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Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts

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A B S T R A C T

Context: The domain of rural areas, including rural communities, agriculture, and forestry, is going through a process of deep digital transformation. Digitalisation can have positive impacts on sustainability in terms of greater environmental control, and community prosperity. At the same time, it can also have disruptive effects, with the marginalisation of actors that cannot cope with the change. When developing a novel system for rural areas, requirements engineers should carefully consider the specific socio-economic characteristics of the domain, so that potential positive effects can be maximised, while mitigating negative impacts.
Objective: The goal of this paper is to support requirements engineers with a reference catalogue of *drivers*, *barriers* and potential *impacts* associated to the introduction of novel ICT solutions in rural areas.
Method: To this end, we interview 30 cross-disciplinary experts in digitalisation of rural areas, and we analyse the transcripts to identify common themes.
Results: According to the experts, main *drivers* are economic, with the possibility of reducing costs, and regulatory, as institutions push for more precise tracing and monitoring of production; *barriers* are the limited connectivity, but also distrust towards technology and other socio-cultural aspects; positive *impacts* are socio-economic (e.g., reduction of manual labour, greater productivity), while negative ones include potential dependency from technology, with loss of hands-on expertise, and marginalisation of certain actors (e.g., small farms, subjects with limited education).
Conclusion: This paper contributes to the literature with a domain-specific catalogue that characterises digitalisation in rural areas. The catalogue can be used as a reference baseline for requirements elicitation endeavours in rural areas, to support domain analysis prior to the development of novel solutions, as well as fit-gap analysis for the adaptation of existing technologies.

1. Introduction

When transforming an existing environment through the introduction of a digital system, traditional requirements engineering (RE) approaches normally focus on the analysis of existing processes, stakeholders' needs, and social relations [1–3]. While this can guide the engineering of suitable solutions that take into account costs, benefits, budget and time within a short-term perspective, it is not sufficient to guarantee that sustainability concerns are addressed in the long run [4,5]. As clearly stated by Becker et al. [4], "*the system the customer wants and the system that should be built are quite different*". Design choices may privilege some stakeholders while marginalising others, and may not consider silent stakeholders, such as the natural ecosystem and future generations.

This is particularly relevant for the application domain of *rural areas*, including rural communities, agriculture and forestry. The field is currently facing profound technological transformations [6–8], with digitalisation being regarded as a strategic enabler towards sustainable growth at social, economic and environmental level [9,10]. ICT

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solutions under the umbrella of precision agriculture, but also logistic systems that support the food value-chain, and even basic communication tools, are considered fundamental means to address sustainability concerns of this domain [9,11,12]. At the same time, the transformation of an existing and highly traditional context with the introduction of a digital system can produce undesired consequences [10,12,13]. To prevent this, RE activities oriented to the development or adaptation of ICT solutions for rural areas need to take into account the domain-specific conditions that influence and are influenced by the adoption of a certain technology [7,12]. In particular, requirements engineers need to know what are the socio-economic, regulatory and environmental *drivers* that can facilitate the introduction of their solution, as well as the *barriers* that can create obstacles towards its adoption. Furthermore, they need to evaluate what are the potential *impacts*, so that positive effects towards sustainability can be maximised, while mitigating negative consequences.

This paper aims to support RE activities with a catalogue of *drivers*, *barriers* and potential *impacts* associated to the introduction of novel ICT solutions in the domain of rural areas. These three concepts incorporate traditional stakeholders' goals among the drivers, but also account for other components that do not currently have a prominent place in RE. In particular, explicitly reflecting on socio-economic, regulatory and environmental concepts that comes before system design (*drivers*, *barriers*) and after its deployment (*impacts*), can help to extend the scope of RE activities so that societal and long-term effects are considered.

