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Keynote article

# Agriculture and rural areas facing the “twin transition”: principles for a sustainable rural digitalisation[1]

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**Abstract.** In this paper some of the key issues related to digitalisation in agriculture and rural areas are addressed. In line with the Green Deal, the paper proposes a framework on how to address the “twin transition” (ecological+digital) through transformative policies based on directionality, market integration and reflexivity. The framework is based on a view of digitalisation as a socio-technical process, which implies taking into account the social implications of any technology development, and centring innovation policies on a clear definition of the problems to be addressed. The paper proposes the concept of socio-cyber-physical system as a paradigm for policy strategies and for innovation and discusses its implications for sustainable digitalisation strategies in the field of agriculture and rural areas.

**Keywords:** digitalisation, transition, transformative policies, innovation.
**JEL codes:** Q16, O33.

## HIGHLIGHTS[1]

- Digitalisation is a socio-technical process.
- To keep together digital transition and ecological transition, transformative policies are needed
- Rural digitalisation strategies should address the specificities of rural areas

## 1. INTRODUCTION

With the Green Deal, the European Union has committed to transform itself «into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use»

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(European Commission, 2020). To achieve this objective, «Europe must leverage the potential of the digital transformation». In other words, the digital and ecological transformations should go in parallel, and should reinforce each other. As the document points out, «Europe needs a digital sector that puts sustainability at its heart».

The choice to stress the link between the two transitions or, as proposed in the Green Deal document, to pursue a "twin transition", addresses a critical point of the strategy. Indeed, the two transitions are very different in in their dynamics and nature. On the one hand, the ecological transition, aiming at reverting the trend towards degradation caused by the fossil-based economy, requires a strong political and societal push, driven by public interest (Mazzucato, 2013). On the other, the digital transformation – at least the one we have experienced so far – is a mainly market-driven process: the advancement of digital technologies has opened huge opportunities for innovative business, which in most cases has taken advantage of regulatory gaps and generated inequalities and harm.

Agriculture plays a key role in the twin transition. Together with energy and mobility, food is considered one of areas where, to meet the sustainability goals, transformation should be deeper (European Environment Agency, 2021). The Farm to Fork strategy[2] emphasizes this aspect. The contribution of agricultural systems to greenhouse gases, reduction of biodiversity, pollution, water scarcity is well-known, as is the importance of the food system for human wellbeing. Ensuring food security and nutrition for all while reverting the trend to ecosystem degradation and ensuring a decent income for farmers and workers is one of the hardest challenges, a "wicked problem" for policymakers. The agro-ecological transition, which translates the ecological transition into agriculture, implies a radical rethinking of landscape infrastructures, farm design, production processes, business models, supply chains, consumption behaviour (Ollivier *et al.*, 2021; Duru, Therond, 2015). Digitalisation can provide tools for managing the complexity of more diversified agricultural systems, to optimize the use of inputs, reduce the burden of an unpleasant and heavy workload, simplify administrative tasks, improve communication with peers and consumers, anticipate risk and accelerate adaptation (Rolandi *et al.*, 2019). It can also improve the quality of life of farming households by making rural areas more liveable (Cowie *et al.*, 2019). However, also different digitalization pathways are possible, much less coherent with the agro-ecological transition and sustainability goals (Klerkx *et al.*, 2019). As is evident in countries where it has occurred earlier, digitalization has mainly benefited the dominant agricultural model, based on specialization and large-scale farms, which was the most profitable market for technology providers (Lajoie-O'Malley *et al.*, 2020). The mechanical sector has been the fastest to propose digital solutions to farmers, by embodying them into agricultural machinery (Wolf, Buttel, 1996). Decision support tools in precision farming have been focused on a limited number of crops such as wheat, maize, canola, and soybeans. As pointed out by many observers (Bronson, 2019), this might have increased the disparity between large and small farms, providing much lower than needed improvements to the sustainability performance of farms.

