reduction target, including the land use sector. https://ec.europa.eu/clima/policies/forests/lulucf_en#:~:text=The%20LULUCF%20Regulation%20implements%20the,including%20the%20land%20use%20sector.

Pathway 2: Full circularity of food systems

The second pathway implies a reorganisation of the food system around principles of circularity. A circular economy is based on: a) design of the product and production processes to minimise waste and to extend the product life cycle; b) reduce the amount of "funds" by shifting from "goods" to "services"; c) an industrial ecosystem with "functional diversity" that allows industrial symbiosis; d) improving the processes of reuse and recycling e) improving cooperation between firms for reusing and recycling; f) reorganising logistics for optimised flows; and,g) connecting the individual stakeholders of the system. Table 1 shows the potential impacts of digitisation in this respect. The food system can rely on several naturally circular processes, related to the role of living species in the biogeochemical cycles. The key for a circular economy is the value of biomass to be recycled and reused, and that the cost of biomass procurement and manipulation should be lower than its use value. At the level of primary production, this implies "closing the loops" at the farm or landscape level, with the soil (and living beings therein) having a pivotal role in transforming organic matter; for example composting (a practice that allows an upgrading of discarded biomass to increase the fertility of soil) is more profitable than burning it. At the level of secondary production, circularity implies reorganising "industrial ecology" to make the reuse and recycle of organic matter profitable (Canali et al., 2020; Gkisakis & Damianakis, 2020).

Redesign products and processes

A circular economy needs an alternative approach to product and process design. Product design should extend the life of products and minimise the disassembling costs. Diversity of input and output multiplies the possibilities that leftovers are turned into input for another process. This principle is translated into the construction of industrial ecologies (Marescotti et al., 2020). To maximise the (bio-)value that can be extracted from biomass, its hierarchy should be reflected in its exchange value and proportionally in the costs of procurement. These practices imply a rapid characterisation of feedstocks, proximity between buyers and sellers, improved logistics, and availability of data among potential users. The focus of research is to reduce the costs of manipulation of the feedstocks, of the transformation of biomass, and to reduce the friction between transactions. Robots can help manipulate the feedstock more rapidly and more safely, and sensors allow its rapid characterization. RFID systems can facilitate the logistics. Sharing such information will reduce the transaction costs between firms. Big data will allow a real-time, locally based, assessment of hierarchies of value between biomass utilisation (Dubè et al, 2018). Open data databases, platforms for B2B collaboration, monitoring tools, and similar solutions can be used to foster circular industrial ecosystems.

Increasing the awareness of firms, consumers, and citizens

Circular economy represents a new socio-techno-economic paradigm, as its main principles are related to the efforts of designing the product, the processes, and the legal/built environment around the optimization of reducing, reusing, and recycling activities. Adopting this new paradigm is an effort that involves all actors of the economic system, including producers, policymakers, and citizens. This adoption requires strong efforts in the field of education, training, access to information, and support services. Digital education and training courses, open information and experimental data, and dedicated social media for peer-to-peer interaction can strongly support this process. Citizens and consumers fill an important role, choosing products with lower environmental footprint and providing the first step of separation of domestic leftovers. At the consumer level, digitalisation can provide footprint tools, “nudging” software to positively influence the consumers’ behaviour, sensors to monitor domestic waste, and collaborative consumption platforms.

[INSERT TABLE 1 HERE]

Pathway 3: Reversing the erosion of diversity

The third transition discussed in the SCAR foresight exercise focuses on diversity. Diversity is a key to resilience of socio-ecological systems in face of change. In fact, diversity broadens the range of the functions that a system can provide, as well the range of responses to factors of change. This applies to both biological systems and social systems:“In systems with low diversity, there is less chance to create new ideas, components, or connections. Tinkering, mutations, and fortuitous errors are essential to derive new components and links in a system” (Young et al., 2006, p. ?) A substantial increase of biological, social, and economic diversity requires: a change of technical paradigms, consumers and citizens’ awareness; access to information; an ecosystem of farms with “functional diversity” surpluses to exchange; and, availability of market and technical alternatives. Digitisation can give an important contribution to these efforts, as shown in Table 2.

Biodiversity data

One of the first steps of biodiversity conservation is improving information availability. Digital cameras, remote sensing, field data, and citizens’ observations can increase such availability. Satellite data can measure biodiversity indicators (Cazzolla Gatti & Notarnicola, 2018), analyse population dynamics, species interaction and community diversity, functional traits and functional diversity, and biodiversity management (Tang et al., 2018). Data coming from biodiversity datasets can be used to train AI in recognising (Cope et al., 2012) and assessing living organisms and their features (Li, 2020). The challenge of developing this field is integrating data from different sources and improving data quality (Zeb et al., 2021). The Global Biodiversity Information Facility provides a single point of access to specimen data from databases of biological surveys and collections. Biologists have access to more than 120 million observations (Yesson et al., 2007). The possibility of creating global databases of biodiversity has generated the measure of global biodiversity, and with it an opening for new avenues for greater sustainability policy and practice (Devictor & Bensaude-Vincent, 2016).

