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The digitalization of agriculture and rural areas: towards a taxonomy of the impacts

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Abstract: The literature about digitalization in agriculture and rural areas is vast and sectorial at the same time. Both international political institutions and practitioners are interested in promoting digital technology, indicating and describing potential benefits and risks. Meanwhile, academics analyse the actual and possible impacts of digital technologies using case studies. However, the extensive literature makes it challenging to derive a comprehensive synthesis of the possible impacts that digital technologies are and might generate in the rural domains. In the given context, the present work aims at contributing to the construction of a framework providing a first classification of the digital technologies impacts to use in both research and political agenda.

Keywords: agriculture; digital technologies; digitalization; socio-economic impacts.

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1. Introduction

Digitalization redefines people's routines and can produce positive effects from both economic and environmental perspectives (EU Declaration 2019). However, as the literature stresses (Vasile 2012; Floridi et al. 2018; Vial 2019), the digital transformation could also cause social and ethical issues. The impacts of digitalization are investigated in the scientific literature to identify potential and controversial aspects to govern its settings or to adapt policies and practices (Scholz et al. 2018). A wide range of the literature contributes to unfold the impacts focusing on use cases based on the use of specific technologies (e.g., blockchain, artificial intelligence, Internet of Things) and applied to specific scenarios (e.g., agriculture, energy, commerce). What seems to be missing is a more comprehensive analysis that proposes a taxonomy of the impacts due to the introduction and use of digital technologies. There are indeed a few and recent attempts in the literature aiming at shedding some light on the impacts of digital technologies, (Scholz et al., 2018; Eastwood et al., 2019 García Zaballos et al., 2019; Klerkx et al., 2019; van der Burg et al., 2019; Barrett and Rose, 2020).

This paper aims at proposing some considerations on the digital, socio-economic, and ecological impacts of digitalization in agriculture and rural areas. The main research question is unfolded in three levels: what are the main areas of impacts identified by scholars in agriculture and rural areas? What are the outcomes? What are the connections between digital solutions and impacts? Thanks to a thorough literature review, this paper identifies the main areas of impacts and proposes a summary of those. Thus, the main purpose of this work is not to provide a theoretical analysis of technological innovation *per se* built on existing theories but rather to identify, classify, and describe the potential impacts of digital technologies in rural areas and agriculture reported in the scientific literature. Through this analysis, we propose tools (the taxonomy and a grid, see paragraphs 5 and 6) useful to policymakers and other users to reflect beforehand on the potential impacts due to digital technologies.

The rest of this work follows this structure: firstly, we propose a brief reflection on technological innovation theory and present the analytical framework carried out in the H2020 DESIRA project[1], of which this work is one of the first outcomes. How digitalization is provoking a systemic transformation is emphasized. In the following section, we propose a short discussion about the role of digitalization in agriculture, according to the international policy indications and the ongoing debate in the scientific literature. Possible limits identified in the existing literature, are highlighted, opening to the proposal of a grid of impacts created to improve both the analysis and the consequent considerations on digital impacts. Then, firstly the methodology used for the conducted literature review is described, followed by the design of a summary of impacts. Finally, the summary is detailed and discussed, and examples are also reported. The conclusions report both the scope of this work and its limits, highlighting the need for further investigations.

2. The digital innovation

The literature on technological innovation is quite vast, and it includes different disciplines, like economics, sociology, and psychology. These studies highlight diversely the social role of technology, how and why it emerges, how it can (or not) spread and be adopted by agents, what type of impacts can be forecasted, and other aspects. Theories on the process of technological innovation evolved from *linear models* – which prioritizes the scientific research in the innovation process, underestimating the role of later players in both diffusion and adoption steps – to *systemic perspectives* (Greenacre et al. 2012; Salazar-Acosta and Holbrook 2008). The latter, considering some theories rather different in both ontological and epistemological sense (e.g., the *multi-level perspective*, Geels 2002; the *actor-network theory,* Shove et al. 2012; or the *social practice theory*, Latour 2007), emphasizes the knowledge flows among actors in the technology adoption process, their expectations, and the culture of technology. Market developments are considered, but also policies and the institutional structures as factors that promote or limit technological development, its diffusion, and its adoption. In short, these theoretical perspectives tend to emphasize the role of multiple agencies and distributed learning mechanisms in technological changes focusing on inter-organizational networks in which the innovation develops (Lai 2017; Winskel and Moran 2008). In short, technological change is not considered just in terms of 'physical' inventions or developments, but as a process interacting with changes in people behaviour and the institutional and socio-economic structures (the market, firm organizational forms, consumer preferences, policy goals, actors' skills, and knowledge).

The systemic perspectives shed some light on the activities, connections, and contextual conditions that foster or hamper innovations to manage the innovation processes themselves (Hekkert et al. 2006). They also allow the reader to observe how innovation affects multiple socio-economic spheres. Since the classic contributions of Schumpeter's and Kuznets' models (deBresson 1991) or even Marx's perspective (Jimenez-Barrera 2018), it was reported how innovation can be disruptive for socio-economic systems, particularly novel technologies (Downes 2009). Precisely, some technological innovations can be defined as *game-changers* (Avelino et al. 2017), because their adoption deeply transforms the wide context in which both routines and interactions take place due to their connection with multiple elements of the socio-economic system. As it was stressed (Küppers 2002; Plowman et al. 2007), due to their multiplicity of intersections, game-changers may trigger the unpredicted emergence of novel social phenomena or cascading effects because of the reorganization of processes in socio-economic systems that react or adapt to the game-changers.