Evidence shows that digitalization, driven only by market forces and in the absence of an effective policy environment, might take our food systems far from sustainability. Policy approaches to technological development in many cases have considered the link between market and technology as unproblematic, considering technological innovation fully coherent with the public interest provided it generates efficiency and economic growth (Schot, Steinmueller, 2018). Keeping separate policy agendas for technology development and environmental, health and social issues has generated divergent pathways. Unintended consequences of technology development, framed in policymaking as "market failures", have limited the capacity of public policies to steer the evolution of technology towards societal goals (Weber, Rorhacker, 2012). Coherence between the digital and ecological agendas will require a new generation of policies – transformative policies – that get rid of "market failure" approaches in favour of "directionality" (Duncan *et al.*, 2022).

This paper proposes a policy framework for a "sustainable digitalisation", a digitalization pathway that supports the agro-ecological transition of the farming sector by sustaining the competitiveness of low-input, circular, diversified, quality-oriented farms, and prevents the digital divide between rural and urban areas and between large and small farms. Transformative policies in this field require creating the basic (infrastructural and human capital) conditions for digitalization, adapting digitalization to different contexts, favouring digital inclusion, developing digital ecosystems, designing specific policy tools and adaptive governance models.

The paper is arranged as follows: section 2 provides a conceptualisation of digitalisation as a socio-technical process. Section 3 provides an overview of the state of digitalisation, and section 4 describes the main technological opportunities. Section 5 discusses the theoretical implications of transformative digitalisation strategies

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[2] https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf

of agriculture and rural areas, and section 6 proposes a framework for sustainable digitalisation strategies.

## 2. UNDERSTANDING DIGITALISATION

To build strategies for sustainable digitalisation implies a good understanding of what digitalisation is. We start from the analytical distinction between digitisation, digitalisation, and digital transformation, and their relationship with innovation.

Digitisation is an innovation that turns an analogical process/product into a digital one (Rijswijk *et al*., 2020). This innovation has game-changing impacts, because most of the physical processes / products that populate our life have an informational function (for example, paper and ink are physical objects that are combined to produce information, such as text or images). When information is translated into numbers, its storage, reproduction, processing, display, communication can sensibly reduce the weight of the physical components (the handset, printer, electric power) of a digitized process/product per unit of information. The capacity to turn analogical information into digital information enormously amplifies the availability of information.

While digitisation is a purely technical process, digital*is*ation is a term that qualifies the change that digitisation generates in a broader social (or, better, socio-technical) system (Rijswijk *et al*., 2020). When paper and ink are not necessary to produce text, there is a wide set of actors and activities that need reorganization: paper and ink production and distribution, pens and typewriters, writers, publishing companies, booksellers, users. Digitisation has the power to change, in some cases very deeply, the existing networks of actors, artefacts, rules and their relationship with nature. When digitalisation goes beyond the boundaries of local production processes and affects the way the economy and society are organized – the rules, distribution of power, knowledge and resource base – it is possible to talk about digital transformation (Vial, 2021).

To understand – and anticipate – the socio-economic impact of digitisation, it is necessary to analyse the systemic relations between the physical, social, and digital (cyber) worlds and how they change with digitisation. Digitalisation phases have been classified in the literature according to the characteristics of the Internet-related technologies. The current phase of digitalisation, 4.0, is just at its beginnings, and it is based on technologies such as wireless connectivity, cloud storage and computing, artificial intelligence (Schwab, 2017). This phase is characterized by application systems that communicate with each other and act without human mediation. They apply to the concept of “cyber-physical system”: these systems perform *sensing* (gathering and digitising physical information), *communication* (regulating the flow of information between devices), computation (data storage, data analysis and computation architecture), *application* (calculus, classification, prediction), *actuation* (conversion from the digital to the analogical to operate on the physical system) (Bacco *et al*., 2019).

Cyber-physical systems are assemblages of devices designed to perform one or more function in a specific context. For example, a robot that cuts the grass in a vineyard is composed of sensors that allow the robot to recognize its position. The Artificial Intelligence software detects the grass and recognizes the obstacles in its way. Communication devices allow transmission of data to the cloud, computation software signals that the robot is within the assigned perimeter or if the task is done, cutting devices receive information on when to cut and when to stop[3].