To elicit information for these three core concepts, we perform a set of 30 semi-structured interviews with experts across the European Union (EU), who were recruited in the context of the Horizon 2020 DESIRA Project (Digitisation: Economic and Social Impacts in Rural Areas).[1] The experts have diversified knowledge about a wide range of ICT solutions applied in rural areas—e.g., precision agriculture, blockchain-based tracking, and automated milking systems (AMSs). They are selected because of their expertise on families of systems in the domain, and can therefore provide an informed opinion, with the right high-level perspective that gives a (filtered) voice to multiple stakeholders. We perform a thematic analysis of the interview transcripts to identify common categories and provide an expert-based reference catalogue to be placed before any project-specific requirements elicitation activity in the domain of rural areas.

Our results show that typical *barriers* for the adoption of ICT solutions are the lack of connectivity in rural areas, but also fear and distrust towards technology. In addition, the cost of technology and regulatory issues, also related to unclear data governance are relevant barriers. Main *drivers* are economic, as technology can lead to cost reduction, but also institutional ones, since technology can improve monitoring as well as accountability. In this regard, regulators can play a crucial role by means of funding programmes and norms. *Positive impacts* are the replacement of repetitive labour and the possibility of exploiting economies of scale. On the other hand, *negative impacts* are the higher dependency from technology as well as the social exclusion of some players that cannot cope with the change, at least not fast enough.

This work contributes with a catalogue of drivers, barriers and impacts associated to the adoption of technological solutions in rural areas. Our themes represent a reliable snapshot of the state of affairs in rural areas, and can be taken as reference for the development of socio-technical systems in this domain. Although the catalogue is domain-specific, the main concepts put forward can be also extended to other fields in which there is a strong interplay between the digital and the social dimension, and sustainability is a main concern.

The remainder of the paper is structured as follows. In Section 2, we present the DESIRA project and related work. Section 3 describes the conceptual meta-model that describes the constructs of drivers, barriers and impacts, relating them to more common RE terminology. Section 4 reports the research design, and Section 5 presents the results, describing the different categories of drivers, barriers, and impacts. Section 6 summarises the main take-away messages and provides a discussion in relation to existing literature. Section 7 provides conclusions and final remarks.

2. Background and related work

2.1. The H2020 DESIRA project

The paradigm of cyber–physical systems [14] is often referred to as a model to describe how complex systems interact with the physical world, integrating computation and physical processes. Depending on the context, the cyber and physical spaces can be intertwined with the social space [15], giving birth to the concept of socio-cyber–physical systems [12,16], a paradigm in which humans are at the very centre, as opposed to cyber–physical systems that revolve around computation and physical processes. The *socio-cyber–physical* paradigm is the core of DESIRA (Digitisation: Economic and Social Impacts in Rural Areas), a four-year H2020 EU project started in June 2019, which focuses its attention on the digitalisation of rural areas, including agriculture, forestry and rural communities. The analysis conducted within DESIRA activities covers both the past and the present, and also aims at developing future scenarios in which the impacts of digital technology can be defined as *game changing* [17]. A digital game changer can be defined as a disruptive digital technology introduced or adopted in a context. The socio-economic impacts of potential digital game changers are discussed in twenty Living Labs[2] all across Europe, each around its own focal question that embodies a crucial need or desire in a geographical area. The Living Labs will perform the so-called *scenario workshops* to explore different future scenarios with respect to game-changing events, such as the adoption of digital technologies that have the potential to reshape rural areas. The Living Labs will also co-design novel digital solutions tailored on the specificity of rural areas. The co-design will be carried out in the so-called *use case workshops*, involving relevant stakeholders from different sectors as in the scenario workshops.

In this work, we focus on the creation of a baseline catalogue of drivers, barriers and impacts of digitalisation in rural areas, based on experts' interviews. This is the starting point of the analysis in DESIRA. The catalogue will be further specialised, considering the specific contexts of the Living Labs as novel relevant elements will emerge along with the workshops.