Following the previous considerations, a systemic perspective has been adopted in the DESIRA project, of which this work is a first outcome. The aim is to analyse the ongoing digitalization process in rural areas and agriculture to strengthen the capacity of

1 DESIRA: Digitalizsaion: Economic and Social Impacts in Rural Areas – https://desira2020.eu.

society and political bodies in responding to the digital challenges. It is important to note that there is a distinction between the term *digitization* and *digitalization* due to their substantial different impacts (DESIRA 2020s). Digitization has been defined as the technical conversion of analogue information into digital form (Autio 2017). The introduction of computers has led to increasingly automated processes, reducing the need of some manual activities and thus generating a wide array of impacts. In this case, scholars refer to digitization as the third industrial revolution (Greenwood 1997) that affected the business level when using the technology. In the case of digitalization, scholars refer to the fourth industrial revolution (Schwab 2017) because the interconnectivity of digital tools that characterize digitalization has defined a new socio-technical context in which human activities are performed (Lyytinen et al. 2016; Nambisan et al. 2017). These phenomena also apply to agriculture and rural areas. Precision agriculture can be seen as related to on-farm activities involving specific digital solutions (e.g., yield mapping, GPS guidance systems, variable-rate application), while smart farming covers the entire value chain (before, during, and after on-farm production, including e.g., e-commerce platforms, blockchain-enabled food traceability systems, and precision agriculture itself). Similarly, digitalization is a process based on digitization, adding to it the interconnection that enlarges the spheres involved in the innovation process, and provoking socio-economic and institutional changes.

The complexity generated by digitalization and its present and future challenges in literature was also analysed applying the concept of *socio-cyber-physical system* (SCPS) (DESIRA 2020b; Calinescu et al. 2019; Frazzon et al. 2013). The SCPS concept describes the multiplicity of interconnections of cyber (or digital) elements (digital twins, digital infrastructures, big data, etc.) with physical entities (plants, livestock, clime, soil, etc.) and social worlds (culture, values, (institutions, etc.). These new interactions are constantly generating expected and unexpected impacts that should be scrutinized to improve the capacity to respond to the challenges they pose. To do so, we propose a taxonomy of potential socio-economic impacts due to digital technologies in this work.

3. The promises of digitalization in agriculture and rural areas

UN (FAO 2018) forecasts that in 2050 the food system will need to nourish more than 9 billion people all over the world. To feed everyone without compromising the entire ecosystem, it is urgent to intervene by re-designing an efficient and sustainable food production system. At the same time, rural communities suffer from several problems (difficulty in reaching markets, ageing, depopulation, lack of public and health services, etc.) that can also negatively affect sustainable food production. Considering these concerns, reports (García Zaballos et al. 2019; OECD 2019a; WEF 2018) suggest that the digitalization process can contribute to both agriculture (e.g., contributing to efficient use of resources) and rural communities (e.g., defining new and enriched services) sectors. At the same time, it is also stated that digitalization can contribute to achieving the UN Sustainable Development Goals (SDGs) in rural areas, the 17 interlinked goals like 'no poverty', 'zero hunger', 'climate action' (Campbell et al., 2018; FAO 2018). Despite the positive picture, some scholars suggest that to promote digital transformation, international institutions and policies underestimate the social complexity of these technologies and the possible undesirable effects. Lajoie-O'Malley et al. (2020) observe that the way digital technologies can transform socio-economic context is affected by hopes, imaginationss, and visions regarding the role that these tools might play for social actors particularly according to the main international agencies (e.g., FAO, World Bank, etc.). The dominant narrative of these organizations seems to support the *status quo* of global industrial agri-food systems. Academics argue that international agencies assume a neo-Malthusian narrative to agricultural issues and a technological optimism as the solution. In short, there is a mismatch between population growth and food availability, which they assume can be solved by technological innovation, optimistically leading not only to technical, but also to social, political, and even moral progress and environmental protection.

A growing literature reports that digitalization could produce unexpected and negative outcomes, and a too simplistic picture cannot be used to govern such a process. Salemink et al. (2017) observe that initiatives to promote digitization in rural contexts are mainly based on a free-market rationale without considering contextual specificities (e.g., private investments, digital skill levels, trust in technology). For these reasons, policies can contribute to an increase in social exclusion for fragile actors, like elders or low educated people, or forms of dependency by digital providers that control both technologies and collected data. In this perspective, Rotz et al. (2019) report that automatised agriculture significantly improves the lives of farmers and workers who can utilize digital technologies, creating new job opportunities, but also a radically bifurcated labour market increasing social asymmetries. Therefore, on the one side, there are highly skilled, highly trained digital workers that increase productivity and efficiency and, on the other side, the lower-skilled workers in the fields, greenhouses, and warehouses, which are subjected to increased scrutiny and surveillance, further rationalization of their workplaces, and ever-escalating expectations of productivity. These low-skilled workers are at risk to be replaced by robots and automatised solutions. Moreover, digital tools could not contribute to reach the SDGs on climate and environment according Vinuesa et al. (2020). They state that the massive use of digital solutions could increase the world electricity demand up to 20% by 2030, and that without changes in the energy sector (increasing renewables and energy efficiencies) the ecological footprint of human activities will grow considerably.