As these systems affect the relations between humans and their activities, scholars have introduced the concept of “socio-cyber-physical systems” to consider the systemic effects of digitization on social relations (Rijswijk *et al*., 2021; Frazzon *et al*., 2013). The analysis of socio-cyber-physical systems starts from the classification of its components into the three domains (social, digital, and physical) and from the analysis of their relations, to allow a better understanding of the changes that digital technologies generate. For example, digital technologies can enable new functions and tasks (monitoring quality and classifying production accordingly) or disenable other functions (for example, milking manually) (Metta *et al*., 2022).

Understanding digitalisation as a transformation of socio-cyber physical systems allows technology developers, policy makers, civil society organisations and users to assess or anticipate the impact of new technologies, making it possible to improve the contribution to sustainable development goals (Rose, Chilvers, 2018).

## 3. CURRENT STATE OF AGRICULTURAL AND RURAL DIGITALISATION

The landscape of digitalisation in Europe is changing fast. The European Commission measures digitali-

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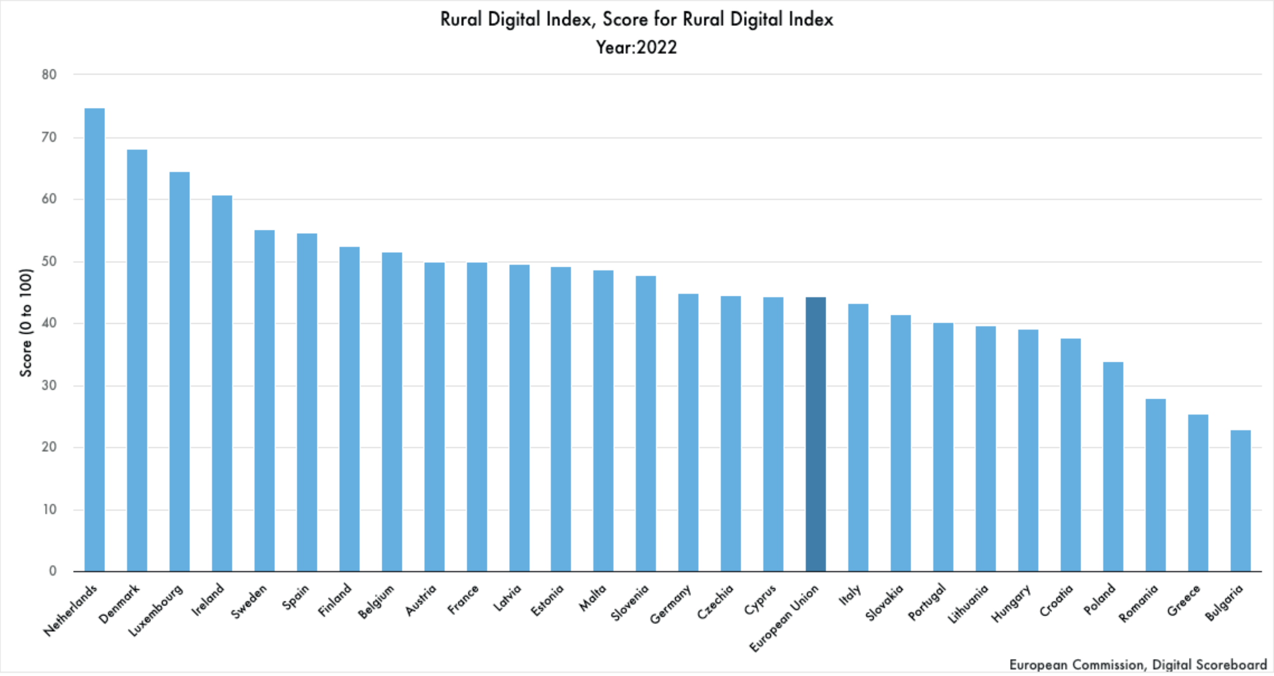
[3] Digitalisation 4.0 is also changing the meaning of “precision farming”, which has existed since the last century (Lowemberg-de Boer, 1996). The power of the new application systems resides not only in the tasks they perform, but also in being part of a network of objects that share huge quantities of data (Wolfert *et al*., 2017). Storage, integration, combination, processing these data gives access to information useful for automatic classification and prediction.

