DIGITISATION: ECONOMIC AND SOCIAL IMPACTS IN RURAL AREAS

Digital Transformation of Agriculture, Forestry and Rural Areas

Developing a futureproof Socio-Cyber-Physical System

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Digital Transformation of Agriculture, Forestry and Rural Areas

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Executive Summary

The DESIRA project aims "*to improve the capacity of society and of political bodies to respond to the challenges that digitisation generates in rural areas, agriculture and forestry in the next ten years.*" (DESIRA, 2018, p. 5). The conceptual and analytical framework (CAF) presented here will form the theoretical underpinning for other activities within the DESIRA project that support meeting the projects aim.

The CAF is building on the information presented in the DESIRA proposal and further elaborated with relevant scientific literature, but can be considered a living document. Through various activities a wide range of project partners and broader project participants have the ability to comment, improve and apply this CAF through using the operationalised concepts in their own project activities. This allows us to further improve the concepts and their operationalisation. The CAF will then be finalised towards the end of the DESIRA project.

The CAF will define and elaborate on the key concepts of this project i.e. digital transformation; the Socio-Cyber-Physical system; digital game changers; the socio-economic impact; and the Responsible Research and Innovation approach. This is all set in relation to digital technology use in agriculture, forestry and rural areas. In this summary we briefly present the outline of the CAF and define the key concepts.

We want to unravel digital transformation in agriculture, forestry, and rural areas by trying to understand what, why, how, when and where transformation occurs. Digital transformation can be described as an ongoing and iterative process (Nochta, Badstuber, & Noura, 2019), which both encompasses processes of digitisation and digitalisation. Digitisation is the technical conversion of analogue information into digital form (Autio, 2017) and is often linked to a single or a low number of digital technologies implemented at business level. Digitalisation is the term often used to describe the socio-technical processes surrounding the use of (a large variety of) digital technologies that have an impact on social and institutional contexts that require and increasingly rely on digital technologies (Tilson, Lyytinen, & Sørensen, 2010). Hence digital transformation allows for a spectrum of digital transformation activities, whereby over time the options of digital technology use, the associated complexity (i.e. interactions between the various aspects, such as (digital) technology, institutions, people & organisations, environment, etc.) and their related, either positive or negative, impacts on society continuously increase.

The object of transformation is a Social-Cyber-Physical System (SCPS). This system is transformed because (parts of) it goes through a process of digitisation and/or digitalisation. In order to understand what a Socio-Cyber-Physical System is we first describe a number of steps:

1. A system is a set of entities with relations and interactions between them. These interactions can create new entities. The entities and the boundaries of a system are defined by the observer in relation to his/her purposes. Hence a description of a system is a representation of reality according to a specific observer. The context within the system boundary may also provide entities to take into account. Outside the system boundary there is the environment,

which may provide external influences. A system is complex and adaptive, due to the interactions between the entities, their relations, the activities, and external influences.

2. Cyber-Physical Systems (CPSs) are next-generation engineered systems that integrate embedded computing technology (cyber part) into the physical phenomena by using transformative research approaches that account for the complexity and multi-disciplinarity of such systems (Gunes, Peter, Givargis, & Vahid, 2014). This integration mainly includes observation, communication, and control aspects of the physical systems, which can involve humans in various ways.
3. A socio-technical system consists of social entities and technical entities. Social actors, e.g. humans with agency, all have various needs, wants, skills, knowledge, etc. They also have different positions in the social structure. Hence there are different power relations. Technical entities are non-human entities, including technologies as well as processes surrounding those technologies. Social and technical entities interact with each other and have equal importance in the understanding of socio-technical systems. These interactions need to be consistently undertaken in order to maintain or adapt the system. In doing so the system may be resilient and positive towards adaptation, while there may also be resistance among the entities towards adaptation.
4. A SCPS consist of three domains (socio, cyber and physical), all of equal importance and with the ability to influence other domains. Each domain has a broad range of different entities that not only within the domain are governed by a set of rules, but also between domains hybrid rules determine the relations and interactions of the entities within the domains.

Digital technologies are a key element in digital transformation, and some of the technologies that are embodied into a SCPS are potential (digital) game-changers. They disrupt existing patterns of interaction and generate a radical redistribution of costs and benefits within the SCPS.

The digital transformation of a SCPS, including the role of digital game changers, has a socio-economic impact. The impact is based on three different mechanisms (design, access, system complexity) and can be measured via a multidimensional approach, e.g. a social, economic, and ecological impact. The Sustainable Development Goals (SDGs) are a consensus framework for the assessment of the socio-economic impact, and integrative approaches help turning from general goals to more specific targets. Trade-offs imply a different distribution of (costs and benefits/ opportunities and challenges) among the entities in the system. Because of these trade-offs between goals, inequalities can arise between social actors. Gender inequality has our particular attention.

A stronger (upfront) awareness of the existing and potential future impact of digital transformation will help all participants in the system to improve the innovation process and the desired impacts. The Responsible Research and Innovation approach will support this and provide an analytical lens.

Introduction

The EU Horizon 2020 Framework, and more particularly the work programme of food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bio-economy, developed a call for proposals under the name of Rural Renaissance. Within this call there was a theme on socio-economic impacts of digitisation on agriculture and rural areas (RUR-02), which ultimately led to the DESIRA (Digitisation: Economic and Social Impacts in Rural Areas) project. The aim of DESIRA is "*to improve the capacity of society and of political bodies to respond to the challenges that digitisation generates in rural areas, agriculture and forestry in the next ten years.*" (DESIRA, 2018, p. 5). To achieve this goal, the project is going to develop "*a knowledge and methodological base that increases the capacity of a wide range of actors to assess past, current and future socio-economic impact – including gender differences – of ICT related innovation, to embody Responsible Research and Innovation into researchers', developers', users', practices and policies, and finally offer mechanisms and tools that will support decision-making to challenges and opportunities related to digitisation.*" (DESIRA, 2018, p. 5). With this aim the project addresses two priorities of the RUR-02 call, namely 'boosting major innovation on land and sea', and 'developing smart, connected territories and value chains in rural and coastal areas'.

The conceptual and analytical framework (CAF) presented here will form the theoretical underpinning for other activities within the DESIRA project that will aim to meet the project goals for past, present and future digital technology use and support the above mentioned social and political bodies. The CAF can be considered a living document. Through various activities a wide range of project partners and broader project participants have the ability to comment, improve and apply this CAF through using the operationalised concepts in their own project activities. This allows us to further improve the concepts and their operationalisation. The CAF will then be finalised towards the end of the DESIRA project.

The CAF is building on the information presented in the DESIRA proposal and further elaborated with relevant scientific literature. Moreover, at EU level there are a number of other relevant (digitisation related) projects, which we will use to inform the conceptual and analytical framework. These projects include (non-exhaustive): IOF2020; SmartAgriHubs; Smart-AKIS; 4D4F; RRI Tools; and RRI-Practice.

The CAF will define and elaborate on the key concepts of this project i.e. digital transformation; the Socio-Cyber-Physical system; digital game changers; the socio-economic impact; and the Responsible Research and Innovation approach. This is all set in relation to digital technology use in agriculture, forestry and rural areas. After the explanation of each concept, where relevant, there is a section identifying implications for empirical analysis. This often contains a set of questions which will make the linkages between the various concepts and provide an operationalisation of the concepts. Together this can be used as a basis that can guide methodological decisions, data analysis and implementation of the DESIRA activities, such as the Living Labs.

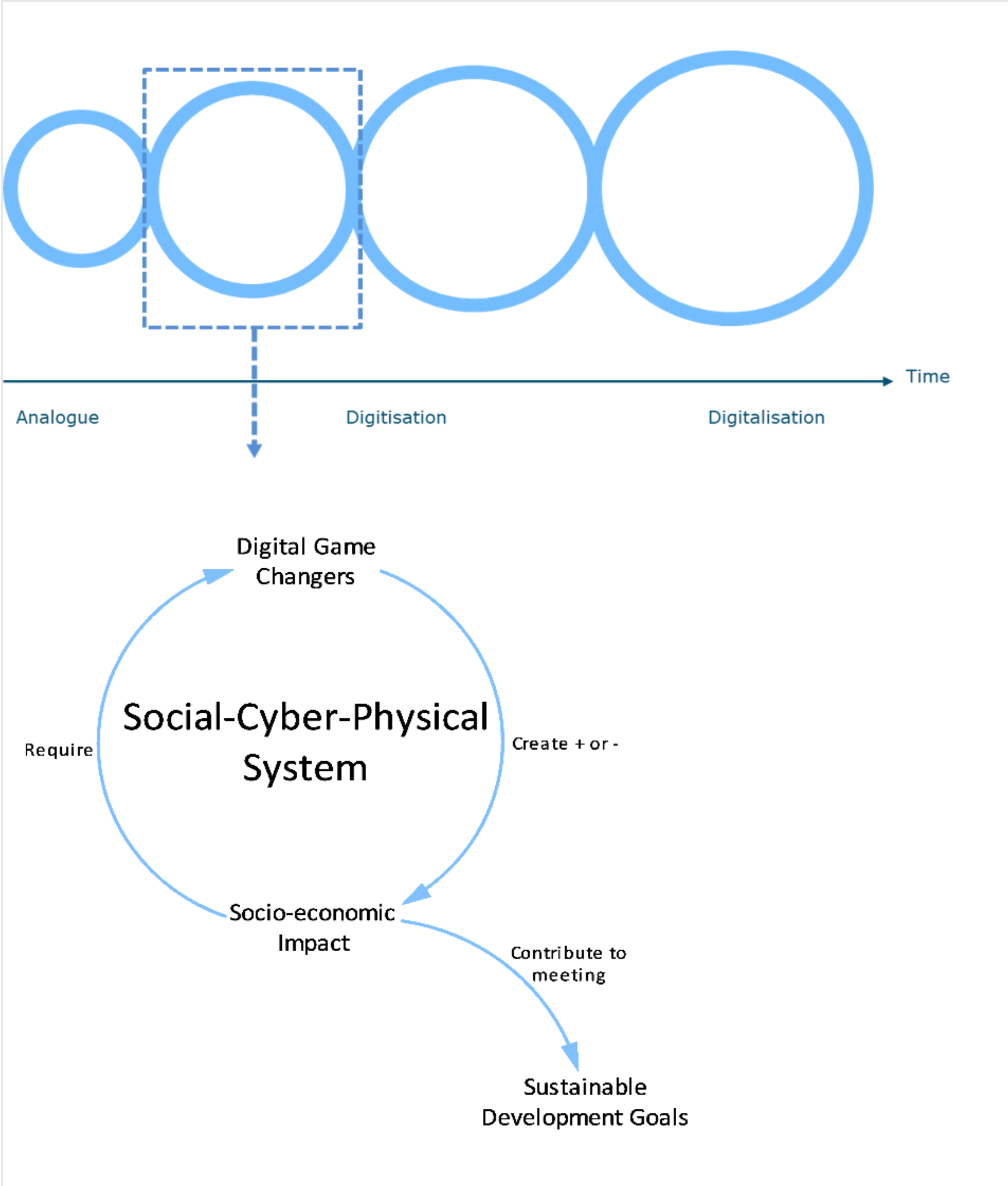
The line of thinking in this document is as follows (see also Figure 1):

- We want to unravel digital transformation, which proceeds from digitisation to digitalisation, in agriculture, forestry, and rural areas by trying to understand what, why, how, when and where transformation occurs.

- The object of transformation is a Social-Cyber-Physical System (SCPS). This system is transformed because (parts of) it goes through a process of digitisation and/or digitalisation. In order to understand what a Socio-Cyber-Physical System is we first describe a number of steps:
  - ✓ What are systems?
  - ✓ What are Cyber-Physical Systems?
  - ✓ What are socio-technical systems?
- Digital technologies are a key element in digital transformation, and some of the technologies that are embodied into a SCPS are (digital) game-changers. They disrupt existing patterns of interaction and generate a radical redistribution of costs and benefits within the SCPS.
- The digital transformation of a SCPS, including the role of digital game changers, has a socio-economic impact. The impact is based on three different mechanisms (design, access, system complexity) and can be measured via a multidimensional approach, e.g. a social, economic, and ecological impact.
- Sustainable Development Goals are a consensus framework for the assessment of the socio-economic impact, and integrative approaches help turning from general goals to more specific targets. Trade-offs imply a different distribution of (costs and benefits/ opportunities and challenges) among the entities in the system. Because of these trade-offs between goals, inequalities can arise between social actors. Gender inequality has our particular attention.
- A stronger (upfront) awareness of the existing and potential future impact of digital transformation will help all participants in the system to improve the innovation process and the desired impacts. The Responsible Research and Innovation approach will support this and provide an analytical lens.