2.2. Sustainability in requirements engineering

Sustainability in system engineering has traditionally been interpreted as the ability of a system to evolve and be maintained in a cost-effective way, while managing technical debt [4,18–22]. This vision, which focuses only on the *technical* side of sustainability, has been criticised by the Karlskrona Manifesto [4], edited by a group of software engineering researchers to raise awareness on the relationship of ICT solutions with ecological and social systems. The manifesto calls for a more systemic view of sustainability during system design, and identifies RE as the key area where system-level thinking can be applied to escape the trap of solutionism [23] and broaden the perspective to reason on potential effects of technological change from the social, ecologic, and economic viewpoints. The call to arms of the Karlskrona Manifesto, which stems from reflections already well developed in the social science field [24], triggered research around the notion of *sustainability requirements* [22,25–28]. These are intended as quality goals that a system shall fulfil to provide long-term benefits for its

[1] Project website: https://desira2020.eu.

[2] The Living Labs can be seen on the DESIRA website: desira2020.eu.

environment and members therein, while minimising damage for other members and the environment as a whole [25].[3]

In recent years, several works have been conducted to address the challenge of eliciting, analysing and satisfying sustainability requirements. Part of the work focuses on experimenting and tailoring RE methods. Others are oriented to surveying the field and provide general frameworks.

2.2.1. RE methods for sustainability

Research in RE and sustainability dates back to the late '00, with the seminal work of Cabot et al. [30]. The authors propose to use the well-known *i** goal modelling framework to represents the sustainability effect of each business or design alternative. Sustainability is defined as a *softgoal* (i.e., a nonfunctional/quality requirement) and is further decomposed into subgoals, such as reuse, recycle, etc. to build a reference taxonomy. Mussbacher et al. [31] introduce goal-oriented engineering for sustainability, and uses the Goal-oriented Requirements Language (GLR), extended with the notion of time to account for measurable aspects relate to this variable and its relation to sustainability. Roher and Richardson propose to use a recommender system for sustainability requirements, so to enable reuse of requirements archetypes [32], later refined into *sustainability requirements patterns* [33].

Mahaux et al. [27] take a more empirical perspective, with an experience report oriented to reflect on the process of discovering sustainability requirements. The paper observes that sustainability requirements can be analysed using traditional techniques, but specific checklists need to be defined and, in addition, a sustainability specialist needs to be involved in the RE process.

Brito et al. [34] combine aspect-oriented requirements analysis with the hybrid assessment method, an approach for multi-criteria decision making. They define a meta-model to represent sustainability concerns, which includes the potential *effect* of a certain requirement, a notion similar to the one of impact that we consider in our paper.

Seyff et al. [35] tailor the Win Win negotiation process to consider the impact of requirements on sustainability. The approach is applied on an industrial case study involving an ERP system vendor. Though the experience was considered successful, discussion on the impact of requirements was hampered by a lack of information to anticipate long-term effects, which leads to participants having different, and uncertain, opinions. Specific to the context of rural areas, Doerr et al. [7] present an RE framework to assess and derive new RE methods for social contexts. The authors highlight the need to consider different RE dimensions, including the attitude of people towards ICT systems, as well as the *impact* of the technology.

In a recent work, Duboc et al. [36] present an RE approach to facilitate the elicitation of sustainability-related requirements. The framework consists of a set of questions to be asked to stakeholders during interviews or workshops, and also includes a diagrammatic notation to graphically support a coherent analysis of the relationship between different types of impacts. Saputri et al. [37,38] propose a complete framework, with guidelines to elicit and assess sustainability requirements and metrics. The approach is applied on multiple case studies, showing that the guidelines provided facilitate the identification of sustainability requirements.

2.2.2. Surveys on RE for sustainability

Based on previous works, also in the broader area of software engineering for sustainability [21,39], Chitchyan et al. [40] gives an overview of techniques that can be applied to support sustainability in each RE phase. On a similar note, García-Mireles et al. [41] present a mapping study on sustainability and software product quality, highlighting that this is a particularly lively area of research, but still at its exploratory stage, with works that are mostly focused on the development of energy-saving solutions, which are only one of the multiple facets of sustainability. In another contribution [42], the same authors focus on surveying RE methodologies for sustainability, pointing out the limited knowledge available on how to *assess* the achievement of sustainability requirements.