**Fig. 1.** Rural Digital Index - 2022.



Rural Digital Index, Score for Rural Digital Index
Year:2022

European Commission, Digital Scoreboard

sation through four indicators: infrastructures, human capital, integration of digital technology in the private sector, and digital public services (Russo, 2020). A distinction between rural areas and urban areas is available at aggregated level for the main indicators. In 2022, the average score[4] for the rural digital index was below 50. The countries with the most digitalised areas in Europe are The Netherlands, Denmark, Luxemburg and Ireland, the score of which is above 60. Italy is below average.

Little is known about digitalisation of agriculture. The last census in Italy has allowed to elaborate a "degree of agricultural digitalisation" for Italy. Data show the extent of the digital divide between Northern and Southern Italy, with most Southern regions using very little or no information technologies (Gnesi *et al.*, 2022). These data provide a lens to evaluate the recent technological trends illustrated below, and to warn about policies that don't actively address the digital divide.

## 4. PERSPECTIVES FOR DIGITAL TECHNOLOGIES IN AGRI-FOOD SYSTEMS

Digital systems of the 4.0 generation are assemblages of multiple technologies (Carolan, 2017) that integrate the variety of functions related to the use of data to provide decision-support or autonomous systems. Some of these assemblages are sold as ready-to-use packages, as in the case of autonomous tractors, which are endowed with GPS systems that track their position and allow automated operations, with sensors to collect data from the field, and devices that connect to the cloud and receive elaborated data and are supported by software that gives real-time instructions to the actuators (for example, spraying)[5]. For most of the other application systems, the design, setup and calibration must be tailored to the characteristics of the farm on which they are applied and requires a mix of digital and agronomic competences (Lin *et al.*, 2019).

Application systems operate in application scenarios (Bacco *et al.*, 2019), defined by the agricultural processes, their purposes and their socio-ecological environments. The study of application scenarios and their specificities is a key to predict the potential uptake of digital technologies. Hereafter we show the most relevant ones, with a review of the related technologies.

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[4] The Rural Digital Index score is calculated as the weighted average of the three sub-dimensions: 1 Use of internet (33.3%), 2 Human Capital (33.3%), 3 Connectivity (33.3%). See https://digital-strategy.ec.europa.eu/en/policies/desi

[5] See for example https://www.deere.com/en/technology-products/precision-ag-technology/

### *4.1. Soil and water management*

Restoring the quality of soils is one of the most urgent priorities in the transition. The basic strategy for regeneration is the adoption of agro-ecology principles, but technology can accelerate the process by improving the monitoring of soil quality. Studies show that remote and on-ground sensing, coupled with modelling, are improving the capacity to measure roughness, soil moisture, salinity and organic matter content (Arrouays *et al*., 2021). Also improving the allocation of water for irrigation requires improved monitoring capacity as well as reliable prediction tools (Abioye *et al*., 2020). Remote and on-the-ground sensors can collect a large amount of data on weather, soil and plants. Prediction tools allow closed-loop irrigation strategies, based on controllers that decide automatically when and how much to irrigate based on either predictive models and / or on AI-based intelligent control (Adeyemi *et al*., 2017).