Figure 1 provides an overview of the connections between the key concepts. The concepts and connections will be further elaborated on in the different sections.

Figure 1. Overview of connections between key concepts



1. Digital Transformation

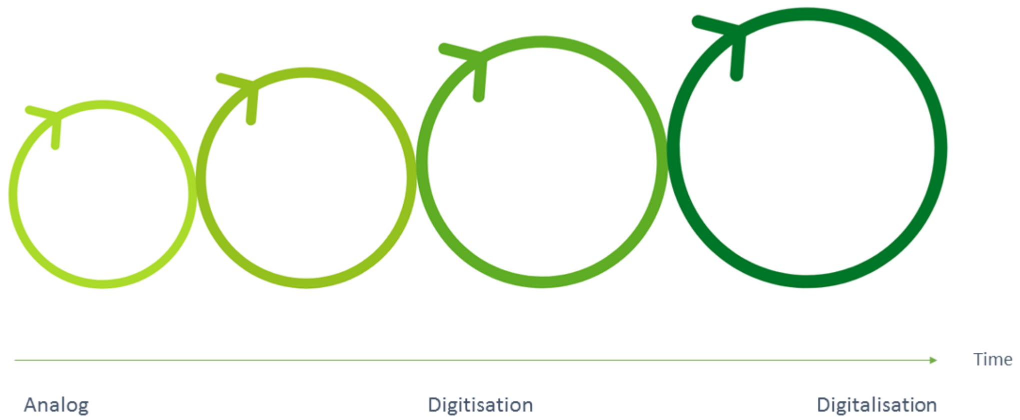
Digitisation can be described as transforming physical entities into digital objects (DESIRA, 2018) or described by (Autio, 2017), the "*technical conversion of analogue information into digital form*". In the DESIRA proposal (2018) digitisation has been referred to as follows: "*digitisation will allow remote (or even self-) control of production, processing and logistic operations*" (DESIRA, 2018, p. 5), summarising what digitisation can achieve. Digitisation is also referred to as the third industrial revolution (Greenwood, 1997; Schwab, 2017), whereby the use of computers became commonplace during the 1960s and 1970s and automation replaced a lot of manual activities. Digitisation is thus often linked to a single or a low number of digital technologies implemented at business level. In agriculture, rural areas and forestry digitisation is often seen in the form of digital technology at the level of a single business or entity, thus focussing on on-farm level often using (mainly spatial) data to feed decision support tools for farmers, such as milking and harvesting robots and other precision agriculture technologies (Klerkx, Jakku, & Labarthe, 2019).

Following the rise of the internet during the 1980s and 1990s, and the increased connectivity this brought, more coordination and integration between activities could take place (Porter & Heppelmann, 2014). While this process of automation and increasing connectivity is still ongoing, the next wave of digital technology has introduced itself (Porter & Heppelmann, 2014) and is often referred to as the fourth industrial revolution (Schwab, 2017), Industry 4.0 (Meyer, 2019; Sommer, 2015), or Smart Industry (Team Smart Industry, 2014). This also impacts agriculture, forestry and rural areas (Poppe, Wolfert, Verdouw, & Verwaart, 2013).

Through ubiquitous connectivity, the use of sensors for (big) data collection, many technologies have become 'smart' and are able to communicate autonomously leading to the Internet of Things and Artificial Intelligence (see for example Alm et al., 2016). These types of technologies and the process of using and implementing digital technologies in everyday life require, however, more than only a technical conversion. *Digitalisation* is the term often used to describe the socio-technical processes surrounding the use of (a large variety of) digital technologies that have an impact on social and institutional contexts that require and increasingly rely on digital technologies (Tilson et al., 2010). In agriculture, rural areas and forestry digitalisation it thus goes beyond the level of a single business or entity, for example using digital platforms to coordinate demand and supply in value chains, linking on- and off farm data and managements tasks, which are enhanced by context- and situation awareness and triggered by real-time events (Rose & Chilvers, 2018; Wolfert, Goense, & Sørensen, 2014). It is therefore often referred to as 'Smart farming', 'Smart Forestry', 'Smart Rural Development' and 'Smart rural areas', as well as concepts such as digital agriculture and Agriculture 4.0 (Klerkx et al., 2019; Klerkx & Rose, 2020; Müller, Jaeger, & Hanewinkel, 2019; Naldi, Nilsson, Westlund, & Wixe, 2015; Watanabe, Naveed, & Neittaanmäki, 2018). Thus precision agriculture can be seen as an on-farm digitisation process whereas digital agriculture is linked to digitalisation, encompassing the entire value chain with the intent to cause broad change in the agricultural sector.

Both digitisation and digitalisation are considered here part of *digital transformation*, allowing for a spectrum of digital transformation activities, whereby over time the options of digital technology use, the associated complexity (i.e. interactions between the various aspects, such as (digital) technology, institutions, people & organisations, environment, etc.) and their related, either positive or negative, impacts on society continuously increase (see Figure 2). Digitisation in this figure can be seen as a crucial part, or step in the direction of digitalisation, as the use of digital technologies often induces social, economic and institutional changes. And vice versa, social, economic, and institutional changes in society result in a demand for the development of digital technologies. This results in an ongoing and iterative process (Nochta et al., 2019).

Figure 2. The digital transformation process

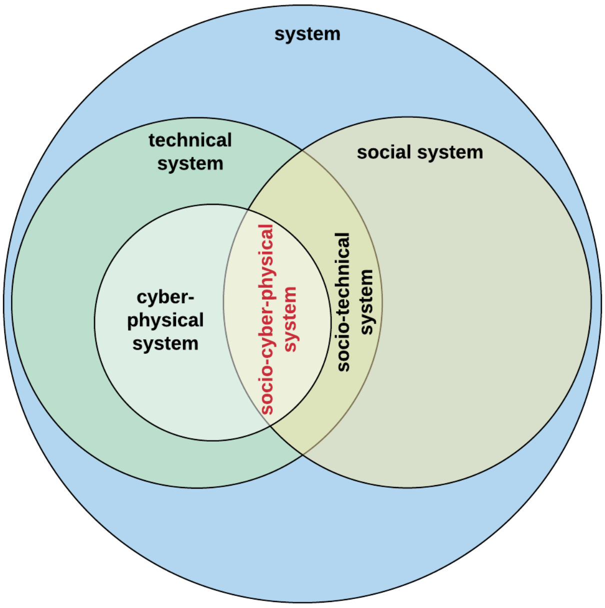


2. Socio-Cyber-Physical System

The concept of Socio-Cyber-Physical Systems (SCPSs) is introduced and used in DESIRA to approach the specific challenges associated with the fourth industrial revolution. This revolution is characterised by the entangling of digital, physical and social worlds through a multiplicity of technologies. This entangling is what we call the digital transformation process (see Section 1).

As illustrated in Figure 3, there is a range of concepts building on the idea of a system, such as a social system, a technical system and the intersection between them, captured in a broader socio-technical system. SCPSs are a particular subcategory of the latter, while a more known concept, namely cyber-physical system (CPS), is a subcategory of the technical system. We will elaborate on this diverse range of systems before deepening the concept of SCPS.

Figure 3. Hierarchy of system concepts



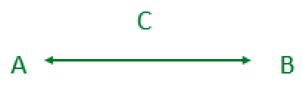
2.1. What is a system?

A system can be defined as a mental representation of given aspects of reality for analysis and control purposes. Through the system concept, reality is represented as a set of **entities** that interact together through (jointly) performing **activities**. In Figure 4, A and B are entities (people, things, animals, or even immaterial entities such as texts or images). A and B can potentially be connected through a **relation** (represented by an arrow).

Figure 4. The potential relation between entities A and B

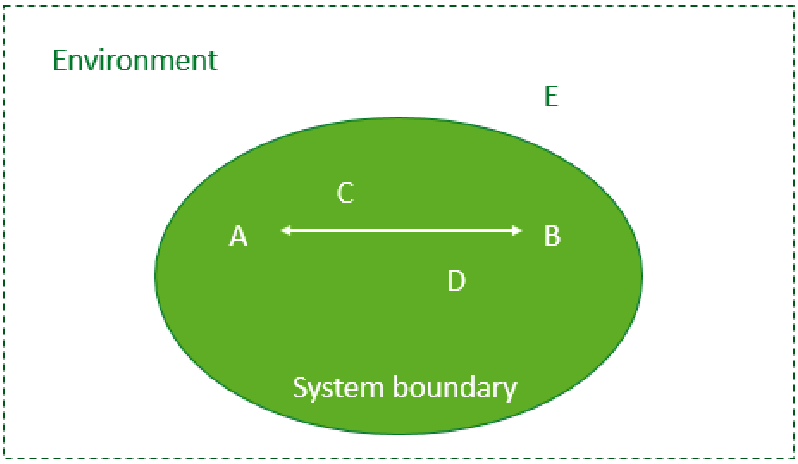
In the case of humans, a **relation** can be based on kinship, neighbourhood, work, casual encounters, business, and many other types. In the case of other living organisms, relations can, for example, be based on parasitism, symbiosis, competition. Relations between humans and the physical world can be identified as services or disservices: tools are things that help humans to do a job or task, food is necessary for nutrition. **Interaction** is possible when a relation between A and B is established, although relations can exist without interaction, e.g. A may be the son of B but living on the other side of the world, and therefore may not have interactions with B. Furthermore, relations can be qualified based on the type of interactions that potentially occur between entities. Relations could for example be peaceful / hostile, autonomous / dependent, cooperative / competitive. In case of interaction it links together A's and B's activities, or is part of a joint activity. These activities require **input** of A and/or B and create **output** for A and/or B. These activities thus generate flows of material and immaterial entities between A and B, indicated by C. These new entities are then also part of the system (see Figure 5).

Figure 5. The flow of material and immaterial entities in a system



Depending on the mental representation of the observer and its purposes a system therefore has boundaries (see Figure 6). Within these boundaries, the entities, and all possible relations and interactions between them operate within a given **context**, which generates additional entities in the system. Also the context may have a particular set of (formal and informal) rules (D in Figure 6). This in turn creates challenges and opportunities for interaction between the various entities. However, the system is not all encompassing and beyond the boundaries there is a wider **environment**. This environment is then a potential external influence (E in Figure 6), which often cannot be controlled by the entities in the system (Gharajedaghi, 2011). The interactions and related activities, based on input and output by and for entities, as well as external influences, may result in (positive or negative) **outcomes** that could change the system and its boundaries.

Figure 6. The system boundary and the environment.



In summary: A system is a set of entities with relations and interactions between them. These interactions can create new entities. The entities and the boundaries of a system are defined by the observer in relation to his/her purposes. Hence a description of a system is a representation of reality according to a specific observer. The context within the system boundary may also provide entities to take into account. Outside the system boundary there is the environment, which may provide external influences. A system is complex and adaptive, due to the interactions between the entities, their relations, the activities, and external influences.

Box 1. Example of a system

In the figure below a milking system is shown. The observer of this system may want to understand how a milking machine works in order to answer a particular question or solve a problem. For example, what is the quality of the milk, what the health status of the cows, or what are the energy cost of the process?

Entities: Involved entities are the cow, the milking cluster, the farmer, the control unit; the milk collection tank.

Relation: Some of these entities are tools, in which the relation to the other entities is to support the farmer and the cow in the milking process.

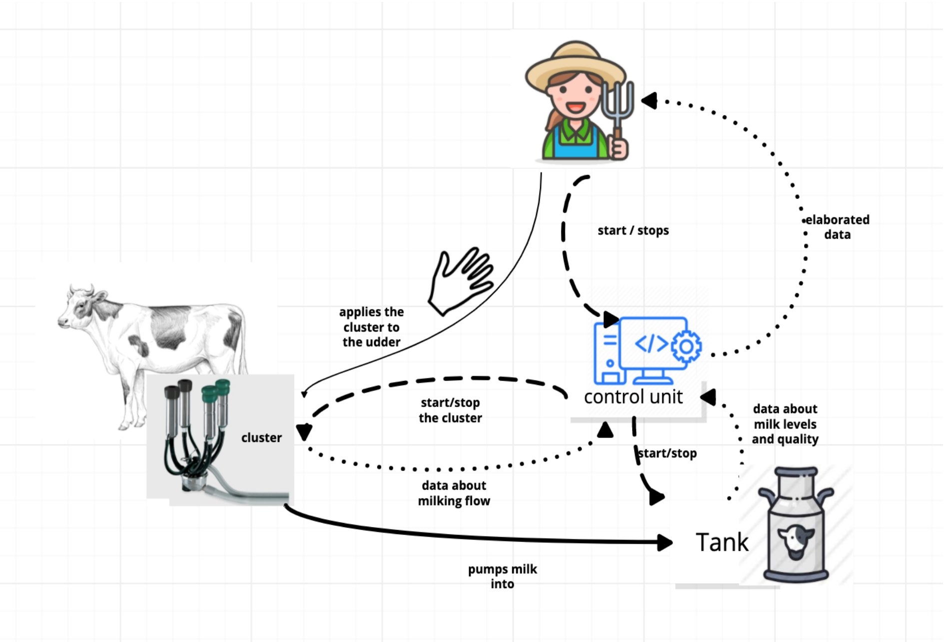
Interaction: The interaction happens through a number of activities, e.g. application of the cluster to the udder, milking, transfer of milk to the tank.