While these works mostly focus on gathering data from the literature, Chitchyan et al. [28] look more into practice, performing an interview study with RE professionals to identify their viewpoints on sustainability requirements. Among the different aspects, the subjects generally complained about the absence of a clear development methodology to support sustainability in their companies, and the lack of support for engineers in understanding sustainability issues. Similarly, Condori-Fernandez and Lago [22] perform an online survey with different software professionals to identify how different quality requirements, framed according to the ISO/IEC 25010:2011 Quality model [43], contribute to sustainability. Building on a previous work from Lago et al. [26], they analyse the responses according to four sustainability dimensions, namely: *social*, *technical*, *economic*, and *environmental*. The results show that the different dimensions are intertwined, as a type of requirement can address multiple dimensions at once. For example, availability and efficiency requirements address the technical dimension, but are also strongly related to the environmental and economic ones.

2.2.3. Contribution

Our work belongs to the line of research on RE and sustainability, as it enables reasoning on potential effects of technological change from the social, economic, and ecologic viewpoints, in line with the indications of the Karlskrona Manifesto [4]. Specifically, it falls into the group of studies concerned with expert surveys about sustainability and RE [22,28]. These previous surveys are domain-agnostic, and ask professionals about system requirements that have a relation with sustainability concern [22], or about the state of the practice of sustainability design [28]. In our case, we ask about concrete sustainability-related effects of system adoption (*impacts*), and about domain-related factors that can affect the adoption itself (*drivers, barriers*). In addition, we focus on rural areas, and we collect domain-specific information.

With respect to previous work, our contribution is thus three-fold: (1) we propose to broaden the scope of RE so to account for societal and long-term aspects [41] by reasoning on the concepts of *drivers* (which subsumes traditional stakeholders' goals), *barriers* and *impacts* associated to the introduction of a novel ICT solution in a socio-physical domain; (2) differently from previous domain-agnostic work based on interviews and questionnaires [22,28], we focus on the specific field of rural areas, as domain-dependent lenses to support RE activities, especially when sustainability is a main concern [21]; (3) we present an expert-based catalogue of drivers, barriers and impacts specific to rural areas that can be used as a reference for RE endeavours in the field.

3. Conceptual meta-model

The goal of this paper is to support RE activities with a catalogue of *drivers*, *barriers* and *impacts* associated to the introduction of ICT solutions in the domain of rural areas. These constructs enrich the set of concepts traditionally used in RE, such as stakeholders, actors, goals (or functional requirements), softgoals (or quality requirements, or non-functional requirements), domain assumptions, and specifications [2,

[3] As pointed out, among others, by Venters et al. [25], the concept of *sustainability requirement* is not well defined in the literature. Here we provide an intuitive idea to clarify what is the topic of discussion, without any ambition for formality or completeness. With respect to the multiple interpretations analysed in the social science literature [29], sustainability is considered here as *the integration of a set of social-environmental criteria or qualities to guide human actions or their products*.