### *4.2. Crop and livestock management*

Sustainable crop management can strongly benefit from the improvement of sensing. Remote sensing based on satellites or drones provide data that can be used to build maps which detect differentials in the status of the crop and allow variable rate operations. Remote sensing is also used to map and estimate weeds in the field (Nawar *et al*., 2017). Machines available on the market are endowed with a myriad of sensors which collect data that are used to adapt their use to the conditions of the environment. The availability of these data allows the development of variable rate systems, which adapt operations to the conditions of the microenvironment where they operate (Antle *et al*., 2017). Digital technologies allow automated coordination between components of the mechanical systems, auto-guidance systems improve adaptation of the operations to the ground conditions. Digital twins – real time simulation models based on a continuous flow of data from the monitored system – can monitor the status of systems in real time, of their energy consumption, or can predict damages, allowing a better planning of maintenance (Pylianidis *et al*., 2021). Unmanned aerial vehicles can collect data and, if endowed with actuators, allow semi-automated operations (Vasconez *et al*., 2019). Unmanned vehicles are already used in harvesting and weeding. 3D printing can be used for producing spare parts locally, limiting delays in repairing the equipment (Javaid *et al*., 2019). Assistive exoskeletons can contribute to relieve agricultural labour and increase labour security (Upasani *et al*., 2019). Digital technologies also offer the possibility to develop alert systems for pest management based on vegetation maps, camera-equipped traps (Jia, Hang, 2019), AI-based recognition of insects and diseases (Abade *et al*., 2021). Variable rate operations can increase the efficiency of applied pesticides.

In the livestock sector, digital technologies allow the monitoring of animal health, to detect diseases early, control movement of animals, monitor emissions, assess the quality of production (Ingrand, 2018). Automation is already widely diffused on livestock farms, especially as far as dairy farming is concerned (John *et al*., 2016), but the possibilities opening with the management of data in the cloud considerably expand the already existing possibilities. Digital twins – simulation models fed by real time data – of animals are being developed to improve the prediction capacity of farmers (Norton *et al*., 2019).

### *4.3. Farm and supply chain management*

Digitalization will also strongly affect other farm management activities. A data-driven approach will benefit from farm management information systems, which will integrate specific decision support systems into platforms that will constitute a dashboard to monitor all operations (Wolfert *et al*., 2017). E-commerce provides alternative outlets to conventional ones and favours the diversification of business models. B2B platforms facilitate the cooperation of farms in the fields of logistics[6], machinery sharing[7], innovation (Rijswijk *et al*., 2019). Access to the internet allows an unprecedented access to information and education – facilitated by the diffusion of smartphones (Schulz *et al*., 2021) – and will encourage advisory services to rethink their organization. Social media allow distance to be overcome and improve organization of work (Morris, James, 160).

There is a growing agreement that the biggest, or the fastest, disruption in the food system will not occur at the level of single activities, but at that of the interaction between activities. We can already recognize the advent of the platform economy in marketing activities, as e-commerce is changing the relational patterns between producers and consumers or between producers. With e-commerce virtually all producers can go on the global markets. Consumers have an unprecedented freedom of choice and the possibility of comparing products (Zhang, Berghäll, 2021). The possibility of getting feedback on customers’ behaviour dramatically changes marketing techniques. E-commerce also entails a revolu-

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[6] https://lacharrette.org/

[7] https://iottechnews.com/news/2019/may/10/hello-tractor-uber-farming-agriculture/

tion of logistics, which has started to make massive use of digital technologies in administration, planning, control, and goes together with revolution of payments and consumers' purchasing patterns. Platforms have developed sophisticated algorithms to assess the sellers and to match sellers with buyers (Kanoria, Saban, 2021). Consumers can find information on the label, in the shop, or in a cloud-based database which can be accessed through a QRcode (Brewer *et al.*, 2021). Increasing availability of bio-physical data will allow the sustainability footprint of each product to be calculated. The increasing amount of information collected at all levels of the supply chains will accompany the products throughout their lifecycle, allowing a full product traceability along the chain. Improved information will increase the responsibility of producers and consumers, as they will be able to link their choice to potential consequences and therefore to account for them. Technologies related to traceability, at present based on documents, will integrate sensing, communication, data management with Internet of Things systems (Lin *et al.*, 2020).