Input & output: The farmer can start and stop the system through a switch. Milk from the cow goes through the cluster. The control unit receives data about the regularity and intensity of the milk flow from the sensors applied to the cluster, and processes them into information that tells to the control unit when to stop milking. The processed information also gets back to the farmer to help in decision making.

Context: Milk hygiene regulation applied by the farmer; animal welfare of the cow; internet connectivity between the cluster and the control unit.

Environment: Farmer household; milk collection routines; energy prices; etc.

Outcomes: Good quality milk; excellent health status of the cows; or low energy costs of the process.



2.1. Cyber-physical system

Cyber-physical systems (CPSs) stem from an engineering and technical perspective, and refers to a generation of systems with integrated computational and physical capabilities. Those systems have the ability to interact with, and expand the capabilities of, the physical world through computation, communication, and control (Baheti & Gill, 2011). Monostori et al. (2016, p. 621) define them as "*systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet*". Or in other words, physical systems are monitored, coordinated, controlled and integrated with and by digital technology, and work together to achieve common goals (Rajkumar, Lee, Sha, & Stankovic, 2010; Sousa & Rocha, 2019).

A framework for CPSs shows that devices are used to sense and interact with the physical world through data collecting and actuation; multiple devices interacting with the physical world and among themselves via data exchanges create a system, which is composed of both physical and cyber components in an intertwined manner. Eventually, a system can interact with other systems, thus creating a system of systems (SoSs) (Griffor, Greer, Wollman, & Burns, 2017). The interaction between the physical and cyber entities is therefore of critical importance (Monostori et al., 2016) and can occur in a myriad of ways that depend on the environment in which the system operates. CPSs can be simple or rather complex solutions, according to the purpose they serve in different scenarios (Khaitan & McCalley, 2014), for instance: vehicular systems and transportation; medical and health care systems; smart homes and buildings; social networking and gaming; power and thermal management; electric power grid and energy systems; surveillance, and so on. Three key characteristics of CPSs can be identified: intelligence or smartness, i.e. the elements are able to acquire information from their surroundings and act autonomously; connectedness, i.e. the ability to set up and use connections with other entities in the system – including human beings – for cooperation and collaboration, and to the knowledge and services available on the Internet; responsiveness towards the context and the environment (Monostori et al., 2016).

Sousa and Rocha (2019, p. 5) emphasise and clearly acknowledge the human role in CPSs, stating that "*it is not sufficient for interconnected and intelligent tools to communicate with each other without any human involvement. Human technology is made by humans, for humans. … In addition to providing basic functionality, openness, heterogeneity, and integration capabilities, it is equally important to discern how systems or tools can be used within a certain [human] context*". Thus also considering issues like e.g. communication, data security and privacy. This has led to the emergence of Human CPSs and Human-Centered CPSs (Hadorn, Courant, & Hirsbrunner, 2016), or Human-in-the-Loop CPS (HiTLCPSs) (Sousa & Rocha, 2019) in which technology is designed to put human beings into the focus often resulting human-machine interaction. Human involvement in CPSs can be determined in a number of different ways, often being an input provider or data source; an information processor and communicator as part of the system; or a user of the service provided by the CPS. This however does not mean the human is always accountable for what happens in the CPS, nor does the human have to be an expert or a deliberate collaborator of the system. In other words a human can unknowingly be part of a CPS by providing data unknown to that human (Calinescu, Cámara, & Paterson, 2019; Sousa & Rocha, 2019).

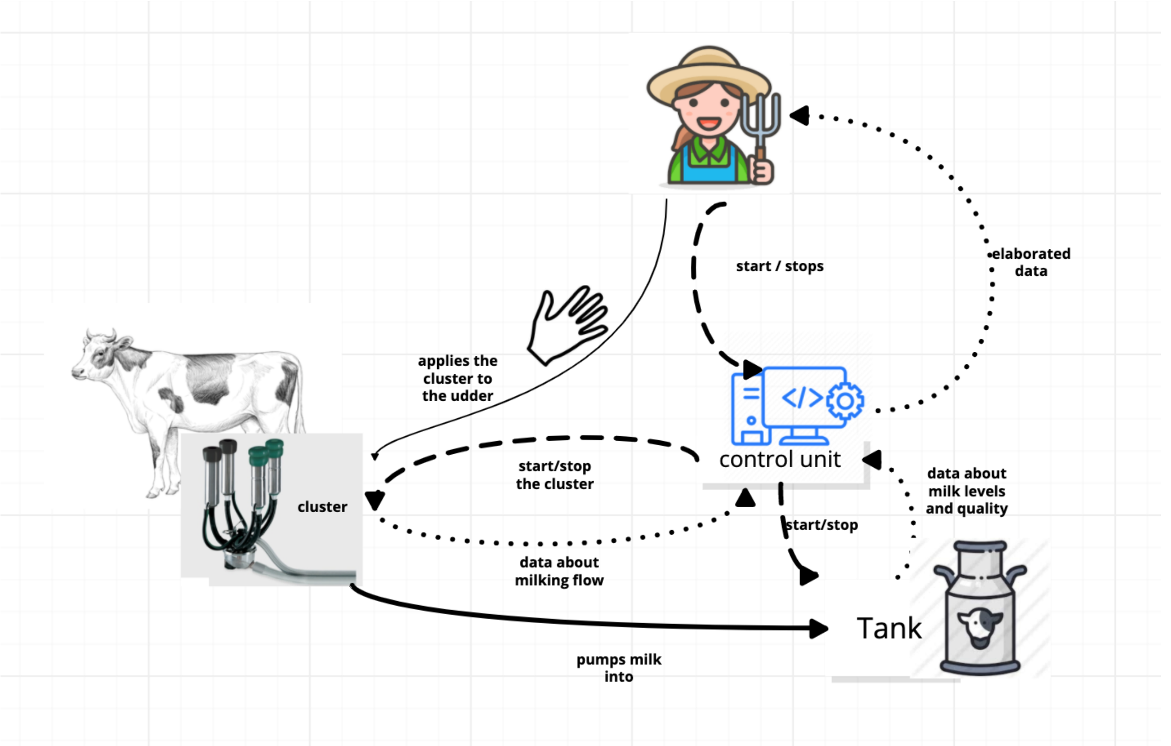
In summary: Cyber-Physical Systems (CPSs) are next-generation engineered systems that integrate embedded computing technology (cyber part) into the physical phenomena by using transformative research approaches that account for the complexity and multi-disciplinarity of such systems (Gunes et al., 2014). This integration mainly includes observation, communication, and control aspects of the physical systems, which can involve humans in various ways.

Box 2. A Milking system as a CPS

Physical entities: Cow, cluster, farmer, milk tank.

Cyber entities: Control unit, sensors on cluster, sensors in milk tank.

Role of human: Collaborative and accountable information processor through starting and stopping the control unit.

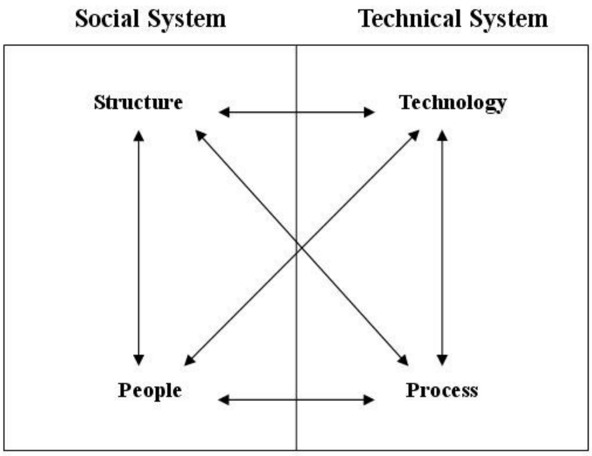


2.1. Socio-technical systems

The notion of a socio-technical system emerged in organisational and labour studies as a response to the predominance of the mechanistic/scientific view of industrial management and the overemphasis on psychological factors in industrial relations (Ropohl, 1999). Researchers interested in organisational performance and change used the concept of the socio-technical system as an approach to design workplaces recognising the interaction between people and technology (Clegg, 2000). A socio-technical system refers both to the interrelatedness of social and technical aspects of an organisation or the society as a whole (Ropohl, 1999), whereby technology, besides material things, also includes organisational structures and processes (Botla & Kondur, 2018). For more theoretical underpinning in social theories such as the Actor-Network Theory and Social Practice Theory see Annex 1.

In more analytical terms: socio-technical systems are composed of a technical system and a social system (Bostrom & Heinen, 1977; Lui, Piccoli, & Desouza, 2007). Imran and Kantola (2019, p. 119) state that "*Sociotechnical system theory accounts for social factors while implementing new technologies [...]. It discusses changes in working practices and social issues during the design and implementation of new technologies. It considers both technical and social issues in quest of promoting change in the organizations*". The technical system encompasses both technology and process and the social system encompasses the people involved in the system and the structure in which they are embedded (Lui et al., 2007) (see Figure 7).

Figure 7. Information System as a socio-technical system (Lui et al., 2007)



In order for a system to function, these four components should not only be present, but they should also interact with each other. Thus, while technology, process, structure and people are distinct components of an information system, they are interdependent and interact with each other (Lui et al., 2007).

The complexity of the interactions among the system entities has been highlighted by various authors (Lamb & Kling, 2002; Saurin & Patriarca, 2020). To bring structure to this complexity Saurin and Patriarca (2020) propose a holistic taxonomy of socio-technical interactions, considering multiple criteria, e.g. the nature of actors and for each criterion two descriptors are proposed; i.e. interaction between entities and what the interaction looks like. By using this taxonomy in the analysis of a specific socio-technological system, and therefore better understanding the different interactions that exist, it can help to clarify both the system outcomes as a result of the internal interaction among entities, and the leverage points in the system regarding its resistance to innovation processes, which can be considered as a negative point for stable systems, and its resilience, which the ability of the system to adapt and is considered a positive. This in turn is then useful in systems (re-)design.

It is important to stress that resistance and resilience are not only related to technological and organisational limits/flexibility, but also to social actors (Geels, 2014; Taysom & Crilly, 2018). Social actors that are part of the socio-technical system have different aims and interests among them, and are also endowed with different resources (knowledge, social capital, etc.). They hold different positions in society or in a specific organisation), and act by following different routines, norms and social values.

Furthermore, some actors can hold a power position over others. For example, they can control the system performance, influence other actors' activities, and restrict access to technology. At the same time, the use of new technologies or new regulations can also reset existing social asymmetries, depending on how socio-technical relations change the connections among technologies and social actors.

In summary: A socio-technical system consists of social entities and technical entities. Social actors, e.g. humans with agency, all have various needs, wants, skills, knowledge, etc. They also have different positions in the social structure. Hence there are different power relations. Technical entities are non-human entities, including technologies as well as processes surrounding those technologies. Social and technical entities interact with each other and have equal importance in the understanding of socio-technical systems. These interactions need to be consistently undertaken in order to maintain or adapt the system. In doing so the system may be resilient and positive towards adaptation, while there may also be resistance among the entities towards adaptation.

2.1. Socio-Cyber-Physical System

Building on the socio-technical system, as described in the previous section, a Socio-Cyber-Physical System (SCPS) is a particular form of such a socio-technical system, distinguishing between physical and digital entities within the technical part of the system. In the DESIRA proposal, a SCPS has been defined as "*a system constituted by the social world (people), the digital world (data), and the physical world (things)*" (DESIRA, 2018, p. 4). The SCPS can also be seen as an extension of the Cyber-Physical System (section 2.2.), hereby putting greater emphasis on the social aspect and the interlinkages between the three aspects. In other words, moving beyond the 'human' aspect as it is described in CPS, towards the social actors as described in the socio-technical systems.