These considerations suggest that the relevance of reflections on ethical and normative aspects of the digital transformation in agriculture and rural areas have not yet reached satisfying conclusions (Jakku et al. 2019; van der Burg at al. 2019). How and which data should be collected and shared, what are the benefits and for whom, and other questions could be answered by engaging relevant stakeholders in a participatory process anticipating future farming trajectories to define guidelines and norms to implement digital tools. For this purpose, studies on the impacts of digital agriculture are pivotal. They figure out possible impacts supporting the elaboration of adequate solutions. The literature on this issue is quite recent. Works can be roughly divided along a continuum that analyse digital impacts based on the specificity of the considered technologies and the considered scenarios. On the one hand, some studies examine the effects of digitalization as a factor for the optimization of activities (e.g., seeding, milking) and resources (e.g., water, energy, land, fertilizers) to achieve economic or environmental benefits. In these cases, scholars take into consideration a specific set of digital tools, like sensor nodes (Thakur et al. 2019), WebGIS (Gheshlaghi et al. 2020) or Internet of Things-based solutions (Sarkar and Changala 2018). On the other hand, some works report changes in distinct wider contexts, like farming or rural communities, considering a small set of technologies, such as robots (Sparrow and Howard 2020) or digital platforms (Boursianis et al. 2020). Here, scholars take into consideration not only the effects on production processes, but also on socio-ethical dimensions like privacy, data ownership, lack of digital skills. In other cases, scholars propose general considerations on digital transformation proposing an analysis in specific application scenarios[2], like farming (Wolfert et al. 2017), agriculture knowledge (Fielke et al. 2019) or even wider contexts. For instance, by considering the consequences as anticipated by media, experts, and farmers for the digitalization process (Barrett and Rose 2020) or the perceptions of digital risks by key governance actors (Regan 2019). These studies highlight the complexity of the interrelated socio-economic and environmental impacts as well as ethical dimensions in digitalization.

2 An application scenario can be defined as the way users interact with a digital system in each context.

Said analyses make it difficult to identify a comprehensive and detailed overview of the impacts of digital technologies. This consideration is based on the fact that, on the one hand, there is a general attitude to focus on very specific technologies, sectors and dimensions (e.g., sensors for reducing costs in milking), which are analysed using a quasi-experimental method or interviewing experts and stakeholders; on the other hand, other analyses (e.g., on agriculture and on digital tools) are based on a literature review or on illustrative examples. In both cases, they offer useful information about digitalization, but they lack the design of a summary of impacts to anticipate the possible effects of the digitization process. As Klerkx et al. (2019) observe, the intricate relationship among different entities involved and interconnected in the digitalization process (plants, technological tools, biological processes, cultural aspects, etc.) [3] needs a more comprehensive picture to address questions still under inquiry (like the complex socio-economic and environmental impacts as well as ethics and policy issues).

Following these considerations, we propose in what follows a taxonomy of the impacts to unravel the complexity of digitalization. Our proposal consists of a classification of the impacts based on a systematic literature review, scrutinizing the outcomes of digital tools in the main areas of impacts for agriculture and rural communities. The aim is to provide a tool in the form of a grid, which can give practitioners (e.g., farms, rural communities, rural workers, officials) the possibility to identify potential impacts (both positive and negative, depending on the specific context) and connections between digital solutions and their possible uses in specific application scenarios. In this sense, our tool can stimulate a preliminary reflection on possible outcomes, and also support the design of policies to address side effects.

4. Methodology

Among the plethora of different analysed methodologies to conduct literature reviews, a stand-alone literature review (Xiao and Watson, 2019; Templier and Paré, 2015) is used in this work. Such an approach enhances the analysis of the existing literature upon a specific and identified subject while aggregating or interpreting expressed concepts (Xiao and Watson, 2019). In facts, the present work aims at answering the research questions anticipated in the introduction by reviewing the most relevant literature. The aim is in increasing the understanding of the actual and forecasted outcomes of digitalization in agriculture and rural areas. To do so, an inductive thematic analysis (Clarke et al., 2019) was conducted to answer the research question and achieve a comprehensive, not yet exhaustive, overview of the impacts.

The identification of relevant literature was performed by selecting both grey and white literature published between 2015 and 2021 in English only. Following literature indications (Atkinson and Cipriani, 2018), we used a search query using specific keywords and their combination on Scopus, Google Scholar and in the University of Pisa library system. The used keywords are: 'digitalisation' (or 'digitisation') AND 'impact' OR 'effect' OR 'outcome' AND 'agriculture' OR 'rural area'. The papers have been selected based on their pertinence with respect to the research questions by taking into consideration titles, abstracts, and keyword. 130 works have been preliminarily selected, then reduced to 34 because they provide a description of digital solutions associated with socio-economic and environmental impacts as well as application scenarios and contexts. The impacts were identified by conducting a qualitative inductive thematic analysis (Clarke et al., 2019) and then clustered. The clusterisation has been performed to homogenize the language. The relation among the documents and the identified impacts (which may have been renamed during the clustering process) is carefully maintained, and each word reports the references from which it was extracted before being clustered. The collected literature

3 Klerkx et al. (2019) propose the notion of socio-cyber-physical-ecological systems to grasp a new social ontology generated by the intricate relationship of entities involved and interconnected in the digitalization process.

has been organised (see Table S1 in Supplementary Materials) indicating the 'issue analysed', meaning the main object of the document; the 'digital tool', meaning the technological instruments application and utilization[4]; the 'reported effects', such as the positive and negative impacts that were previously clustered; and the 'outcomes' keywords detailing the effects.