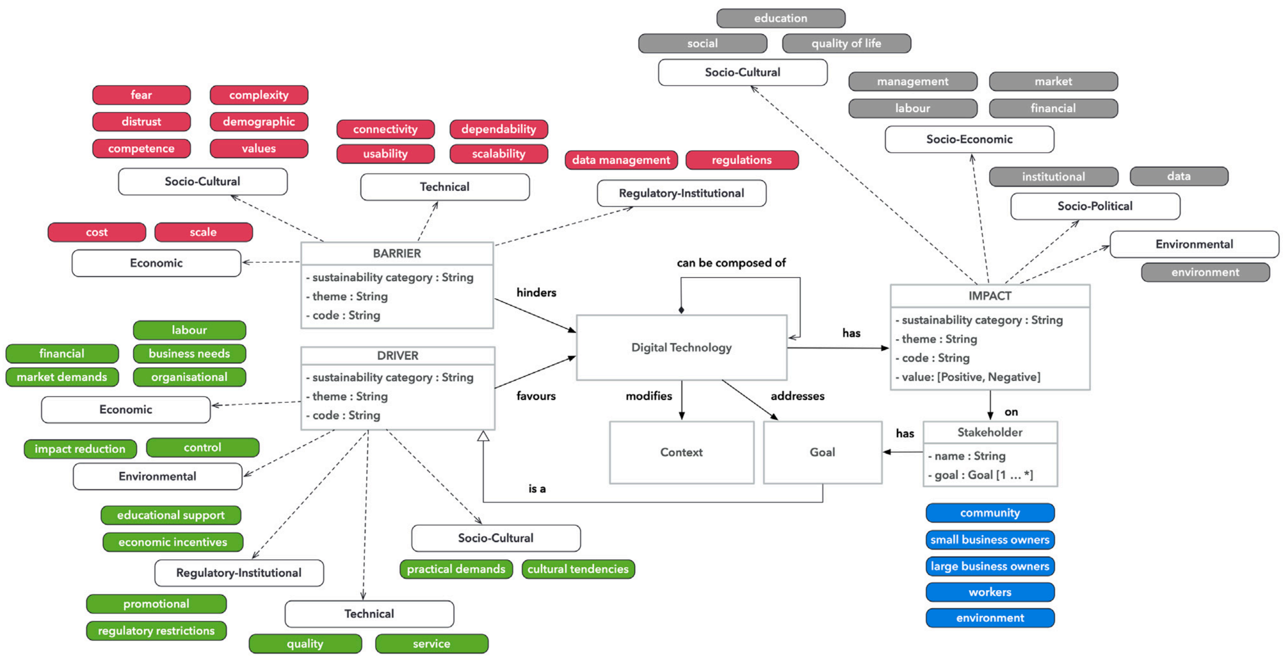

Fig. 1. Informal meta-model describing the relationship between the constructs of our study. Rounded and coloured elements are the specialisation of the meta-model for the domain of rural areas derived from our study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3]. The objective of this section is to describe the constructs of drivers, barriers and impacts in a way that resonates to requirements engineers, and relate them to more traditional RE terminology. To support the descriptions, we find it useful to represent these constructs through an informal diagram, reported in Fig. 1 (elements in squared boxes). This should be regarded as the conceptual meta-model behind our catalogue. The figure also includes the categories and themes identified by of our study, i.e., classes of drivers, barriers and impacts specific to the rural area domain (rounded boxes), which can be considered as the specialisation of the meta-model. In the following, we describe the main concepts and their relations, while the actual catalogue will be presented in Section 5.

A **Digital Technology** represents a family of digital systems, or composition thereof, which aims at satisfying or satisficing a given set of hard- and soft-**Goals**, and in doing so it modifies an existing socio-cyber–physical **Context**.[4] For example, a vegetation monitoring technology based on hyper-spectral cameras and signal processing can have the goals of monitoring the field and ensure grain quality; the technology socially and physically modifies a context made of farmers (e.g., by introducing technological experts) and fields (e.g., by introducing cameras onboard drones). The introduction of technology in a context is favoured by **Drivers** and hindered by **Barriers**, and has certain **Impacts** on existing **Stakeholders**.

Drivers include goals of some stakeholders, for example the need to improve wheat quality required by farmers, but also other higher-level aspects, for example the funding from institutions to support specific technologies. Similarly, **Barriers** include obstacles in KAOS terms [3], intended as elements preventing the achievement of a specific goal, but also more structural impediments that hamper the introduction of the digital technology as a whole in the given context. For example, the difficulty of farmers in interacting with the novel technology, or the regulatory problems related to the use of drones.