SCPSs have been described and defined in the literature in a number of ways. Zayalova et al (2017, p. 396) mention that a "*social network integrates social system and its cyber system, and further then the physical and social system can be mapped equivalently to their cyber systems. On that basis, the physical and social system and their cyber systems can communicate*". In their view, however, SCPSs aim at modelling human behaviour to better understand complex situations. Ahmed et al. (2019) think along similar lines, aiming to understand human behaviour based on collected data and then influencing that behaviour through feedback loops. Sokolov, Yusupov, Verzilin, Sokolova, and Ignatjev (2016) acknowledge the complexity of SCPSs and indicate the dynamics of the parameters and the structures, i.e. boundaries, of such a system. Frazzon, Hartmann, Makuschewitz, and Scholz-Reiter (2013) furthermore also take the agency of humans into account, referring to them as 'human stakeholders' who are creative, flexible and have problem solving capacities. They place human stakeholders at the centre of the SCPS, meaning that both the cyber and physical aspects are there to support the social aspects. They also expand the thinking about the social aspect from human stakeholders as individuals towards the level of the organisation or other contextual backgrounds. Lioutas, Charatsari, La Rocca, and De Rosa (2019, p. 3) place the SCPS in a smart farming context and state that "*human action is a necessary condition for transforming big data and the farm, while, at the other end of the spectrum, humans continue to be in charge for the decision making processes [...] which, in their turn, further alter the physical and the cyber dimensions of the system*".

This aligns with the DESIRA perspective where the SCPS is being used to understand the digital transformation in agriculture, forestry and rural areas. Novel or existing digital tools and platforms can be used to enhance knowledge exchange, interaction and documentation of information and in this way stimulate multi-actor innovation (Hansen et al., 2014). At the same time, Lindblom, Lundström, Ljung, and Jonsson (2017) argue that implementation of new technologies for (sustainable) smart farming should not only offer 'technological fixes', but should also lead to the involvement of different stakeholders in the development of new knowledge and practices.

From an analytical perspective a SCPS consists of three domains, e.g. social, cyber and physical, which in turn each consist of a variety of entities (see Table 1 for definitions). Intradomain relations and interactions (see Figure 8) are often governed by a particular type of entity within that domain, which is a set of rules. The domains also interact with each other leading to certain (wanted and unwanted, known and unknown) outcomes and adaptations to the system which they form together. There is an existing SCPS in which actors operate at different scales (e.g. individual, organisational, markets and value chains, regional, national, global), which can be adapted according to the needs and desires of actors at these different scales and due to the interactions (e.g. feedback loops) between social, cyber and physical domains.

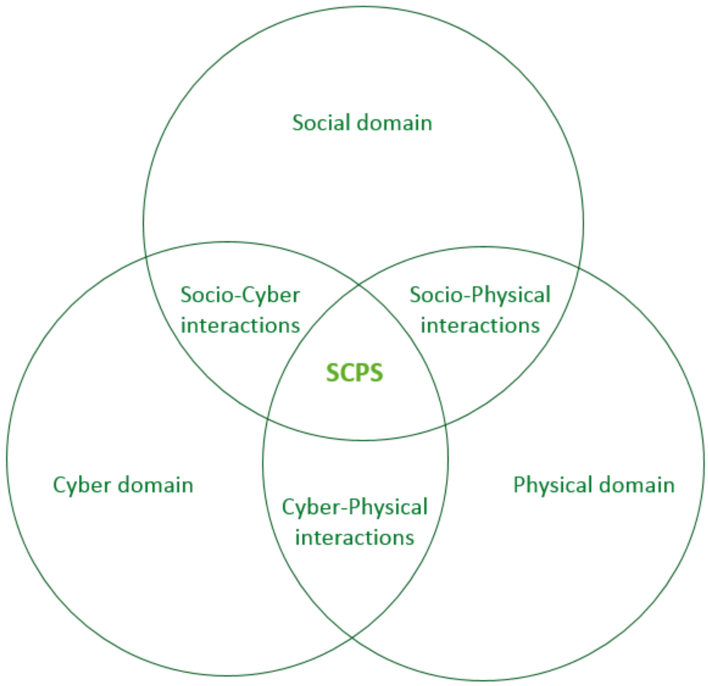
Table 1. Entities and domains of the SCPS

	Entities	Domain
Social	Markets, institutional elements (formal rules and regulations and informal – cultural non-written rules, norms and values), actors (more than the human aspect of CPS, because actors are also :considered to have agency in order to make free choices) and the resulting groups, communities or organisations and their particular behaviour.	Relations between entities in the social domain are regulated by **social rules**, such as laws, conventions, routines, ethical norms, informal behaviour.
Cyber	Cyber entities are composed of a) digital reproductions of the physical sphere, as well as b) original digital constructs. In the first case, digital entities are created by digitisation processes, that is transformation of analogue entities into digital entities. In the second case, for example through the creation of software, data mining and analysis, image creation, digital entities are created through the interaction of other digital entities. Digital technologies can for example include big data; digital infrastructures; connectivity, e.g. 5G; sensors; front facing technologies, e.g. applications.	The relations between entities in the cyber domain are regulated by **cyber-rules**. For example, communication between devices is regulated by specific protocols (such as WiFi, Bluetooth, 5G); another example is the data format (PDF, DOC, …), a specific arrangement of data so that they can be stored, exchanged, and correctly interpreted, for instance. Digital technologies can communicate with other technologies, digital entities interact with other digital entities, performing operations and making choices potentially independently of humans, while initially being designed by humans.
Physical	These entities can be natural or artificial, according to the degree of manipulation they have undergone as a result of human activities. This includes living organisms and natural resources (plants, animals, etc.) and physical things to support living and	Relations between entities in the physical domain are regulated by **natural rules** and by **technical rules**. For example, wild animals select in the environment the entities – plants or animals – that suit their nutrition, avoiding

	working in the (natural) environment (e.g. analogue technology, infrastructure, finances)	harmful entities. Water cycles are regulated by natural processes, such as evaporation and precipitation, but also by technical processes, such as water extraction from wells or circulation into pipes.

As can be read in Table 1, in the context of agriculture, forestry and rural areas, the physical world can also be understood to comprise the ecological world, so a socio-cyber-physical system may even be seen as a socio-cyber-physical-ecological system as has been tentatively argued (Klerkx et al., 2019). This already shows that it is difficult, in the real world, to isolate interactions between entities belonging to a single domain. Our social interaction is profoundly influenced by our physical world, and even when machines interact only amongst themselves, they have been designed by actors that can switch them off at any time. However, for analytical purposes, it is useful to make distinctions. Firstly, the interactions between cyber and physical domains occur through automation, data collection, management, monitoring and controlling, e.g. Internet of Things. This also includes feedback loops from cyber to physical. E.g. milking robots causing the cows to adjust their milking patterns. Secondly, the interaction between the social and physical domains, which could include the governance of natural resources, e.g. irrigation systems or the legal requirements for buildings in a natural environment. Other examples are ecotourism, or the connection between farmers and their livestock, the links between the quality of road infrastructure and rural entrepreneurship. And finally the interactions between the cyber and social domains that for example influences jobs, enhances sensing capabilities of people, creates social media networks – i.e. the cyber entities function as a multiplier of the social entities. The social entities, such as values, in turn create the basis for, for example, programming and algorithm development.

Figure 8. The socio-cyber-physical system with related interactions based on the three domains (social, cyber and physical).



Hence, entities belonging to different domains interact through **hybrid rules**: that is, combinations of rules governing the respective domains or utterly new rules. In the interaction, the three domains constantly provide new inputs to each other and at the same time also receive outputs. In the process of digital transformation, special emphasis is put on the cyber domain, as the physical and social entities become encoded into digital entities. The interaction between the physical and social domains with the cyber domains opens unprecedented possibilities. In fact, the cyber sphere can augment the experience of social actors by amplifying human perception with additional information to sensorial experience, by reducing the friction of space (by interacting remotely) and drastically reducing execution time of operations. Moreover, the cyber sphere can create virtual realities, multiplying the experiences of actors. The interaction between the social domains and the other domains is operated by **interfaces**. A keyboard is a physical interface between the social and the cyber world. When we type on a keyboard, we transfer meaning from the social domain to the cyber domain. Likewise, a camera is a physical interface between the social and the cyber domain.

In summary: A SCPS consist of three domains (socio, cyber and physical), all of equal importance and with the ability to influence other domains. Each domain has a broad range of different entities that not only within the domain are governed by a set of rules, but also between domains hybrid rules determine the relations and interactions of the entities within the domains.

Box 4.

Example of AirBnb as a SCPS

Airbnb is a digital technology that influences a socio-cyber-physical system which exists of people looking for tourism experiences (social) through means of housing (physical), making use of the Airbnb platform (cyber). However, the interactions between those elements have multiple (positive or negative) consequences. They affect the tourism market for accommodation, the experiences as a tourist (accessibility, privacy, etc.), the city infrastructures, rules and regulations about sub-renting and ownership of housing, liveability in cities (busier city centres, increase tourism oriented shops), housing markets (price increase). Airbnb consequently needs to provide insight into their algorithms, adapt them accordingly to meet local legal requirements, moreover data privacy of both owners and renters has become an issue, as well as the physical safety of owners, renters, as well as the surrounding neighbourhood.

Example of a Milking system as a SCPS

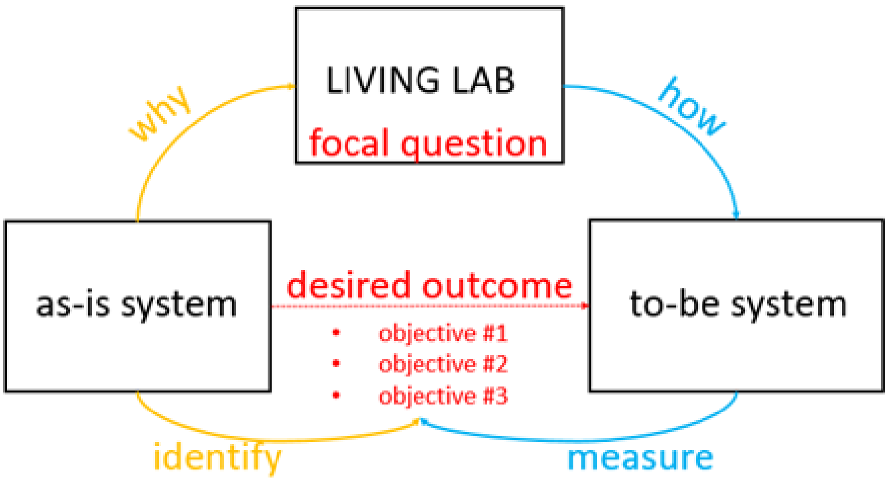
If a robotic arm is introduced in a milking system (e.g., milk, farmer, control unit, etc.). The arm can replace the activity of the human in applying the cluster to the udder of the cow. However, access to the control unit; the ability to use it; the choice for a particular type of robotic arm; the regulation of the milking process; etc.; are set by social aspects. These social aspects can include organisational rules around the farming household or the developer of the robotic arm, skills of the farmer, regulations for using a robotic arm, social values of the farmer and the farming community.

2.2. Implications for analysis

One of the purposes of DESIRA is to analyse the potential of digital technologies to improve conditions in 20 European regions. Each region or Living Lab has an existing SCPS, which will be further explored and developed in Living Labs by means of a 'focal question'. This question, co-developed with the Living Lab participants, embodies local needs and expectations. Moreover, the focal question provides guidance to build the representation of the local SCPS and to set its boundaries.

Ultimately, the focal question will guide the Living Labs to analyse the current state of the SCPS in terms of the **outcomes** it generates and to explain why and how the process of digital transformation has affected this state. The analysis of the state of the SCPS (**as-is system**) allows Living Labs to identify the desired outcomes of the system, to set the targets to be achieved and to measure the distance to these targets. The Living Labs will then continue to analyse how the desired outcomes could be achieved through incorporation of digital game changers into the current SCPS (**to-be system**) (See Figure 9).

Figure 9. Process of analysis of SCPS within a Living Lab



The following analytical questions may guide the analysis of the system.

- What are the specific social, cyber and physical entities that contribute to answering the focal question?
- What activities do these individual entities undertake?
- What are the inputs and outputs of the activities?
- How are the entities (of different domains) related to each other?
- Who uses the outputs of the system? In what way?
- What interactions occur between the entities (of different domains)?
- What are the (positive/negative, expected/unexpected) outcomes of the activities, relations and interactions?
- How do you define the system and its relation with the environment?
- Which entities (social, cyber, physical), activities, relations, interactions and potential outcomes, will be potentially affected by the digital transformation of the SCPS? In what way?
- How do outputs turn into outcomes, and for whom, in what way?

- What is the current distance-to-target?
- How do stakeholders' needs and expectations change over time, for whom and in what way?

3. Digital Game Changers

3.1. Disruption and digital transformation

From the Collins dictionary the following definition emerges: "*When there is disruption of an event, system, or process, it is prevented from continuing or operating in a normal way*". Disruption interrupts the normal way systems work. When a system undergoes disruption, all elements of a system are reorganised: some entities become obsolete, new entities are embodied, the material and immaterial flows change, and relations and interactions between entities are reshaped. Also the outcomes change, both in diversity, quantity and in quality. Disruption is an "*outcome that can be measured not just by its process but by both its results and its process*" (Millar, Lockett, & Ladd, 2017, p. 254).