Building biodiversity-based value chains

Given the characteristics of conventional retailers, products that do not comply with the rules that retailers pose are not accepted. Even if they were accepted, farmers would not be able to communicate to consumers the differences between alternative and conventional varieties. Therefore, the value of biodiversity should be turned into market value through dedicated chains, able to preserve the identity of the product and adequately remunerate all actors. In recent years, the use of e-mail, social networks, or cloud-based tools have made it possible for networks of consumers to organise purchasing groups. E-commerce or B2B platforms have helped farmers to find market channels appropriate to product size and characteristics. Consumers, along with conventional retailers, are increasingly interested in agro-biodiversity. Digitalisation can reduce transaction costs and inform consumers about the identity of both products and producers. Distributed ledgers, for example, can conserve the identity of the genetic variety along the chain (Antonucci et al., 2019).

Supporting policies

Policies for biodiversity need appropriate data collection, analytics, and measurement methodologies for monitoring diversity, mapping biodiversity distribution and risk, assessing the impact of policies, and controlling individual practices (Ehlers et al., 2021).

Knowledge development

The current techno-economic paradigm of conventional agriculture is still influenced by the Fordist principle, according to which efficiency is based on standardisation. For more circularity in systems, deep transformations of production processes and business models are needed. Digitalisation can foster education, access to information, training, and technical support. Moreover, as information about functional diversity is key to its use, sharing of trial data can accelerate dissemination and adoption of innovation. Knowledge about diversity can be enhanced through systematic data collection, open data, and knowledge sharing platforms.

Raising awareness of consumers and citizens

An increasing demand to protect diversity can foster new techno-economic models. Despite the variety of brands that consumers can find in the grocery stores, they may have a limited awareness of the variety of food that nature offers. Access to information can be improved through digital communication channels and through decision support systems on smartphones. By reducing transaction costs between producers and consumers, digitalisation can support biodiversity-based value chains to be clearly differentiated from conventional ones.

[INSERT TABLE 2 HERE]

Recommendations and conclusion

New generation of ICTs are potential game changers. Their embodiment into existing socio-technical systems will change societal organisation, generating winners, losers, and opponents. The risks related to digitisation and ability to diminish a transition towards sustainable diets can be classified into three types. **Design-related risks** are inherent to the purpose and the quality of the technology design. For example, technologies may “nudge” users to specific patterns of behaviours that may support unsustainable industrial agricultural models (e.g., monoculture, heavy use of external inputs, high degree of mechanisation); they could be vulnerable to cyber-attacks, show bias, give inaccurate responses, lead to missed opportunities, be characterised by fast obsolescence, and cause privacy breaches. Risks could be related to **unequal access** to digital opportunities, which is the distribution of physical, social, and human capital necessary to get access to digital practices. Non-adoption or late adoption may enlarge the gulf between social groups and territories, generating social and economic marginalisation. **Systemic effects** are related to the dynamics activated by the introduction of a given technology into a socio-technical system and generating consequences at a ‘macro’ level. Impact may be related to delayed, cumulative, indirect, or feedback effects. There is also the risk of relying on single technologies and ignoring the full system. One of the issues raised about agricultural ICT is the need of technological ecosystems. Given the interdependency between technologies, the introduction of a new technology would be ineffective without the right contextual conditions. For example, increased productivity at farm level may generate unemployment at industry level; information on pollution may ignite social stigma on those who, even accidentally, pollute; power imbalances in data ownership may bring the creation of monopolies and loss of autonomy by weaker actors.

Considering these potential risks, channelling digitalization toward societal interests will require deep revisions of the regulatory and governance contexts of food production and consumption. As ICTs can be game changers, anticipation of risks and benefits of digitisation should be strongly encouraged at all levels. When possible, regulation should avoid already known consequences, like breaches to privacy, concentration of power, and cybersecurity (Demestichas et al., 2020). A key area of intervention in the food system is the digital divide. Besides the importance of ensuring regional access to broadband, it is important to prioritise access for disadvantaged groups, to launch broad programs of training to give everyone the opportunity to achieve basic ICT skills, and to develop standards that avoid bias. Research and innovation policies should encourage the development of innovations tailored to small farming and food business. Initiatives such as "smart villages" aim at encouraging rural communities to look for digital solutions for pertinent issues.

Furthermore, a strong emphasis on **open data** would substantially reduce the cost of initiating service-providing start-ups and affordable technological solutions would be possible. Increased information availability, linked to a distributed capacity to produce, use, and communicate knowledge, can increase the level of responsibility of actors.

In conclusion, technological advancement is so far largely separated from the assessment of socio-economic consequences, since the approach to technology design is mainly based on performance remunerated by the market. Ethical considerations should be embodied into innovation processes, and legislation and governance should ensure that potential risk effects are not left only to individual innovators.

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