Finally, to build the overview of the impacts, which we refer to as the taxonomy hereinafter, aggregation has been performed through a conceptual analysis of the outcomes and of the effects described in the literature. Three different layers have been identified: 4 'domains' (layer 1), 14 'areas of impact' (layer 2), and 61 'outcomes field' (layer 3): see Table S2 (in Supplementary Materials) and Figure 1.

The 'domains' represent macro-dimensions where the digitalization take place; the 'areas of impact' refer to sub-dimensions within each domain, identifying several areas where the clustered effects are allocated. For both clarity and comprehensiveness purposes, the terms have been labelled (see Glossary S3 in Supplementary Materials), using the definitions found in the literature and therein cited.

Through the elaboration, an exercise to connect the elements of the taxonomy to the digital technologies is proposed as well, as reported in the grid (Table 1). This grid may help to stimulate reflections on possible outcomes in specific situations and contexts. In the grid, the taxonomy is reported together with some digital technologies to show plausible connections. To suggest how the grid could be utilized by academics and practitioners when analysing a theme (e.g., labour opportunities, ecological footprint) in the field of digitalization of agriculture and rural areas, two examples are provided in Section 6. The two topics were chosen and analysed based on the literature review, leading to the description of the impacts that a specific technology could generate in different domains. In the conducted analysis, ethical issues are not explicitly reported, even though any change by digital tools implies ethical issues to be considered (Eastwood et al., 2019; Martin, 2020; Sparrow and Howard, 2020; van der Burg et al., 2019). On this, some insights are discussed.

5. A taxonomy of digitalization impacts

As previously mentioned, the literature review aims at answering the identified research questions to provide a summary of the digital impacts. As anticipated, three different layers are identified: 'domains', 'areas of impact' and 'outcomes field' (Figure 1). The study outcome is reported by following the structure of the research question. The starting point is: what are the main domains and related areas of impacts of digitalization as identified in the literature in agriculture and rural areas? What are the involved outcomes?

Based on the literature review on digitalization impacts (e.g., Klerkx et al., 2019; Sparrow and Howard 2020), it is possible to identify macro-dimensions, as to say the coherent summary of the socio-economic and environmental spheres modified by the digitalization process. It helped us to specify more analytically the set of the digitalization impacts and outcomes. Through it, four macro-dimensions are identified – the 'domains' – opening to an analytical description of the digitalization impacts and outcomes. The 'domains' are 'economic', 'environment, 'governance' and 'social'. In the literature, the 'governance' dimension is considered as part of the 'social' one, but we separated them to emphasise the former. Moreover, for each domain, different 'areas of impact' have been specified. These areas referred to sub-dimensions to offer a more detailed level of analysis. They should not be considered as exhaustive, anyway. The glossary (Glossary S2) contains a brief definition of each term and some examples about what the areas refer to, along with references to the considered literature. Similarly, for each area of impact, several

4 Digital tools are varied. To reduce this complexity, a synthetic classification described in the DESIRA project's Deliverable 1.3: *Synthesis report on the taxonomy and inventory of digital game-changers* (the document is available on the project website: https://desira2020.eu/).

possible outcomes are indicated starting from the results emerged from the literature review and the approach proposed in this work. Furthermore, a brief description of the taxonomy and of the outcomes is provided through some explanations.