Technologies are important drivers of disruption (Downes, 2009). The Gartner Glossary (Gartner, n.d.) defines digital disruption as follows: "*Digital disruption is an effect that changes the fundamental expectations and behaviours in a culture, market, industry or process that is caused by, or expressed through, digital capabilities, channels or assets*". When introduced into current socio-technical systems, they have disruptive effects, as they profoundly affect daily practices and the roles that people, animals and things play, e.g. robots can replace or complement human labour; smartphones replace computers, cameras, clocks, voice recorders. In other words a disruptive (digital) technology may potentially lead to a disruptive innovation process (Millar et al., 2017), e.g. digital transformation.

Digital transformation involves, in many cases radical technological; social; institutional; economic; and/or environmental change at the level of either individuals, organisations, a (subset) of an industry or even at a societal level (Kilkki, Mäntylä, Karhu, Hämmäinen, & Ailisto, 2017). Schuelke-Leech (2018) categorizes the levels at which disruption takes place: first order disruption is a localised change within an industry or market (e.g. this could be at business level); and second order disruption entails changes across multiple industries and affects social norms, relationships and institutions (e.g. at national or global level). In this project digitisation can be seen as first order disruption, and digitalisation as second order disruption, both contributing to digital transformation.

From a business perspective, disruption is often described as an opportunity, e.g. being disruptive gives a business advantage (Kilkki et al., 2017). Here digital technologies can support in creating more efficiency and efficacy, resulting in more productivity, profitability and ideally sustainability. Fitting with this perspective is the idea that disruptive technologies and/or processes will, for example, be cheaper and of better quality, therefore more competitive and attractive to new customers, better supported by regulation and more sustainable in terms of resource use (Millar et al., 2017). This perspective is often held by new companies and start-ups, or incumbent firms with a clear strategy towards the disruption (Phillips, Relf-Eckstein, Jobe, & Wixted, 2019).

However, disruption is often also seen as negative but unavoidable, i.e. digital technologies are constantly being developed and improved and there is no choice but to use them, for example due to changing context and requirements of stakeholders (Scholz et al., 2018). Disruption is then perceived as something that is external, without the ability to influence it, especially because disruptive technologies are often only identified ex-post (Dotsika & Watkins, 2017). This is often the case when organisations are not yet sure of what the disruption might entail and how to anticipate on it, let alone have a strategy to cope with, or make use of, the disruption (see for example Rijswijk, Klerkx, & Turner, 2019). Furthermore, disruption may also have a number of 'unseens' and 'unknowns' which are not visible yet when a digital transformation starts to unfold (Scholz et al., 2018). In other words, while it is acknowledged that disruption contributes to the volatility, uncertainty, complexity and ambiguity of a given situation (Millar et al., 2017; Pandit, Joshi, Sahay, & Gupta, 2018), not everyone is able to understand and respond to that in an early stage (Dufva & Dufva, 2018; Rijswijk, Klerkx, & Turner, 2019).

3.2. Game Changers

In everyday language, game changers are defined in many ways: it can be a person, a product, a policy, a great idea, or anything that changes 'the game'. The concept of game changers can thus be applied to whatever generates a deep change in the normal routines: daily habits, social relations, working patterns. What becomes clear of the regular use of the term 'game changer' is that something has such an influence on a certain system in a certain environment that thereafter they are significantly different. If we consider a technical system, a game changer is an entity, a rule, an activity, that significantly changes how the system operates, as well as its inputs, its outputs and its outcomes. Taking this into consideration, a way to describe digital technologies and digital transformation, besides disruptive, is *game-changing*.

When looking into the scientific literature game changers is a term that is often used without a clear definition, e.g. similar to the use of the term game changers in everyday language. Broadly, we can distinguish here **external game changers**, and **internal game changers**. External game changers are part of the system's environment (See E in Figure 6, Section 2), and in the literature seen as shocks having an impact on ones' activities. Avelino, Wittmayer, Kemp, and Haxeltine (2017, p. 1), taking a system transformation perspective, describe game changers as "*macro-trends that are perceived to change the rules of the game, i.e., to change how society is organised and defined by today's understandings, values, institutions, and social relationships*" (See also Avelino et al., 2019). Examples are the economic crisis, climate change, natural disasters and, for example, terrorist attacks, such as 9-11 (Campos et al., 2016; Loorbach et al., 2016; Westley, McGowan, Antadze, Blacklock, & Tjornbo, 2016). Some of these events had an impact at global scale, others on national or regional level. Thereby also, logically, impacting on communities, businesses and individuals.

Others see game-changers either being internal, e.g. within the system, using agency to develop great ideas or new combinations. Others see it more coming from inside companies. For example, game-changing is used in the management literature with reference to disruptive business models, which may be connected also to new technologies. Abell (1980) quoted by Markides (2013), defines a business model as the sum of answers that a company gives to three questions: Who should I target as customers? What products or services should I be offering them? How should I do this in an efficient way? Game-changing business models are those that give significantly different answers from competitors: "*significant shifts in market share and company fortunes took place not by trying to play* *the game better than the competition but by playing a different game—in a sense, by avoiding head-on competition*" (Markides, 2013). An internal game changer is therefore an entity or activity embodied into the system (see D in Figure 5, section 1).

In DESIRA, we consider an interaction between internal and external game changers, in the sense that they are connected and may amplify each other – hence, following ideas from complex adaptive systems thinking emergence of new natural, technological or social phenomena may occur or game changers may trigger cascading effects (Burnes, 2005; Küppers, 2002; Loorbach, Frantzeskaki, & Avelino, 2017; Plowman et al., 2007). Such processes of emergence and cascading effects are not fully predictable, as there are many self-organising elements involved which are only steerable to a limited extent. Often, the individual elements in SCPS may not be game-changing per se, but the sum of the parts is game changing, as game changers are often multidimensional, meaning that there are links between for example social and environmental aspects (Loorbach et al., 2016; Olsson, Moore, Westley, & McCarthy, 2017). Following new technologies, or business models often new rules and regulations start to occur; new processes, products and services are being developed; new infrastructures arise; new interactions, networks and relationships are being formed; etc. and this all requires new (combinations of) knowledge, skills and capabilities (Herrero et al., 2020; Klerkx & Rose, 2020).

Game changers are generally considered disruptive, but it is often a question whether they are disruptive for good or bad, according to whom, and for whom or what? For example, climate change, as an external game changer, is largely perceived as negative from a social, economic and environmental perspective, and with a global impact. At the same time it might indeed be positively game changing (internally) for research on climate change adaptation (Campos et al., 2016).

Given the multidimensionality of game changers, it also becomes clear that understanding game changers requires a participatory and transdisciplinary approach (Campos et al., 2016; Swilling, 2016). Additionally awareness and reflexivity are required, as the game changer notion may indeed have winners or losers, thus it can reproduce or strengthen the game that initially was undergoing a change (Avelino et al., 2017).

3.3. Digital Game Changers

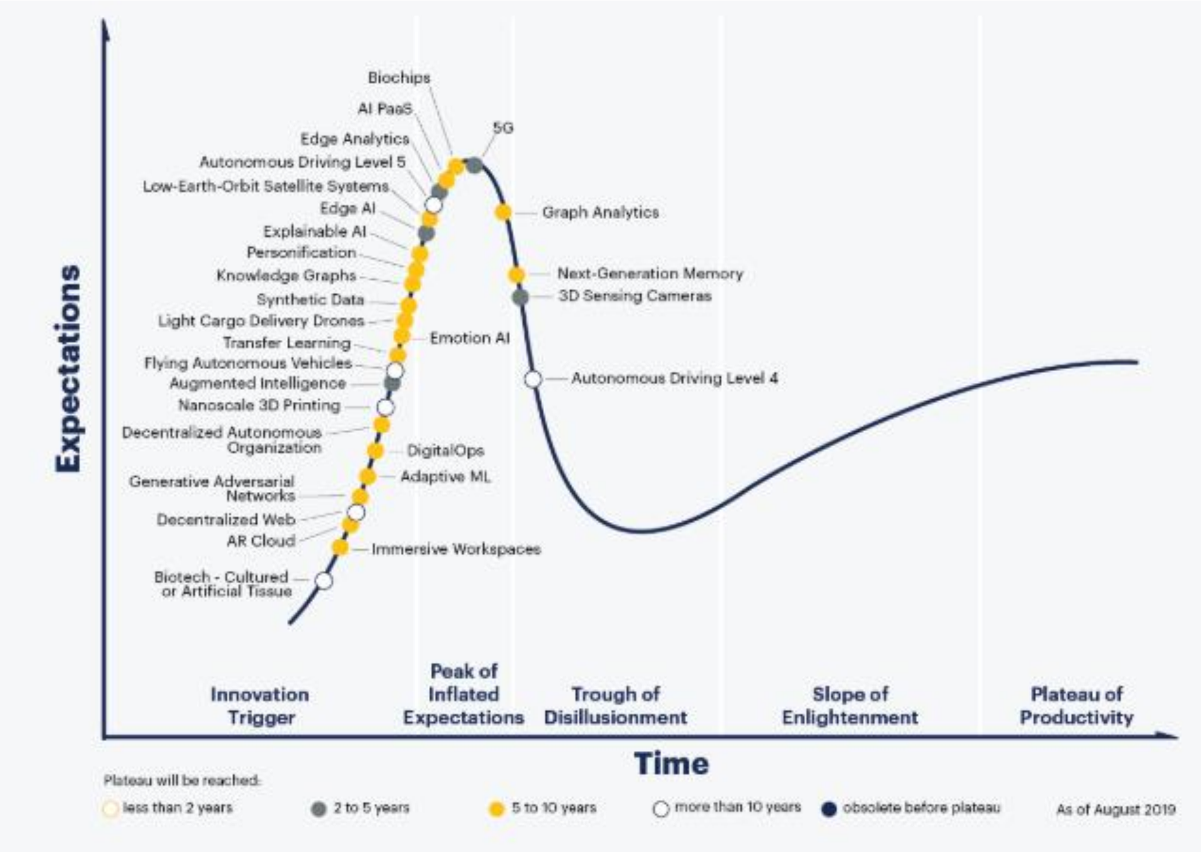
As described above digital transformation can be disruptive and game-changing. When seeing game changers as macro-events, based on the definition of Avelino et al. (2017), digital transformation can therefore be referred to as an external game changer since it can change market offerings, business processes, or models through the availability of digital technologies. However, according to Nambisan, Lyytinen, Majchrzak, and Song (2017), disruption can be related to the use of digital technologies within the system. In other words, digital technologies can be seen as *potential* internal digital game changers (DGCs). Game changing technologies interfere and may have different anticipated and unanticipated outcomes in the social world (Klerkx & Rose, 2020; Scholz et al., 2018), in terms of relationships, markets, institutional arrangements, practices. Potential, since not every digital technology will indeed be game changing in every geographical, temporal or functional context. In the DESIRA proposal DGCs have been defined as "*digital technologies that deeply reconfigure routines, rules, actors and artefacts of social and economic life*" (DESIRA, 2018, p. 4). In addition, the social and economic life are explained as the business models, consumption and shopping styles, service provision, as well as learning processes and innovation. Thus the deepest socio-economic impact of digital transformation occurs when social, economic, legal systems are not ready to deal with digital technologies. Digital game changers are thus digital technologies that change the rules of a game.

In many cases, technology gives huge advantages to early adopters because transformation occurs into a regulatory void. According to (Downes, 2009) the 'law of disruption' implies that "*technology changes exponentially, but social, economic, and legal systems change incrementally*". This has happened, for example, to the cultural sector when sharing applications were launched on the web that allowed bypassing copyright rules. Gartner (2019) provides a yearly forecast with an overview of emerging digital technologies, how they will progress, and the duration before reaching the so-called 'plateau of productivity', i.e. when they have become commonplace (see Figure 10). These emerging technologies include for example Big Data; artificial intelligence (AI); Internet of Things (IoT); augmented reality; 5G networks; virtual assistants to support daily live and work; and digital twins for create virtual models of reality; 4D printing; autonomous and smart robotics; and various levels of autonomous driving (Alm et al., 2016; Gartner, 2019).

The identification of the game (i.e. the system itself, or the domains, or - social, economic, environmental, institutional, etc. - aspects of those domains in the system) helps to understand that disruption may occur at several levels of complexity. A first level of disruption relates to the cyber domain or the broader technical system: when a new digital technology is developed, many technical systems become obsolete. This is the case of analogue cameras, magnetic tapes, vinyl records. Further levels of disruption occur when the disruption impacts on the interaction within the social domain and affects for example legislation that is not (yet) prepared to regulate it.