The concept of **Impact** is analogous to that already considered, among others, by Brito et al. [34] and by Seyff et al. [35], and is intended as the expected effect that the digital technology can have from a sustainability standpoint, and thus in the mid- to long-term. The impact can be positive, as, e.g., reduction of manual labour, but also negative, for example due to the exclusion of small farmers that cannot afford the technology.

A **Stakeholder** includes actors, "standard" stakeholders, and any party that is indirectly impacted by the technology without voluntarily interacting with it or taking part to the decision process that leads to its deployment, such as the environment, the animals, or the community as a whole. Drivers, barriers and impacts are associated to different sustainability categories inspired by the literature. Reference categories, or dimensions, that we have considered and adapted to our domain are *social*, *technical*, *economic*, *environmental*, and *individual*, as in Duboc et al. [36], Lago [26][5] and other authors [4,44,45].

In the following, we specialise the meta-model for the domain of rural areas by interviewing experts in relation to the introduction of digital technology, or *digitalisation*, for short. We focus on the main elements of drivers, barriers and impacts, and we relate them with sustainability categories, and impacted stakeholders. For each driver, barrier and impact, we will identify a theme (coloured rounded boxes in Fig. 1), and a code (cf. content of Tables 3, 4, and 5).

4. Research design

The present study can be regarded as a *judgment study* [46], which is a form of in-depth survey involving selected experts on a certain topic of interest—in our case digitalisation in rural areas. We use semi-structured interviews as data collection technique. The study is carried out by first selecting a set of representative experts as participants, and then by interviewing them according to predefined interview scripts. The interviews are analysed to produce a coherent and complete view of the topic of interest based on the collected opinions. The study is *exploratory* and *descriptive* in nature and it is guided by the following research questions (RQs):

RQ1: *What are the barriers hindering digitalisation in rural areas?*
RQ2: *What are the drivers facilitating digitalisation in rural areas?*
RQ3: *What are the potential impacts of digitalisation in rural areas?*

[4] We refrain from the usage of the term *environment*, which is more commonly used in RE, as the term is reserved to refer to ecosystems.

[5] Lago [26] does not explicitly include the *individual* dimension.

Table 1
Interviewed experts. We report specific expertise, background (social or ICT), and whether they work for academia (A), government (G), or R&D in industry (I).

ID	Sub-domain	Geographical Area	Expertise	Social			ICT		
				A	G	I	A	G	I
1	Agriculture	France	Researcher (remote sensing and computer vision)				✓		
2	Agriculture	France	Support in policy making		✓			✓	
3	Agriculture	France	Operation director						✓
4	Agriculture	France	Instructor and consultant for agricultural cooperatives						✓
5	Agriculture	Finland	Automation technology in farms				✓		
6	Agriculture	Belgium	Researcher (precision agriculture and photonics)				✓		
7	Agriculture	Greece	Researcher (innovation and project management)				✓		
8	Agriculture	Greece	Researcher (agricultural engineering)	✓					
9	Agriculture	Switzerland	Agricultural research (precision agriculture and unmanned vehicles)				✓		
10	Agriculture	Latvia	Consultant, researcher (economy and management)	✓			✓		
11	Agriculture	Latvia	Researcher (dairy farming)				✓		
12	Agriculture	Germany	Agronomist, researcher (precision farming and agricultural economics)				✓	✓	
13	Agriculture	UK	Head of farms networks						✓
14	Agriculture	Hungary	Farm manager						✓
15	Agriculture	Italy	Agronomist, researcher (monitoring, protection, information systems)				✓		
16	Agriculture, rural communities	Finland	ICT project manager, researcher (digitalisation)				✓		
17	Agriculture, rural communities	Spain	Rural development, support for policy making		✓				
18	Agriculture, rural communities	France	Sociologist (health and social research)	✓					
19	Rural communities	France	Advisor, entrepreneur			✓			✓
20	Rural communities	Netherlands	Rural and community development	✓					
21	Rural communities	Netherlands	Ethics, impacts of innovation	✓					
22	Rural communities	Spain	Manager of a protected natural area		✓			✓	
23	Rural communities	Belgium	Policy expert		✓				
24	Rural communities	Germany	Researcher (digitalisation, software engineering)				✓		
25	Rural communities	Poland	Agriculture and food economics				✓		
26	Rural communities	Greece	Researcher (sustainable development and economics)	✓					
27	Forestry	Italy	Manager of non-profit consortium, forest engineer						✓
28	Forestry	Italy	Startup founder, renewable sources						✓
29	Forestry	Austria	Education, training, research	✓			✓		
30	Forestry	Spain	Head technical team of environmental information network					✓	