## 5. A POLICY FRAMEWORK FOR SUSTAINABLE DIGITALISATION

The technologies mentioned in the preceding section offer a range of opportunities for the ecological transition of agriculture. However, technology alone will not be sufficient. So far, the most important drivers of technological change have been market forces: farmers adopt digital technologies based on the perspective of reduced costs and increased productivity, and technology developers push innovation where profitability is higher. This means that in the absence of public policies as a balancing driver, digitalisation would tend to fix urgent problems at the expense of long-term objectives, delaying their transformation. Basso & Antle (2021) point out that the efficiency of precision farming could lead to a greater use of fertilizers and pesticides, as precision technologies can put into evidence the areas of the field where the need is higher. To make digital solutions for multifunctionality, agro-ecology and ecosystem services available (Bellon-Maurel *et al.*, 2022), they should be actively promoted through adequate innovation policies, which are able to balance market forces by referring to societal challenges (Rose *et al.*, 2021). For this reason, digital strategies are needed, and rural and farm communities need to acquire the capacity to obtain control of the incorporation process.

In the new CAP, digitalisation strategies are a component of the National Strategic Plans, where Member States must provide «a description of the strategy for the development of digital technologies in agriculture and rural areas and for the use of those technologies to improve the effectiveness and efficiency of the CAP Strategic Plan interventions»[8]. Digitalisation strategies should explain, in other words, how digitalisation can contribute to the CAP objectives.

However, these strategies risk failure if Member States don't adopt a coherent approach. Transformation cannot be achieved with "normal" policies: transformative policies are needed. As a growing literature shows (Giurca *et al.*, 2022), transformative policies tend to address the root causes of emerging problems, and for this purpose they don't refrain from challenging the mental models, assumptions, and coalitions of interests that shape "normal" policies (Köhler *et al.*, 2019). To be transformative, policies need to give directionality to the change, to actively shape market forces to make innovative solutions emerge, and be capable of encouraging experiments and learning from them (Duncan *et al.*, 2022). However, transformative policies cannot be based on the assumption that the solutions are already there: rather, they mobilize societal forces into innovation processes and leave the pathways of transformation open (Geels, Kemp, 2017). These processes should preferably be "bottom up", by experimenting new patterns of production and consumption, new infrastructures, new rules at local level, and encouraging their scaling up (Geels, 2019; Sengers *et al.*, 2019). Transformative policies can offer these experiments a direction (visions and goals backed by evidence and deliberation), enabling environments (financial support, training, regulatory derogations), and can take the outcomes of experiments as inputs for policy learning (Weber, Rorhacker, 2012). They can also actively promote leadership and entrepreneurship of actors, networks and institutions in making change (Hoogstraaten, 2020; Grillitsch *et al.*, 2019).

What are the levers that digitalisation strategies can mobilize? The most radical option is regulation: setting mandatory standards or forbidding certain practices or technologies, so creating space for alternative ones. However, excessive use of regulation might limit the creative capacity of actors and innovation. More "soft" measures would tend to leave actors free while influencing their behaviour, for example by altering the cost-benefit balance among options, as in the case of

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[8] reg. (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the Common Agricultural Policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing reg. (EU) 1305/2013 and (EU) 1307/2013.

compensation for extra costs of recommended options. They can also act on motivations of choice with information, education and training. Innovation policies can be important levers for transformation strategies.

As research and education are largely funded by public money, public policies can do a lot to balance market forces in technology development. This can start from embodying the principles of responsible research and innovation into policies (Klerkx, Rose, 2020; Rose, Chilvers, 2018; Rose *et al*., 2021), according to which researchers should involve users and stakeholders in the research design, reflect on the motivations, purposes and possible consequences associated with their research, and are directly involved in processes of change.

Following these insights, the DESIRA project[9] has proposed a framework that adopts the socio-cyber-physical system paradigm and identifies three critical properties of Socio-Cyber-Physical Systems (SCPS): design, access and complexity (Rijswijk *et al*., 2019).

*Design* focuses on the problems technologies are supposed to address, on users' needs, and on potential risks. Depending on production approaches and business models, technology solutions can assume very different shapes: for example, multifunctional agriculture and agro-ecological practices need quite different solutions from those related to monocultural practices (Bellon Maurel *et al*., 2022; Hilbeck, Tisselli, 2020). Different configurations, such as centralized systems providing subscription-based services (like Amazon or Google) or decentralized semi-autonomous localized application systems connected in broader networks (such as smart machinery for precision farming), can have different strengths and weaknesses. The issue of design is particularly relevant with AI and robotics, as they can make autonomous decisions with implications for safety and ethics (Coeckelbergh, 2020).