Often these emerging digital and potentially disruptive or game changing technologies depend on each other to function optimally, e.g. without connectivity there is no IoT. Moreover, they allow for combining knowledge, data, and processes of diverse physical machines that were previously disconnected (Yoo, Boland, Lyytinen, & Majchrzak, 2012) and have increasing autonomy, combining monitoring, controlling and optimisation activities (Porter & Heppelmann, 2014).

Figure 10. Hype Cycle for emerging technologies (Gartner, 2019)



Regarding **agriculture**, the FAO states in their recent report on digital agriculture that it will not only change how farmers farm, but will change "*fundamentally every part of the agri-food value chain*" (Trendov, Varas, & Zeng, 2019, p. 2). Digital agriculture can thus be considered as a potentially disruptive innovation (Bronson & Knezevic, 2016; Kelly et al., 2017), providing both opportunities and threats to all parties within agriculture, forestry and rural areas. Klerkx and Rose (2020, p. 2) note in their review article that many articles now allude to the potential game changing capacities of digital technologies:

> *"The scientific literature on digital agriculture has primarily focused on the technical aspects of applying these technologies for improving agricultural practices and productivity (Rutten et al., 2013; Wathes et al., 2008), as well as improving post-farmgate processes, such as postharvest quality monitoring in logistic process and real-time traceability (Wolfert et al., 2017). By now, there is a large body of predominantly natural and design science oriented literature on (potential) applications of digital technologies in agriculture. This is evidenced by an increasing number of review articles on topics such as precision farming, big data analysis, drones, artificial intelligence and robotics, 3D printing, artificial intelligence, IoT, and the transformative potential of these digital technologies for agricultural production systems, value chains and food systems (de Amorim et al., 2019; Dick et al., 2019; El Bilali and Allahyari, 2018a; Hunt and Daughtry, 2018; Kamilaris et al., 2017; Mogili and Deepak, 2018; Patrício and Rieder, 2018; Portanguen et al., 2019; Shamshiri et al., 2018; Skvortsov*

et al., 2018; Smith, 2018; Verdouw et al., 2013, Verdouw et al., 2016a, Verdouw et al., 2016b; Voon et al., 2019; Weersink et al., 2018; Zhang and Wei, 2017; Zhao et al., 2019)."

In **forestry**, similar technologies have been observed, for example using remote sensing and drones for plantation management decisions, and robotics for plantation management and tree harvesting. While the literature on game changing technologies in forestry is less extensive than in agriculture, it is now also emerging (Bayne, Damesin, & Evans, 2017; Bayne & Parker, 2012; Müller et al., 2019; Ogilvie et al., 2019; Parker, Bayne, & Clinton, 2016; Torresan et al., 2017; Watanabe et al., 2018; Zou, Jing, Chen, Lu, & Song, 2019)

For **rural areas**, as an authoritative review by Salemink, Strijker, and Bosworth (2017) describes, as well as other works in rural sociology (Pant & Odame, 2017; Philip & Williams, 2019; Roberts, Beel, Philip, & Townsend, 2017), game-changing technologies mainly relate to ICTs enhancing access and connectivity, such as wired and mobile broadband, and optic fibre internet in rural areas. In addition to this, also phenomenon like rural makerspaces are emerging in which technologies such as 3D printing are employed (Ensign & Leupold, 2018)as well as platform technologies for social exchanges in rural areas (Chowdhury & Odame, 2013).

In DESIRA, the taxonomy of game-changing technologies (see Work Package 1, task 1.2) will further unravel what actual game-changing technologies are manifesting and in what way they can be considered game-changing, as the game-changing technologies mentioned here are potential, as their game-changing properties may differ across systems and are dependent on the specific context (see also section 2 and 4).

3.4. Implications for analysis

The previous section shows that disruption and game changers are closely linked despite being used as concepts in different disciplines. We also see that digital transformation fits within both concepts. Therefore, we describe digital transformation as an external game changer, e.g. as a macro event or second order disruption. In this process (cumulative) digital technologies may have potential internal game changing effects. I.e. not every digital technology will indeed be game changing in every geographical, temporal or functional context.

For DESIRA the game that will be analysed is the socio-economic situation in the context of 20 Living Labs on agriculture, forestry and rural areas in Europe. Despite zooming in on the socio-economic situation we also take other aspects into account (e.g. institutional, environmental), as game changers are often multidimensional (see also Section 4 on socio-economic impact and in particular de Sustainable Development Goals, and Section 2.4 on the Socio-Cyber-Physical System). Moreover, it requires a transdisciplinary, participatory process.

Game-changing and disruption are key to understand the socio-economic impact of technologies, as we will see in the next section. Here we want to flag that:

1. disruption occurs at different levels of complexity;
2. the level of disruption that technologies generate depends on how disruption in one domain is transmitted in other domains;

3. disruption can be generated by external as well as internal game-changers.

Some key characteristics of a digital game changer can be identified: it is based on the use of digital technologies, and has the potential to become widespread because of low cost (with respect to those in the past) or because it comes for free. Software-only solutions typically spread faster than those also involving hardware because the digital world operates at faster speeds than the physical one: that is why Facebook or Twitter took very little to enter our lives, or why solutions for online working are becoming increasingly popular. According to Aris, four fundamental questions need answering: is the new technology meeting a need (in a specific field)? Is it easy to use? Is it affordable? Is the right set of technologies in place? Answering yes to all those questions is a good hint to identify potential digital game changers to appear. For instance, drones are meeting the need of having improved monitoring abilities, and they are proving increasingly easy to use at affordable costs; the technological system was ready, while the legal part of the social system (consider the use of the aerial space, privacy concerns, potential damages due to falling, and so on) was not really in place, but it is catching up rather fast because of the diffusion of those objects due to their large versatility.

Analytical questions:

- How have digital technologies contributed to the present state of the system? E.g. how have entities, relations and activities, outputs and outcomes, relations with the environment changed?
- How can or digital technologies (potentially) change the way activities are carried out in the area?
- Will digital technologies help to bypass regulatory barriers?
- Will digital technologies reduce the costs of activities?
- Will digital technologies change the relations between people?
- Will digital technologies make it possible to offer new products and services in the area?
- Will digital technologies give access to information previously not available?
- What might be potential new games that will be changed by digital technology use?
- Are there any specific potential agriculture, forestry or rural areas games that might be changed?

Box 5. Examples of potential Digital Game Changers

Cultured meat could be a game changer for the beef industry independently on its efficiency. If accepted by consumers and economically viable, cultured meat could make the beef industry obsolete.

Robotics can replace human labour, and this may increase dramatically the productivity of a firm. This is a positive outcome for the adopting firm. However, adopters of this technologies may gain a strong advantage against non-adopters. Non-adopters, less competitive, are expelled from the market. This generates unemployment and difficult reemployment of jobless people. In a context where there is a program for support, training and reemployment of jobless people, the transition can be smooth, and disruption limits itself to the technical and economic sphere. When this does not occur, higher level disruption occurs.

One example of this gap between speeds of change between domains is copyright systems. With the possibility of digitising texts, images, and music, replication and circulation have become costless. The legal system built upon paper and vinyl was not ready to regulate the digital circulation of copyrighted material, so everybody could have easy access to digitalised copies without being caught by enforcing authorities. Even when enforcing authorities have adapted their surveillance systems, the easiness of circulation of information imposes a revision of the regulation to let the technology be beneficial to society.

Another example is UBER: the app that allows simple car owners to run a taxi, that allow travellers to order a taxi, to track its position, to pay a fixed rate, and evaluate the driver has disrupted the taxi services that operated in a regime of quasi-monopoly. When legislation has restricted the freedom of Uber taxi drivers the system has found an equilibrium.

As a last example, the use of Unmanned Aerial Vehicles (UAVs) or drones in several fields is having a large impact, thus provoking disruptions. Consider the use of UAVs in agricultural application to monitor fields from above in real time, or to their use in monitoring the health of ancient buildings: monitoring from above provides a different point of view, offers digital imagery that can be analysed for different purposes, can remove the need for scaffolding, all at acceptable costs with respect to similar services in the past. That is why they are being so largely used and firms providing such services are thriving.

4. Socio-economic impact

In the DESIRA proposal socio-economic impact has been defined as: the opportunities and threats of digitisation which has "*deep repercussions on people's lives, and generates losers (who are marginalised by the changes), and opponents (who resists and elaborate alternative rules of the game), as well as winners (who benefit from the change)*" (DESIRA, 2018, p. 5). This section first elaborates on the access, design and complexity as three conditions that the impact depends on (4.1). It then focuses on two particular areas of impact: the Sustainable Development Goals (4.2) and gender (4.3) and concludes with the implications for analysis (4.4).

4.1. Three conditions of impact: access, design, and system complexity

Impact can have multiple dimensions: we can group them into economic, social, and environmental dimensions or articulate them into more detailed categories (see next section). In each of the three dimensions, impact can depend on three conditions: access, design, and system complexity. Table 2 summarises the socio-economic opportunities and threats of digitisation related to these conditions:

Table 2. Socio-economic impact of digitisation (Adapted from DESIRA, 2018, p. 9)

	Opportunities	Threats
Access	Increase equal access to digital technology	Digital divide
Design	Solutions that anticipate unintended consequences	Design-related risks
System Complexity	Synergies between digital game changers	Digital traps

The first and most commonly known condition for benefitting from digitalisation are related to *access*, i.e. "*the distribution of physical, social and human capital necessary to get access to digital opportunities*" (DESIRA, 2018, p. 5). With as a result that some (groups of) people do not have access to digital technologies, leading to social and economic marginalisation (DESIRA, 2018) and uneven socio-economic development (Rotz, Gravely, et al., 2019; Salemink et al., 2017). Assessment of access conditions should consider potential users of the systems and those who may be excluded from it. What are the social, physical and cyber conditions necessary to access the technology or its outputs? How have the outcomes of the system been distributed as an effect of the change in the system?

Another condition for benefiting from digital technologies is related to the *design* of these technologies. Digital technologies are designed to realise a given (desired) outcome, i.e. to have intended consequences. However, digital technologies that aim to improve productivity, profitability and sustainability (Global e-Sustainability Initiative & Deloitte, 2019) can also have unintended consequences. In some cases, these outcomes can be harmful to people or to the environment, as in the case of weapons or technologies intended to discriminate, steal, or trick. For example, an irrigation system can be designed to save water and optimise the timing of irrigation. If the irrigation system is not designed properly, the application of this technology may have harmful outcomes, such as waste of water or interruption of water irrigation. Design-related impacts may also be related to the vulnerability of the system to environmental conditions, such as heat, wind, humidity. Moreover, they can be vulnerable to espionage or cyber-attacks. Poor design can lead to privacy breaches, data appropriation, sabotage. A recent example: Zoom, one of the most used teleconferencing systems the use of which has grown from 10 million to 300 million users, has generated strong security concerns, as unwanted actors have entered video meetings and disrupted them. After these attacks, Zoom has released a new version of its app.

A third condition is *system complexity*. The more digitisation proceeds, the stronger the need to connect system entities to each other. Increasing connectivity adds to complexity because of the multiplicity of ways that each entity interacts with others. Complexity raises a number of issues on which each outcome of the system can depend, and decreases the manageability of the system. According to Perrow (2011) complexity of a system combined with too tight coupling (strong cause/effect links between entities) leads to vulnerability of systems and to domino effects. With systems that have a low level or a poor integration it is likely that adaptation is challenging and may have negative socio-economic consequences, or *digital traps*. The higher the integration level and the quality thereof "*the better the outcomes of innovation*" (p.6). Assessing system complexity should consider the outcomes of changes of entities and activities of a system in relation to the connections with other entities and other domains. For example, new operating systems of a laptop are not fit to old computers, and this implies that old computers become obsolete. When devices need to communicate with each other, emerging problems can be only fixed by specialists. In complex systems, choice of the right technology may be a problem in itself, as it requires skills and time.

Further and more elaborate cases of complexity relate to the cross-dominion implications. For example, social exclusion related to digitalisation can be caused by lack of access to the Internet and the cost of an application (*access* conditions), or the design of a technology with a gender or racial bias or intrusive forms of conditionality (see the UN report on e-government, UN 2019) (*design* conditions), or to the difficulty to make all parts of a system work (for example, the electronic Identification code for access to the health service) (*complexity* conditions). The integration between digital technologies and the social organisation (e.g. institutions, leadership, skills) may add to complexity. For example, social networks and connectivity can amplify social disparities such as exclusion, bullying, criminal organisation. In relation to agriculture, forestry and rural areas the three conditions (access, design and system complexity) often come with a number of potential threats and opportunities commonly described in the literature.