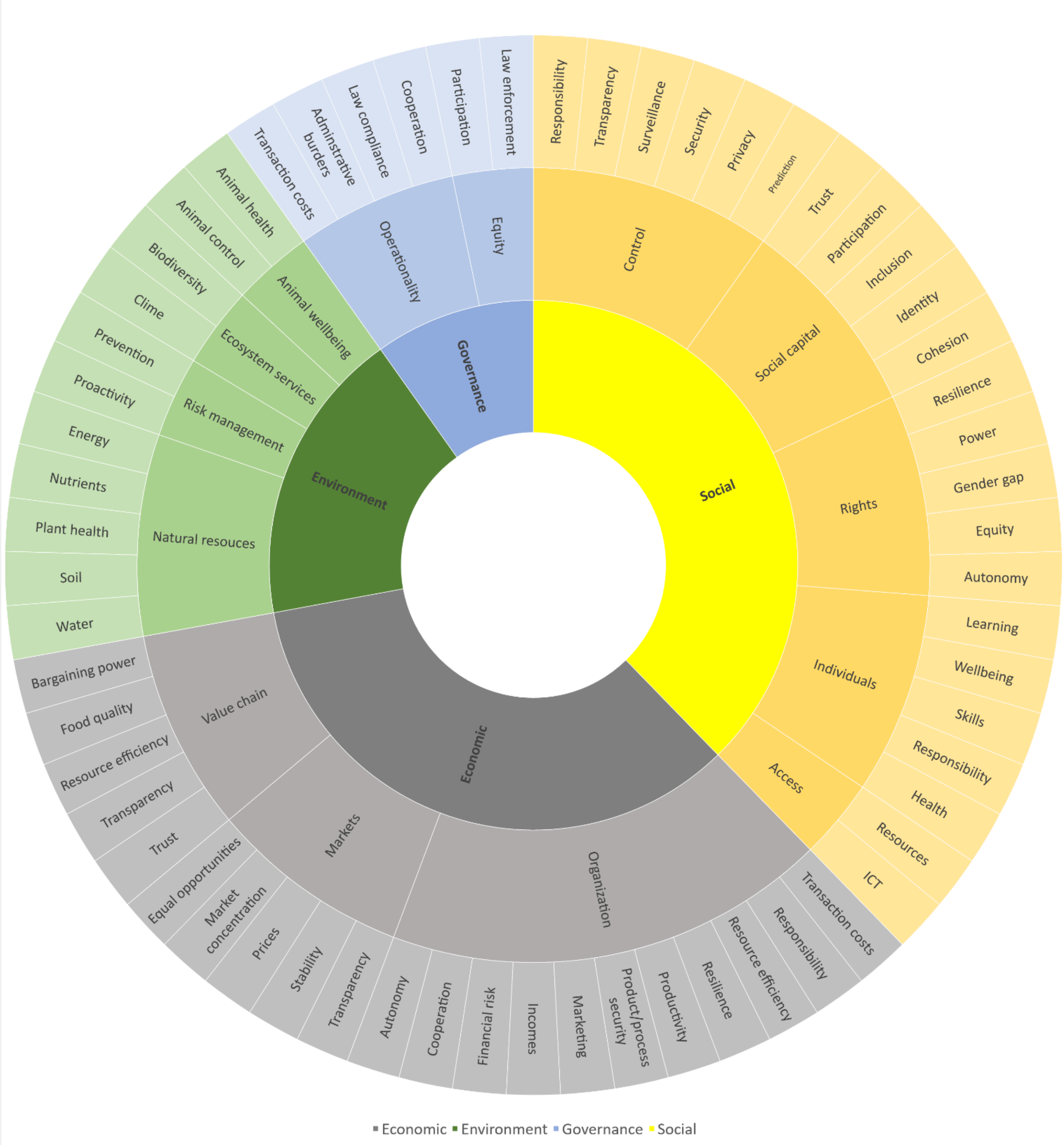

Figure 1. Domains, areas of impacts and outcomes of digitalization.

The first and largely mentioned dimension in the literature is the 'economic' one. It refers to all the activities and resources used for the production and provision of a good or service. It also includes the income and value-chain, involving the working conditions and decision-making processes. Under the economic label, three areas of impacts are identified and defined as follow:

- *organization*, the working flow and management activity related to the production process;
- *value chain*, the 'sequence of activities that a firm undertakes to create value, including the various steps within the supply chain but also additional activities, such as marketing, sales, and service'[5];
- *markets*, places where parties gather to exchange goods/services defining prices.

Digitalization can produce relevant outcomes in this dimension and related impact areas. As it is emphasized (Jha et al., 2019; Vinuesa et al., 2020), Artificial Intelligence, for example elaborating data collected by in-field sensors, satellites or drones about soil moisture, weather conditions and plants status, can suggest cost-efficient use of resources (e.g., water, fertilisers, pesticides), thus potentially increasing production, food quality, and farm incomes. These technologies can promote users' autonomy in farm management, but also forms of cooperation due to data sharing among users. At the same time, the possibility of processing a large amount of data and gathering information can improve organisational resilience for both producers and consumers (Lipper et al., 2017), as to say, the ability to anticipate, prepare for, respond, and adapt to relevant changes for the farms. Web-based technologies, like digital marketplaces or e-shopping solutions, can increase the market access and the bargaining power of small farmers. Possible unclear effects of digitalization need to be taken into consideration as well. In particular, digital solutions may impose an 'algorithm governance' (Henman, 2020). If users rely on the digital tools – which incorporate a pre-established definition of adequacy and correctness of production – farmers could lose their autonomy in corporate management. This seems particularly evident in the case of completely automatized processes, like irrigation. Farmers may also become dependent on digital service providers, becoming the real (invisible) farm managers.

The second domain is the 'environment', which can be positively affected by digitalization (Balafouris et al., 2020). It can be defined as a complex interrelation of different elements, biotic and non-biotic ones, that supports living conditions on the Earth. It includes all the natural resources – like air, land, water, woods, etc. – and related issues such as their protection and valorisation for human purposes. In this case, four areas of impacts are identified:

- *animal wellbeing*, issues related to the principle of species-appropriate housing;
- *ecosystem services*, benefits provided by the natural processes (e.g., pollination, clean air);
- *natural resources*, 'natural assets (raw materials) occurring in nature that can be used for economic production or consumption'[6];
- *risk management*, 'the process by which early efforts and assessments are taken to prevent environmental risks or accidents'[7].