*Access* regards the endowment of infrastructures, human capital and financial resources that can affect the capacity to adopt digital technologies and create value with them. Different access conditions are at the root of different digital readiness of farmers (Pirola *et al*., 2019). Inequalities in endowment of these capitals are at the root of the digital divide (Van Dijk, 2020). Different access conditions affect the digital readiness of potential users. In relation to rural areas, the digital divide has an external dimension (rural vs urban) as well as an internal one (Koutsouris, 2010). Access also has a dynamic nature (Van Dijk, Hacker, 2003): early adopters can gain cumulative advantages over late adopters. The removal of barriers to access digitalisation is one of the key aspects of sustainable digitalisation strategies, able to contrast the digital divide and intervene in its dynamics.

*Complexity* describes the systemic conditions for adoption and scaling up of digital technologies. As the key characteristic of application systems 4.0 is their interconnectedness, successful use of digital technologies for farmers implies being connected to a well-functioning socio-technical network. Lack of specific components (for example, of sufficient quantity and quality of data, advanced digital skills, system integrators), lack of key actors (for example, advisors or service platforms) or inappropriate relational configurations (for example, excessive centralization or decentralization of platforms) can generate unintended systemic consequences, such as structural inefficiencies, concentration of power, or systemic errors. One of the key systemic aspects to be considered is interoperability (Kerber, Schweitzer, 2017), which is the possibility to exchange, pool, integrate data between actors and devices. Interoperability requires regulatory conditions as well as governance and technical solutions (World Bank, 2021).

## 6. DIGITALISATION STRATEGIES AND FOOD SYSTEM TRANSFORMATION

Implementation of digitalisation strategies will give important insights into how public policies can orient these processes and will stimulate policy learning. However, it should be noted that the reflection on rural digitalisation policies is much less advanced than needed. In a recent overview document of the National Strategic Plans[10], the EU Commission analysed Member States' digitalisation strategies, and identified several shortcomings: a limited consideration of digital technologies as enabling tool for other CAP objectives (particularly for environment, climate and rural-related objectives), a scarce consideration of the needs of rural areas, and limited focus on the development of digital skills that can help to close the digital divide. Moreover, it is said that strategic plans fail to establish consistent links with dedicated interventions, and do not provide a clear picture in terms of planned financial support to digital-related investments.

If Member States have invested little and late in digitalisation strategies, it is to be considered that an EU-level policy framework for rural digitalisation, coherent

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[9] https://desira2020.eu/

[10] Proposed CAP Strategic Plans and Commission observations: Summary overview for 27 Member States. June 2022. https://agriculture.ec.europa.eu/document/download/a376aab6-3a1d-4996-bb35-33c90b90c3bd_en?filename=csp-overview-28-plans-overview-june-2022_en.pdf

**Tab. 1.** A framework for sustainable digitalisation strategies

| | Design | Access | Complexity |
|---|---|---|---|
| Directionality | Diversity, system management, relief of heavy and low added value tasks | A minimum level of digital readiness | Build conducive digital ecosystems; build European data spaces |
| Market articulation | Conditionality, interoperability standards, ethical codes | Incentives to users | Supporting data-based services |
| Reflexivity | Promoting Living labs | Systematic monitoring of the digital divide | Formative evaluation |

with the Green Deal and the Long-Term Vision for the rural areas, is still under development. Table 1 provides an application of the DESIRA framework to transformative digitalisation strategies. The properties of transformative policies - directionality, market articulation and reflexivity (Weber & Rohracker, 2012) - are divided into the three dimensions of the socio-cyber-physical systems - design, access and complexity.