Poor access to digital opportunities by certain groups of people (often based on location) create a *digital divide* (Rotz, Duncan, et al., 2019), which hampers the socio-economic development of certain areas and people. This divide is often a divide between urban and rural areas, but this divide also exists among rural areas (Townsend, Sathiaseelan, Fairhurst, & Wallace, 2013). Across Europe, rural areas are lagging behind when it comes to digital connectivity and accessibility. Only 40% of rural households in Europe have next generation access (fibre-based, high-speed broadband services), compared to 76% of total European households (European Commission, 2017). Among EU countries, the rural-urban gap differs across countries, with only a 2% gap in the Netherlands compared to a 25% gap in Bulgaria (Trendov et al., 2019). Rural areas are dependent on lower internet speeds and less reliable connections (Skerratt, 2010). Lack of digital access and/or connectivity puts pressure on social and economic development of rural areas, essentially excluding rural areas from completely participating in temporary society (Salemink et al., 2017; Trendov et al., 2019) because they have less or no access to services such as eHealth (Hage, Roo, van Offenbeek, & Boonstra, 2013), eGovernment (Quinn, 2010; Trendov et al., 2019), (public) transportation services (Velaga, Beecroft, Nelson, Corsar, & Edwards, 2012), educational services (Trendov et al., 2019) and entertainment and leisure (Townsend et al., 2013). But rural areas are also disadvantaged because there is limited or no market competition (amongst others due to unattractive investment conditions such as physical distance and lower population density) (European Commission, 2013; Malecki, 2003; Salemink et al., 2017). This widens the gap between rural areas with unattractive business opportunities and urban areas with growing markets and increasing business investments (Townsend et al., 2013). Digital technologies and mobile services in particular have great potential in realising socio-economic benefits for (remote) rural areas, especially related to health, agriculture and financial sectors (Boekestijn, 2017). Broadband connections for rural communities can be a solution to reduce inequalities and can ensure that rural areas enjoy the benefits of better connectivity (Roberts et al., 2017; Townsend et al., 2013). Others warn that digital technological advancement in rural areas can also have adverse effects such as excluding rural people within their own communities if they do not use new digital technologies or devices (Kilpeläinen & Seppänen, 2014). Moreover, limited access does not only relate to the availability of technologies, for example internet connectivity, but also to the ability to adopt and use these technologies (Salemink et al., 2017; Townsend et al., 2013) . Due to the large variety of technologies and applications, as well as the related adoption and (abilities to) usage, the digital divide represents a broad range of access problems (Salemink et al., 2017). The digital divide may thus reinforce existing power differences, for example between farmers and suppliers, as well as social and economic differences in relation to labour and skills (Bronson & Knezevic, 2016; Townsend et al., 2013; van der Burg, Bogaardt, & Wolfert, 2019).

Design-related risks are the (unintended) consequences of unequal distribution of power and risks created by the innovation itself, resulting in winners and losers (DESIRA, 2018, p. 6). Examples of design-related risks are disappearance of the need for human skills (and subsequent potential unemployment) due to automation, discrimination based on profiling or loss of privacy (Scholz et al., 2018). These risks also apply to digital technologies in agriculture, forestry and rural areas, for example robotics in precision farming taking over human work or risks regarding privacy and data protection in forest and farm management applications. However, there are also design-related risks that apply more specifically to agriculture, forestry and rural areas. Agricultural advisors play in important facilitating role in the digitalisation of rural areas and agriculture (Eastwood, Ayre, Nettle, & Dela Rue, 2019), because they are critical for diffusing digital innovation (Fielke, Taylor, & Jakku, 2020). Digitalisation will likely increase connectivity of humans and technologies, driving and driven by growing connectivity (Fielke et al., 2020). However, digitalisation of agricultural knowledge and advice networks is also likely to create a challenge in balancing various agricultural stakeholder's' priorities (Fielke et al., 2020). As Bronson (2018) warns: certain digital innovation in agriculture (e.g. big data or the way algorithms are designed) may reinforce power among agricultural businesses by their very design, serving already rich and powerful parties. Moreover, there are often societal concerns regarding the introduction of digital technology in agriculture, forestry and rural areas. For example, public concerns about privacy and safety of digital biosecurity measures to protect forest health

(Ogilvie et al., 2019). User-centred design and participatory design methods where end-users as well as those affected by digital technology are included upfront in the design of new technologies has been suggested as an important measure to combat design-related risks, improve outcomes and anticipate unintended consequences (Bronson, 2018; Ogilvie et al., 2019; Rose & Chilvers, 2018). Of course, there are also design related opportunities of digitisation, i.e. solutions that anticipate unintended consequences (DESIRA, 2018). Specific to agriculture, opportunities of digitalisation typically centre around increased efficiency, such as automation, precision mechanisation or improved decision-making (Fielke et al., 2020). To be able to anticipate unintended consequences, it is important to identify potential winners, losers and opponents of a digital technology and take their considerations into account. This implies the importance of applying the principles of Responsible Research and Innovation, which will be further elaborated upon in Section 5.

Examples of *digital traps*, in relation to agriculture, forestry and rural areas, are the blurring roles of knowledge providing organisation, technology suppliers and farmers (Eastwood et al., 2017), but also "*information overload, digital addiction, virality of fake news, cyberbullying and cybercrime and loss of human control over machines*" (DESIRA proposal, p.6). For many companies and other organisations, complexity challenges are related to incompatibility or lack of standardisation of software and lack of data storage (European Innovation Partnership AGRI, 2015; Higgins, Bryant, Howell, & Battersby, 2017); uncertainty around the value of data (Poppe et al., 2013); suitability of existing large databases (Magee, Lee, Giuliano, & Munro, 2006; Philip Chen & Zhang, 2014); lack of trust in the quality of industry databases (Cooper & Green, 2015; Minet et al., 2017) and data ownership issues (Bronson & Knezevic, 2016; European Innovation Partnership AGRI, 2015; Poppe et al., 2013). We can already observe that existing digital technologies are changing business models, market integration, coordination among businesses, configuration of Agricultural Knowledge and Innovation Systems (AKIS) but also interaction with policy organisations (Poppe et al., 2013, DESIRA proposal, p. 24). In agriculture, there are already many tools to deal with these complexities, for example decision support systems are widely used among both farmers and their advisors (Rose et al., 2016). While less developed, forestry and rural areas are developing such tools as well. Positive socio-economic impacts related to systems complexity is that complexity allows synergies between digital game changers (DESIRA proposal, p. 10), because system complexity implies integration between both technologies as well as social organisation (DESIRA proposal, p.7).

4.2. Sustainable Development Goals

One particular area of socio-economic impact is the Sustainable Development Goals (SDGs). Succeeding the Millennium Development Goals (2000-2015), the SDGs (2015-2030) make up the 2030 Agenda for Sustainable Development, as defined by the United Nations (2015). The United Nations Member States adopted the SDGs as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. 'Leaving no one behind' is the pledge of the Agenda 2030. It is a set of 17 goals, that are structured around five pillars (5Ps): people, prosperity, planet, peace and justice, and partnership. The 17 SDGs are integrated - that is, they recognise that action in one area will affect outcomes in others, and that development must balance social, economic and environmental sustainability (UNDP, n.d.). They combine the challenge of coping with planetary boundaries (Rockström et al., 2009) – a safe operating space – with the challenge of dealing with social concerns – a just operating space – into creating a 'safe and just operating space' (Hajer et al., 2015).

The relevance of the SDGs in the context of digital transformation is threefold. First, developing digital technology is prominent in the Agenda 2030, in particular in SDG 9 (Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation) and in related mechanisms that support the multi-stakeholder collaboration such as the Technology Facilitation Mechanism and the Science Technology and Innovation (STI) Forum. The latter aims at ensuring inclusiveness and equality, including gender equality (SDG 5, see for more on gender section 4.3). The development of digital technology is also a prerequisite for Member States in order to build sufficient digital government capacity that allows to achieve the SDGs (Janowski, 2016).

Second, digital transformation may have an impact (see also www.diplomacy.edu/blog/digital-technology-sdgs) on the SDGs, in a positive or negative way: they may contribute to or hinder meeting the SDGs. There is ample, though often uncritical, literature on how the digital transformation can accelerate the SDGs (ITUNewsMagazine, 2017). It shows amongst others how digital transformation can lower food waste (Jagtap & Rahimifard, 2019), promote smart water management (Yildiz & Ansmann, 2019), impact on gender equality (Sorgner et al., 2017), citizen empowerment (Kouroubali & Katehakis, 2019), protection of biodiversity (Nagendra, 2001) or smart grids and smart sustainable cities (Mehmood et al., 2017). Counterproductive effects of digital transformation often relate to (unforeseen) processes of social and economic exclusion of more vulnerable actors, hence drifting away from the pledge of 'leaving no one behind', especially when policies do not sufficiently anticipate this. Many of these effects are still vague, although it is clear that automation of the labour market and the accompanying more flexible ways of working will impact upon the lower skilled or less flexible employees(Freddi, 2018; Mönnig, Maier, & Zika, 2019). The integrational character of the SDGs also warrants for trade-offs: contributing to a particular SDG (say SDG 9: industry, innovation and infrastructure) might negatively impact upon another SDG (say SDG 10: reduced inequalities, or SDG 8: decent work and economic growth).

Third, the SDGs' call for action is based on an 'outside in' approach (GRI, UN Global Compact, & WBCSD, 2015) by looking at what is needed externally (required by society) from a global perspective and setting goals accordingly, businesses will bridge the gap between their *current* performance and *required* performance. The SDGs represent an unprecedented political consensus on what level of progress is desired at the global level. This has far reaching consequences for digital transformation. It implies that digital technology has to be designed in such a way that it performs in a desired way, i.e. within the 'safe and just operating space' that the SDGs delineate. In this way, and adding to the first element of the SDGs about having *impact on* the SDGs, the SDGs now become a compass for the design of digital technology and the digital transformation: the SDGs steer the development of the future of agriculture, forestry and rural areas, and the possible position and role of digitalisation within it.

4.3. Gender

Given that the SDGs are connected and strive towards sustainability, the gender aspect (and intersectionality more broadly) is an essential part of the SDGs. The gender aspect has been made explicit in SDG 5: improving gender equality, and in SDG10: reducing inequalities. Therefore, it is also crucial for the DESIRA project to investigate gender aspect around the access, design and system complexity of digital technology use, in order to fully understand the socio-economic impact of digital transformation.

It has been found that digital engagements and digital capital can play a key role in a range of outcomes for individuals and that those individuals who are more digitally included enjoy more advantages than those who are not; and as time progresses forms of digital exclusion change (Robinson et al., 2015). Which is closely linked to the earlier mentioned digital divide. Additionally the *gender digital divide* is used to refer to gender differences in access to resources and digital technology. Research considering the gender digital divide began focusing on identifying gaps and differences, but in the last decade has moved onto explore the consequences of such a divide (Robinson et al., 2015).

Generally, women use digital tools less than men and are at a disadvantage when learning about digital technology (Cooper, 2006) and as such there are gendered processes associated with jobs and technology (Robinson et al., 2015). Moreover it has been found that users' behaviour online is an extension of their offline roles (Colley & Maltby, 2008) and women additionally tend to underestimate their digital literacy in comparison to men (Hargittai & Shaw, 2015). In Europe, in 2017 women had a rate of basic ICT skills (55%) lower than males (60%) (Eurostat, 2017). While the gender digital divide exist all over the world, it is especially prevalent in developing countries (Antonio & Tuffley, 2014).

Access to digital technologies thus plays a big role in the digital gender divide. According to Hilbert (2011), lower access is related to unfavourable conditions of employment, education and income: in other words, the digital gap is an outcome of the broader gender gap. Vice versa, the gender digital divide also further broadens the gender gap. According to the World Economic Forum (2016) expected job losses due to digitalisation are likely to amplify the current gender gap. For example, in sectors such as banking and retailing, where the percentage of female employees is higher, there will be strong job losses (Hauer, 2017). Nevertheless, even in developing countries, the gap has closed in terms of access (Blank & Groselj, 2014; Ono & Zavodny, 2003). This is, however, somewhat misleading as women have lower frequency of use, intensity of use and a narrower range of digital activities (Haight, Quan-Haase, & Corbett, 2014).

Another key element of the gender digital divide is the actual design of digital technologies. Who design the technologies implicitly or explicitly bases this design on their own norms, values and biases. Yet for example software development seems to be a profession from which women are disappearing in Europe and the USA (Tassabehji, Harding, Lee, & Dominguez-Pery). There seems to be a general assumption that women are least suited for coding and writing of algorithms (Miltner; Tassabehji et al.). This is in line with the general view of women in STEM professions (Beede et al., 2011; Leung, 2019).