In the case of livestock, the Internet of Things may promote e.g. an eco-efficient cattle management (Ingrand, 2018; da Rosa Righi et al., 2020). Battery-powered sensors on collars can monitor livestock location and crucial physiological parameters (temperature, blood pressure, heart rate) opening to the possibility of differentiated feeding. This also allows controlling the cattle health, reducing the risk of illness. At the same time, digital automatized waste management in cattle farms can reduce the ecological footprint of livestock reusing waste for energy production (e.g., anaerobic digester). This process reduces the risk of pollution to groundwater and soil, also lowering greenhouse gas emissions. Similarly, on-vehicle sensors can detect the status of soil (nutrients and water), plant conditions (their needs in the vegetative cycle) and the need for pesticides, if any.

5 Deardorff's Glossary of International Economics in https://iate.europa.eu/search/standard/result/1601363661654/1.

6 OECD, https://stats.oecd.org/glossary/search.asp.

7 https://iate.europa.eu/search/standard/result/1601307996433/1.

They can help in estimating the correct amount of water, fertilisers, and pesticides of each field area, which can be irrigated by automatic machines (e.g., automatized sprinkler), lowering the use of chemicals that can harm e.g. insects (Hrustek, 2020). At the same time, some negative ecological impact can be reported. Digital tools, for example, need power to function, thus their wide-spreading use can increase energy demands. If fossil fuels continue to be used, this may have an impact on climate emissions (Vinuesa et al., 2015). Because of this, the promoted energy efficiency of ICT tools may be strongly reduced or completely nullified (Lange et al. 2020). Also, some digital devices like smartphones, need to be redesigned in a recyclable and repairable way to minimise material consumption (Patrignani, 2017).

An emerging relevant domain affected by digitalization is the 'governance one', which refers to the mechanisms and the processes through which people can articulate and mediate their interests and needs while exercising their rights and obligations. For this domain, two areas of impact are detected:

- *operationality*, the bureaucratic and legal procedures that enable to operate;
- *equity*, the conditions of access to legal/norms information and administrative tools.

In the agricultural sector, many bureaucratic requirements aim to certify the quality of food production, but also to provide recognition – and thus a competitive advantage – in the market (e.g., organic food certification). At the same time, certifications and controls guarantee consumers about agricultural products. On this, digital tools can facilitate bureaucratic procedures or forms of control to ensure farmers and consumers against trade fraud (Bürgin, 2020; Kritikos, 2019; Räisänen et al. 2020). Dedicated web-solution – like apps, websites, digital databases – can simplify the communication between farmers and public offices, offering access to valuable information and simplified bureaucratic procedures. Automatized field mapping by drones, e.g., after a flooding, can reduce the time of recovery and increase the accuracy of public support. Blockchain or similar technologies can be a solution to prevent false declarations on food, for example, the place it was produced, processed, stored, etc. However, these digital solutions may prove hard for people with low digital skills, increasing the complexity of the relation between farmers and public bodies. Farmers can become dependent on professional or company services, especially if digital procedures are compulsory to obtain certifications or public incentives (e.g., organic food certification).

The last domain is the 'social' one (Eastwood et al., 2019; Klerkx et al., 2019). It refers to the conditions, resources and norms that define the forms of interactions between the different subjects and their characteristics, which are also defined by the social interaction and conditions in the area where they operate or live. In this case, the areas of impacts identified are five. They refer both to the social conditions in general and social resources endowed by subjects. Specifically, there are:

- *individual*, aspects and characteristic that refers to a single person;
- *access*, the chance and conditions to enlarge social interactions;
- *rights*, effects on the related issue of fundamental rules;
- *social capital*, the key resources like information and social contacts and related issues;
- *control*, the issue of the data security, utilization, and the pervasiveness of digital change.

For example, focusing on rural communities, researchers stress that the digitalization can mitigate the disadvantages in rural areas, such as the low level of public services, e.g., through telemedicine, e-commerce, and e-learning opportunities. These solutions can also enhance social relations within rural communities and between rural communities and urban areas promoting a process of social inclusion and participation. Social media and web-solutions can contribute to share information and promote discussion among the community stimulating an identity-building process, a sense of belonging, useful to activate local resources and abilities not only for the socio-economic development, but also for the resilience capacity (Piser et al., 2019; Ye and Yang, 2020). Digital tools can be used to reduce social asymmetries in accessing resources and information to promote self-development by breaking down traditional social gaps such as the gender gap, territorial differences, age disparity, ethnic separation, etc. (OECD, 2018). Despite these advantages, studies on the social domain also highlight several possible negative aspects and risks related to digitalization (van der Burg et al. 2019; Klauser, 2018; Klerkx et al., 2019; Gupta et al., 2020). Firstly, the unequal endowment of e-skills among rural workers and the lack of IT infrastructure in rural areas reduce the change to implement and use digital tools. In this sense, the benefits of digitalization can be grasped only by actors in a good social position (high knowledge and skills, good economic resources, large social relations) increasing social asymmetries and social exclusion (OECD, 2018; 2019b). Furthermore, artificial intelligence combined with big data and real-time information collected with remote sensors can estimate potential social behaviours in several contexts. It poses serious problems on privacy, data ownership and their use. Some works stress how digitalization can define a new form of surveillance (Klauser, 2018), which aggravate social asymmetries by defining and suggesting a specific range of standards of 'correctness' in social activities.