Table 2
Interview scripts covering digital technologies (DTs). Q1 and Q6 are common for both profiles.

	ICT Expert	Social Science Expert
Q1	Which are the DTs you deal with or encounter most commonly in your work? What are their main uses in the three domains?	
Q2	Which is a plausible tomorrow's use of the DTs you cited in Q1?	What are the socio-economic impacts of the DTs you cited in Q1?
Q3	Can you provide some examples of uses of DTs/new developments you are participating to/aware of? Do you think those developments have the potential to be game changers?	What do you consider as drivers for the adoptions of DTs in the three domains?
Q4	Which are the positive and negative impacts of technological advancement on SMEs, workers, and other actors, especially considering cases you have been involved into?	What do you consider as barriers for the adoptions of DTs in the three domains?
Q5	What do you consider as drivers and barriers for the adoption of DTs in the three domains?	How new and deeper reflections/methodologies to assess the impacts of technology could help you in your work?
Q6	Have you already been involved in any activities to assess the socio-economic impacts of DTs?	

4.1. Study participants selection

Participants of the study were selected by the authors based on opportunistic sampling. The goal was to involve experts that: (a) could cover the main sub-domains of rural areas, namely agriculture, forestry and rural communities; (b) covered ICT and social-science background; (c) could be representative of different geographical areas of the EU. The participants to the DESIRA project, who have interdisciplinary backgrounds including ICT, social science and agriculture, contacted specific subjects in their fields that were considered as reliable experts due to their professional position and their publicly recognised active role in the theme of digitalisation for rural areas. Table 1 lists the selected participants together with their reference subdomain, nationality, and main expertise.

4.2. Data collection and analysis

To collect data, we first defined a set of interview scripts to guide the interviews and then we applied thematic analysis [47,48].

Interview scripts and delivery. The selected subjects have an interdisciplinary background, but broadly belong to two groups: social science and ICT experts. Therefore, we defined two main interview scripts, one for each group. The questions for the two groups are reported in Table 2. Interviews were conducted remotely, or in person, according to different conditions, by the different authors of this paper and by other partners of the consortium, and then transcribed. The transcription was checked by the interviewed subjects for misunderstanding.

Interview analysis. Each interview was initially evaluated by the first author in two cycles. In the first coding cycle, from each interview, he extracted independent paragraphs (469 in total from 18,000 words, 38 words per paragraph on average) and coded them based on their content, and following the coding guidelines of Saldaña [49] for *descriptive coding* by associating descriptive codes to them. In a second cycle, the codes were selected, reviewed and aggregated into themes, and then into higher-level sustainability categories, by means of *axial coding* [49] and leveraging the sustainability dimensions from the literature [4,26,36,44]. For example, the paragraph *Historically [...] there is solidarity among neighbours and people who live in rural areas,*

Table 3
Barriers hindering digitalisation in rural areas.