Thus there are a number of hurdles that account for this gender digital divide, ranging from access conditions, affordability, lack of education and technological literacy to socio-cultural norms and values that cause gender-based digital exclusion (OECD, 2018). However, it is also expected that ICTs can contribute to reducing the gender gap. Strong social networks appears to affect access to the Internet positively for women in rural India (Venkatesh, Shaw, Sykes, Wamba, & Macharia, 2017) and rural Spain (Correa, Pavez, & Contreras, 2017) for example, which has led women to be more entrepreneurial than men. At the same time there is the aim at EU level of empowering women to take op job opportunities in the ICT sector to enhance the high growth potential of that sector (Morrow, 2015). Apart from job opportunities for women in the ICT-sector, there is some hope that digital transformation will help with the reconciliation of work and family life, as in the case of telework, but the real impact will depend on the contractual arrangements in place and on enabling conditions (Lohman, 2015). Another field of attention is the role of digital transformation on access to decision-making and to education (SIDA, 2015).

With regards to agriculture, forestry and rural areas, thus far the debate on gender and digital transformation has mainly been linked to the following questions: In what ways can digital transformation be used as a source of empowerment for women in agriculture, forestry and rural areas? What are the links between gender and social capital in agriculture, forestry and rural areas? (DESIRA, 2018). Therefore, the DESIRA project will, for example, need to further investigate:

- The impact of digital transformation of women's position in the (labour) markets of agriculture, forestry and rural areas;
- Women's participation in decision making processes regarding digital transformation;
- Women's role as consumers and producers of digital technologies;
- Gender-sensitive technologies.

The Responsible Research and Innovation approach (see section 5) will help to be aware and further identify relevant gender equality questions regarding digital transformation, as well as other (potential) digital divides linked to a broader range of inequalities and intersectionality.

4.4. Implications for analysis

The following questions can help to assess the socio-economic impact of digital transformation within the LLs:

- Which digital divide related to digital technologies do you identify?
- Which design related risks related to digital technologies do you identify?
- Which digital traps are related to digital technologies do you identify?
- Which opportunities do you identify related to access, design and system complexity?
- What are the most relevant SDGs for your LL and how does digital transformation impact these goals? E.g. positive, negative, for whom in what way?
- What is the impact of digital transformation of your LL on gender equality?

5. Responsible Research and Innovation

In the DESIRA proposal Responsible Research and Innovation (RRI) has been described as "*an approach to research and innovation that aims at anticipating and assessing potential implications and societal expectations with regard to research and innovation*" (DESIRA, 2018, p. 4). Using this approach is relevant as "*there is a tendency to highlight only the opportunities of digitisation, and underestimate the threats*" (DESIRA, 2018, p. 5) and digital transformation includes winners and losers, as well as proponents and opponents. RRI aims to "*bring issues related to research and innovation into the open, to anticipate their consequences, and to involve society in discussing how science and technology can help create the kind of world and society we want for generations to come*" (RRI Tools, 2020).

Moreover, RRI allows us to not only reflect on the things we know or can predict/expect, but also helps to consider the unseen and unknown aspects of digital transformation, whereby unseen aspects are unintended side-effects or impacts (both positive and negative) on the same or a different system in which an action took place (Scholz et al., 2018). This is different than unanticipated barriers (or opportunities for that matter) that can prevent or support an action unintentionally, usually within the same system (Scholz et al., 2018). Unknowns can be divided into 'known unknowns' and 'unknown unknowns'. This division originates from a quote by former US Secretary of Defence, Donald Rumsfeld, who stated: *"(...) there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know*" (Rumsfeld, 2002). Known unknowns and unknown unknowns have also been explored in scientific studies (Little, Cleven, & Brown, 2011; Logan, 2009; Pawson, Wong, & Owen, 2011) where it is stressed that we can study and hypothesise about known unknowns, but that it is unclear how we deal with unknown unknowns. Unknown unknowns represent uncertainties and unforeseen phenomena. If unknown unknowns go undetected, they could lead to missed opportunities, but in extreme cases could also result in catastrophes (Pawson et al., 2011; Wintle, Runge, & Bekessy, 2010).

Using an RRI approach involves a framework with four main principles. This framework is based on the AIRR (anticipation, inclusion, responsiveness and reflexivity) framework developed by Stilgoe, Owen, and Macnaghten (2013), which has been further adapted in EU project on RRI Tools (www.rri-tools.eu) (see also figure 12):

- Diversity and Inclusion: Be sensitive to research biases, include diverse voices and make results beneficial to a wider community.
- Anticipation and Reflection: Think on the purposes and possible implications of your research and its outcomes and envisage all possible strategies and methods.
- Openness and Transparency: Share objectives, methods and, whenever possible and appropriate, results, and inform about potential conflicts of interests.
- Responsiveness and Adaptive Change: Be responsive to changes and external inputs, adapting your research plans to changing social values and expectations.

Furthermore, agricultural innovation is not an inherently good and value free process, but normatively laden and driven by different worldviews and visions. Correspondingly, different development directions exist, each with its own winners and losers (Brooks & Loevinsohn, 2011; Thompson & Scoones, 2009; Vanloqueren & Baret, 2009).

Figure 12. Overview of main principles of RRI

Additionally there are six key issues that should be part of the considerations when undertaking an RRI approach: ethics, gender equality, governance, open access, public engagement and science education (RRI Tools, 2020).

The RRI framework has been applied to a variety of topics and is studied in various EU projects. The EU project RRI-practice (see www.rri-practice.eu) reviews 22 organisations and aims to further outline RRI objectives, targets and indicators. This project looks at barriers and drivers of successful implementation of RRI, reflection on organisational structures and cultures and identification and support of best practices. A number of scientific publications focus on RRI in a variety of fields, from synthetic biology (Macnaghten, Owen, & Jackson, 2016) and information and communication technologies (ICT) (Stahl, Eden, & Jirotka, 2013) to nanotechnology (de Bakker, de Lauwere, Hoes, & Beekman, 2014). This has resulted in further development of RRI in new directions, although more empirical research is still needed in order to provide a broader empirical basis for further development of the concept (Burget, Bardone, & Pedaste, 2017).

Even though RRI is now increasingly studied and adopted by national research councils, e.g. in the UK, the Netherlands and Norway (Von Schomberg, 2013), there are also authors who voice their concern or critique about its definition and/or application. Lubberink, Blok, Van Ophem, and Omta (2017) describe several problems with current RRI application as being developed by researchers and policy makers without differentiating between research, development and commercialisation, thereby neglecting the implementation of RRI in a business context. Blok and Lemmens (2015) first conclude that practical applicability of RRI as a concept is problematic and requires a more thorough examination of RRI, because of a mismatch between the ideal of responsibility and the realities of existing innovation processes. Second, they challenge RRI as a concept and judge the concept of *innovation* within RRI to be narrow and uncritical, as responsible innovation is seen as: 1) *technological* innovation, 2) primarily recognised from an economic perspective, 3) innovation is inherently good and 4) an assumed symmetry between moral agents and 'the other'. Forsberg, Shelley-Egan, Ladikas, and Owen (2018) point out that there is a lack of research assessing the possible challenges, efficacies and impact of programmes focused on RRI. This can be explained by the lack of standardised methodologies and because the concept of RRI itself is still new (Forsberg et al., 2018). Therefore, further research should also focus on addressing the challenges that are now being discovered (Blok & Lemmens, 2015; Forsberg et al., 2018; Lubberink et al., 2017).

The RRI framework has also been applied to (smart) agriculture. Several authors have indicated, however, that socio-ethical implications of smart agriculture have been neglected (Bronson, 2015, 2019; Eastwood, Klerkx, Ayre, & Dela Rue, 2017; Rose & Chilvers, 2018). Innovations around smart farming have focused on technological development and on-farm use without taking into account socio-ethical implications (Eastwood, Klerkx, Ayre, et al., 2017). Failing to engage certain food system actors (e.g. citizens, consumers, rights holders) in the innovation process is mentioned by several authors as well (Bronson, 2015, 2018, 2019; Eastwood, Klerkx, & Nettle, 2017). Rose and Chilvers (2018) argue that we need a more comprehensive framework for RRI in sustainable agriculture in order to make ideas around RRI more relevant and robust for upcoming agri-technology. To achieve this, they call for: 1) a more systemic approach to map innovations associated with digitalisation of agriculture; 2) broadening of notions of inclusion in RRI in order to include a diversity of participants; and 3) testing responsible innovation frameworks *in practice* to estimate if innovation processes can be made more socially responsible.

Annex 1. Underpinning sociological theories: Actor-Network Theory and Social Practice Theory

There are sociological frameworks which focus specifically on the relations among humans and technologies, i.e. material and organisational constraints, and propose a social theory to analyse the society and its functioning. One such theory is the **Actor-Network Theory** (ANT) (Latour, 2005)[1], which questions the interaction between human and material entities, postulating that the activities and outcomes in socio-technical systems depend on the whole set of connections established by entities themselves, while social actors (i.e. human entities with agency) do not necessarily have a prominent role in the system. In the ANT, we should rethink natural events, social phenomena and the discourse about them. They are not seen as separate objects, but as hybrids made and scrutinised by the public interaction of people, things and concepts. In short, everything in the social worlds exists – and is continuously changed – by networks of relationships among material and semiotic elements (Dolwick, 2009). Latour (1993) argues that for example climate change or pandemics are a mix of politics, science, popular and specialist discourse so that a nature/culture dualism needs to be questioned.

Here, non-human entities (e.g., ideas, technology, natural entities, etc.) and human entities (e.g., social movement, social actors, etc.) are so called *actants*, and are on the same level of importance in the configuration of specific, situated social order. Together they form an actor network, whereby it is important how the actants interact, what is the relation between them, and the meaning subjects attribute to the elements involved in the *actor-network*. When the entities are connected, they act as a whole and their relations with one another shape any other single element in this network (Latour, 2005). Following the ANT thinking, a SCPS can thus also be seen as an actor-network, and as described in section 2.4, all the entities and domains involved in a SCPS are at the same level of importance. What is relevant is how the entities in a network, or system interact and are in relation.

Callon (1986) observes that there is a need for a *translation process*, in order for entities to coherently assemble, i.e. how an entity can become part of an actor-network. Moreover, an actor-network only exists due to constant making and re-making. This means that relations need to be repeatedly 'performed' or the network will dissolve. It also suggests that systems of connections are not intrinsically coherent, and they contain conflicts. Social relations, in other words, are only ever in process and must be performed continuously (Callon, 1986). Callon (1986) thus describes how actants influence the socio-technical system activities, routines, etc., depending on the translation process.

The different performances of technological innovation, for example, depend on how some actors (institutions, for example) define the nature of the problem and a possible technical solution (problematisation). A fast internet connection can be established as a solution to economic issues in rural areas. Around this technological solution, different subjects – such as economic actors, local institutions, civil society organisations, etc. – with different interests, values and aims, are activated by modifying the initial solution (interessement). In this case, for example, farmers, tech companies, internet providers, local institutions, etc., express pros and contras related to the fast internet

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[1] Other social theories following with a similar focus are the Cyborg perspective (Haraway, 1991) and the Social Practice Theory (Schatzki, 1996; 2016)

connection pressing to change it. Once a stable solution has been defined, the different actors work to perform the implementation of the technological novelty (enrolment) so that it can change the socio-technical system as it was set in the mediation process (mobilisation). In short, the translation process can describe how an entity (e.g., organisational forms, new technologies, natural events, etc.) become a game-changer concerning the actor-network (that can be a socio-technical system).

In this line game changers can be seen as everything that transforms the activities, relations, interactions, and outcomes. Still, how these game changers are incorporated and transform the social-technical system depends on the mediation processes put in place by social actors.

Close to the ANT perspective is the **Social Practice Theory** (SPT). Starting particularly from the concept of practice proposed by Schatzki (1996, 2019), Shove and Pantzar (2005) designed a scheme to define the dynamic of social change taking in account elements that constitute a social practice: materials (objects, technologies, etc.), meaning (social values, norms, imagines, etc.) and competencies (skills, know-how, etc.). Focusing on the making and breaking linkages among these elements, SPT analyses the social life of an innovation. Specifically, a practice changes when different links between the entities of which it is composed change because links define the practice. In this sense, it is crucial to understand what kind of link is made among a new event, technology, ideas, etc., with others' entities. From this perspective, we can argue that the practice of writing changed dramatically with the introduction of word processing software because there were previous skills (e.g. typing on analogue typewriters) and it perceived as linked to relevant social values (such as productive efficiency, aesthetic canons, etc.). For examples see Hand and Shove (2007); Shove and Pantzar (2005).

Similarly to the ANT, the SPT suggests us that everything can be a game changer, and the chance that an entity becomes relevant in social change is related to the ongoing process of *normalisation*. It refers to the analysis of in which way social practice changes and stabilises by the time, which links contribute to it and which interpretation of the shift is prominent.

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