As illustrated, although not exhaustive, the taxonomy encompasses a wide range of possible impacts of digitalization in agriculture and rural areas. In the next section, we discuss the last step needed to understand how the taxonomy can stimulate a reflection about the impacts on digitalization.

6. A grid to reflect on the digitalization

Section 5 provides the information needed to answer the last question, that is 'what are the possible impacts when using digital tools'? To provide an answer, the grid, combined with digital tools, offers a solution that stimulates reflections on the possible impacts of digital technologies (Table 1) in an application scenario. The table contains the list of outcomes and the related domains and areas of impacts. The glossary (Glossary S2) provides definitions and references of each outcome, thus helping in better describing the potential effects of digital technologies in each application scenario.

Thanks to these tables, it is possible to describe (1) what are the impacts that digital technology can generate and (2) what are the technologies, presently available, that can generate said impacts. In this way, the grid may be able to support a wide reflection on digitalization in rural area and agriculture. Two examples are provided in what follows.

In the first example, we take into consideration the so-called 'cloud' technology. It refers to cloud computing, the on-demand computing resources such as data storage and computing power, without direct active management by users. Through the cloud, users can store, manipulate, share, and use data thanks to the provider's services. A well-known example is Google Drive that combines a cloud store, office applications and data sharing options. Cloud can be combined with other digital tools or ICTs producing an extensive range of possible outcomes. Sensor nodes can send in-field data to a remote cloud for storing purposes or for analysis, then triggering a sprinkling system based on the results of the data analysis. Looking at Table 1, cloud technology has sixteen possible outcomes. For example, in the impact area 'organization', the cloud has as outcomes 'autonomy' and 'productivity'. Farmers can become independent in decision making thanks to data collected and analysed with the cloud services contributing to enable cost-efficiency production (Klerkx et al., 2019). At the same time, cloud has as outcome 'cooperation' in the domain of 'governance'. This is because cloud services by public authorities may simplify bureaucracy and controls on farms by public entities, thus stimulating forms of users' collaboration with public administrations (Lindgren et al., 2019). Cloud is also linked with the social domain in the impact area 'individual' and some outcomes are 'skill' and 'learning'. On the one hand, they may highlight that effective use of cloud technology is affected by personal skill level (abilities and competencies). High skills reduce the risk of 'digital exclusion' and appear relevant to acquire new notions and knowledge. On the other hand, it indicates that the use of cloud computing can stimulate digital skills through learning opportunities that may enhance employability in the labour market or exploit the chances of the digital society.

The second example refers to expected impacts. For instance, a more efficient use of resources, such as water or soil, in a cost-effective manner. According to the glossary (Glossary S2), 'resource efficiency' – in the area of impact 'organization' – refers to the use of energy, materials, chemicals, water and other essential resources for farming and all along the food-chain (Bronson 2019; Zhao et al. 2019; OECD, 2019a). In Table 1, the 'resource efficiency' is linked with 'local and remote sensing', 'big data and analytics', artificial intelligence, autonomous systems, and connectivity. So, the efficient use of resources can be an outcome of several digital solutions, which may be used in different ways because they are applied to specific application scenarios. A complex system that combines sensor nodes, artificial intelligence and automated machines in a greenhouse outlines a scenario in which farmers do not actively intervene because the smart system autonomously performs the needed actions. A large economic investment and high digital skills may be necessary to actually implement such a solution. In the case of field cultivation, simple solutions may be more feasible. For example, sensors can detect the humidity of the soil, reporting it to those in charge of irrigation.

For a deeper reflection on the impacts, it is useful to check which effects are connected to the technologies indicated in the grid (e.g., artificial intelligence has impacts on 'resource efficiency' and on 'transparency' in the value chain) considering the application scenario (greenhouse or field cultivation). This exercise forces a broader consideration on the impacts of digitalization in concrete cases, also providing hints for unintended or unforeseen outcomes.

7. Conclusions

The literature review performed in this work has unveiled that existing studies concerning digitalization in agriculture and rural areas do not provide an overall picture concerning actual and potential outcomes. In this regard, while other works investigate a limited set of plausible outcomes of digitalization, this work proposes a more comprehensive exploration of digital systems, while attempting to classify their impact (Barrett and Rose, 2020; Eastwood et al., 2019 García Zaballos et al., 2019; Klerkx et al., 2019; Scholz et al., 2018; van der Burg et al., 2019).

This paper contributes to the current discussions on digital change, defining a taxonomy and a grid that could help to determine how to face both predictable and unintended digitalization effects. Several digital technologies (e.g., blockchain, artificial intelligence, sensors) have been considered, as well as a large set of applications. The main domains and areas of impacts of digitalization, as well as their outcome, have been identified and described. The proposed taxonomy and the grid may stimulate a reflection on possible outcomes and support in the shaping of appropriate responses, like policies or practices to address the side effects. Furthermore, they provide the possibility to identify potential impacts (both positive and negative) and connections between digital solutions and their possible uses in specific application scenarios. For example, thanks to digital technologies, it will be increasingly possible to determine with extreme precision which crops to grow according to market trends and when to intervene with agricultural work (ploughing, irrigation, fertilization, pesticide treatments) considering the state of the soil, plants, and weather forecasts. Digitalization may reduce costs for farms and the environmental impact of agricultural production and improve crop yields, farmers' income, and offering quality and safer food. However, there is a risk that these improvements will only occur for some farmers (in high-income countries but not in low-income ones, for example). Farms can become increasingly dependent on high-tech companies providing digital tools and services, or food production may become increasingly reliant on algorithms, reducing human control. The taxonomy here reported wishes to help to prefigure negatives outcomes to reduce the unexpected impact of digitalization.