*Directionality* of *design* should encourage pathways for digitalisation fit to multifunctionality, agro-ecology, small and diverse farming, and adaptation of digital technologies to different contexts. This implies a thorough understanding of the needs related to these practices, which are related to the management of diversity, relief of heavy and unpleasant tasks, improved collaboration and network economies. *Directionality of access* could focus on combating the multiple dimensions of the digital divide. According to the DESI data[11], only 42% of people between 55 and 65 have basic digital skills, while this share raises to 71% in the segment of 16 to 24 years old, and the share of women between 16 and 74 is 52% compared with 56% of men. *Directionality of complexity* should be aimed at developing conducive digital ecosystems (Boiley, Chang, 2007) wherein all actors have the possibility to benefit from the use of data and to establish fruitful interactions with other actors. The specificity of digitalisation 4.0, in fact, is related to the interdependence of actors and technologies with related skills, so that the performance of individual actors depends strongly on to what and whom they are connected, and what are the conditions for exchange between them. Conducive digital ecosystems will depend on the combination of social, human and digital capital and on their relationship with the natural environment. Specific governance arrangements should aim at creating integrated data spaces sufficient to allow data use and re-use. Interoperability standards and clear rules for data sharing, use and reuse are necessary.

When it comes to *market integration*, strategies should be able to make transformative technologies competitive with conventional ones. This could occur in the field of *design*, where research fundings could specify required standards and prioritize application scenarios such as those of small size and marginal areas and focused on agro-ecological practices. In the case of *access*, strategies should guarantee the basic conditions of digitalisation. As seen before, rural areas lag behind urban areas in the parameters of digitalisation (connectivity, human capital, use of Internet). Lagging behind with these parameters implies the reproduction and broadening of inequalities. To keep rural areas within a level playing field, there is the need to be proactive, by constantly monitoring the digital divide, identifying the vulnerabilities, and addressing them with adequate tools. As far as *complexity* is concerned, policies can encourage the consolidation of data-related infrastructures and services, such as advisory service platforms based on specific quality standards. They can play a game changing role in the market, as they can harness the network economies related to the number of their connections.

Introducing *reflexivity* in design-related strategies could shape the characteristics of the design process. For example, the involvement of users in the design – such as in the Living Lab approach – supports adaptation to a diversity of contexts. Considering the anticipation of the impacts as an evaluation parameter could encourage researchers to link innovation to its outcomes. Policy tools should be designed to activate dynamics of transformation through networking and market integration. Operational Groups, Eco-schemes and Agro-Environment and Climatic measures can be designed in a way to encourage the fulfilment of environmental objectives while fostering the uptake of digital technologies in support of them. Reflexivity should also apply to *access*: given that the digital divide is a dynamic process, there should be systematic monitoring and adaptation of the strategies to its evolution. Finally, applying reflexivity to *complexity* would foster policy evaluation approaches aimed at improving the learning processes of all actors in the system, rather than just measuring outcomes, and building adaptive governance. Rural Digitalisation affects

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[11] https://digital-agenda-data.eu/datasets/desi/visualizations

several sectors: infrastructures, training and education, data, regional policies, sectoral policies. Moreover, lack of jurisdiction for rural matters hinders coordination under a clear leadership. Governance arrangements should be capable of adaptation in relation to the feedback received from the policy implementation outcomes.

## 7. CONCLUDING REMARKS

To grasp the opportunities that digitalisation offers to transformative sustainable development policies are needed, organized into coherent strategies based on directionality, market integration and reflexivity, with a strong bottom-up approach. These strategies should be based on an understanding of digitalisation as a socio-technical process and should intervene in the process of technology development and diffusion by addressing critical points of design, access and complexity. As digitalisation can open up a multiplicity of pathways, real-life experiments are necessary to test the most appropriate socio-technical solutions to emerging problems, and the lessons learned at local level should be shared and elaborated to activate higher level learning processes.

Given the fragmented landscape of intervention in this field, a strong emphasis on governance is necessary. Rural digitalisation strategies should have the strength to make the components of several administrations act in a coordinated and coherent way, and institutional actors with strong legitimacy and authority should oversee their implementation. The Next Generation EU has provided a strong injection of resources in the system with a clear transformative purpose. It is now time that these purposes are clearly translated into appropriate governance and policy arrangements.

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