However, this work has four limitations, in our view, for which further investigations and reflections are needed. First, the literature on digitalization in agriculture and rural areas is constantly updated due to new technologies and innovation systems. Therefore, the taxonomy must be continuously updated. It contains key and almost well-established technologies, but it cannot be handy to forthcoming innovations, for example, the quantum computing. Second, the grid directly identifies systemic effects. The outcomes reported can have a retroactive effect on other domains. Third, even though both the taxonomy and the grid focus on agriculture and rural areas, the work does not discuss all the possible application scenarios (which are hundreds, or even thousands). This allows for more flexible use of the proposed tools, but the outcomes depend on the application scenario, which must be carefully identified as the first step. Fourth, ethical issues are not considered, but only briefly mentioned.

In conclusion, a first systematisation of digitalization impacts in agriculture and rural areas has been presented in this work. The proposed taxonomy and grid may require further elaborations, nonetheless, contributing to manage or govern the digital transformation without leaving anyone behind.

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Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: *Issues analysed and impacts (positive and negative) of digitalization in the agricultural sector according to selected literature review*; Table S2: *Digitalization: domains, areas of impact and outcomes*; Glossary S3.

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Table 1 – The grid of digital technologies and possible set of socio-economic and environmental outcomes

			TECHNOLOGY									
DOMAIN	AREA OF IMPACT	OUTCOME IN	*Social Media*	*Cloud*	*Local and remote sensing*	*Distributed ledger*	*Big data and analytics*	*Augmented reality*	*3D printing*	*Artificial intelligence*	*Autonomous systems*	*Connectivity*
Economic	Organization	Autonomy	x	x	x	x	x	x	x	x	x	x
		Cooperation	x	x		x					x	x
		Financial risk	x		x	x	x			x	x	
		Incomes			x	x	x	x	x	x	x	x
		Marketing	x		x		x	x		x		x
		Product/process security	x		x		x			x	x	x
		Productivity		x	x		x	x		x	x	x
		Resilience	x	x	x		x		x		x	x
		Resource efficiency			x		x			x	x	x
		Responsibility	x			x	x					
		Transaction costs	x		x	x	x			x		x
	Value chain	Bargaining power		x	x		x			x	x	x
		Food quality	x		x	x	x			x	x	x
		Resource efficiency					x			x		x
		Transparency			x		x			x		x
		Trust	x		x	x						x

			Social Media	*Cloud*	*Local and remote sensing*	*Distributed ledger*	*Big data and analytics*	*Augmented reality*	*3D printing*	*Artificial intelligence*	*Autonomous systems*	*Connectivity*
	Markets	Equal opportunities			x	x	x			x	x	
		Market concentration			x		x			x		
		Prices			x		x			x	x	x
		Stability	x	x	x	x						x
		Transparency	x		x	x						x
Environment	Animal wellbeing	Animal health			x	x	x			x	x	x
		Animal control			x	x	x			x	x	x
	Ecosystem services	Biodiversity	x		x		x	x		x		x
		Clime	x		x	x	x			x	x	x
	Natural resouces	Energy			x		x			x	x	x
		Nutrients			x		x			x	x	x
		Plant health			x		x	x		x	x	
		Soil			x		x			x	x	
		Water		x	x		x			x	x	
	Risk management	Prevention	x		x	x	x			x		x
		Proactivity	x			x						
Governance	Operationality	Cooperation	x	x		x					x	x
		Law compliance	x			x						x
		Administrative burdens	x		x	x	x			x		x
		Transaction costs	x		x	x	x			x		x
	Equity	Law enforcement	x			x						x
		Participation	x			x					x	x

			Social Media	*Cloud*	*Local and remote sensing*	*Distributed ledger*	*Big data and analytics*	*Augmented reality*	*3D printing*	*Artificial intelligence*	*Autonomous systems*	*Connectivity*
Social	Individuals	Health	x		x		x			x		
		Learning	x	x	x	x		x	x		x	x
		Responsibility			x	x	x			x	x	x
		Skills	x	x		x	x	x	x			x
		Wellbeing	x				x			x	x	x
	Access	ICT	x	x	x	x		x	x			x
		Resources		x	x						x	x
	Rights	Autonomy	x	x	x	x		x	x	x	x	x
		Equity	x		x	x	x			x	x	x
		Gender gap	x		x		x			x	x	x
		Power	x		x	x	x			x	x	x
		Resilience	x	x	x		x		x		x	x
	Social capital	Cohesion	x			x				x		x
		Identity	x				x	x				x
		Inclusion	x	x		x		x				x
		Participation	x	x		x	x	x	x			x
		Trust	x		x	x						x
	Control	Prediction			x		x	x		x		
		Privacy	x		x	x	x			x		x
		Security	x		x		x			x	x	x
		Surveillance	x		x		x	x		x		x
		Transparency	x		x	x				x	x	x
		Responsibility			x	x	x			x	x	x