Socio-cultural barriers	
Demographic	Age issues, social isolation, sparse population, seasonal work
Distrust	Distrust of funders, distrust of regulators, distrust of ICT supplier, distrust of technology
Fear	Fear of dependency from technology, fear of hidden costs, privacy concerns
Values	Attachment to tradition
Competence	Lack of education, lack of knowledge, lack of skills, digital debt
Complexity	Complexity of regulations, complexity of technology, paradox of choice
Technical barriers	
Connectivity	Absence of infrastructure, low quality of infrastructure
Dependability	Poor reliability, low efficiency
Usability	Poor ergonomic standards, poor usability in the field
Scalability	Limited data storage, limited computing capacity
Economic barriers	
Costs	Cost of technology, modernisation cost, maintenance cost, lack of evidence of cost-effectiveness, lack of funding
Scale	Small market size, small business size, atomised business structure
Regulatory-institutional barriers	
Data management	Unclear data ownership, unclear data governance
Regulations	Frequent change of regulations, legal restrictions on technology, inadequate grant schemes criteria

and what the digital does is to allow that natural resilience and solidarity to come out more was initially coded with "solidarity spirit", "community support". Considering similarity with other codes, a higher-level theme called "cultural tendencies" was created as part of the *axial coding* process. The descriptive code "solidarity spirit" was kept as more representative of a driver, while "community support" was not considered as it was regarded more as an enabler than a driver. In addition, the category Socio-cultural Drivers was produced to aggregate the theme "cultural tendencies" with the one called "practical demands" (cf. Table 4), created in a similar manner. This process, here presented in a linear form, was iterative in practice, and codes, themes and categories were revised, selected and adjusted in multiple cycles. Furthermore, here we considered an example clearly belonging to a single theme in a specific category. In general, a paragraph could be associated to multiple codes, later associated to different themes. For example, the paragraph *[...] However, not everybody corresponds the criteria set by the grant schemes and some farmers distrust these funds*, coded as Socio-cultural Barriers→"distrust"→"distrust of funders", and as Regulatory-Institutional Barriers→"regulations"→"inadequate grant scheme criteria".

The first author used a shared spreadsheet file (a Google sheet) to record themes and categories. From this hierarchical grouping, he produced a set of summary tables that answer the different RQs. The link between data, themes and categories were cross-checked by the third author, who commented for unclear links or theme names (11 disagreements were identified), to come to a consolidated output.

4.3. Threats to validity

Validity of the findings is discussed according to the categories of validity, reliability, and generalisability outlined by Leung [50].

Validity. The main requirement for judgment studies is the adequate expertise of the subjects involved, so that the collected opinions are authoritative and informed ones [46]. The level of expertise of the selected subjects was checked by the DESIRA project consortium, which is formed by multiple institutions that study rural areas from different viewpoints (ICT, economic, legal, etc.), and have an up-to-date vision of relevant voices in the field. To balance the specific background of each subject, two types of script were defined, one for ICT experts and the other for social-science experts. To increase content validity, the scripts were reviewed and piloted within the consortium. Concerning the completeness of the information collected from each participant with respect to the RQs, we defined interview questions that are derived from the RQs, but are also sufficiently broad to allow interviewees to freely and completely express their opinions on the discussed topics. A limitation of the study is the reduced number of negative impacts elicited, as the subjects appeared to mostly emphasise positive aspects of digitalisation. Further work within the Living Labs will be conduced with interviews oriented to stress on negative aspects. Member checking was adopted to ensure descriptive validity, as the interviewee could review and correct their transcribed interviews.

Reliability. Different forms of structured procedures were adopted to support triangulation and increase the reliability of the findings—correctness cannot be achieved within the constructivist paradigm inherent to our method: (a) the coding activities were applied to the whole text of each interview, and all codes and associated interview data were shared in a spreadsheet, to facilitate cross-checking; (b) one researcher performed the coding activity and a second one cross-checked the results with respect to the original data—the first has an RE background, while the second one is a social scientist, and native English speaker; (c) the resulting findings (i.e., the preliminary versions of the tables reported in Section 5) were further reviewed by the other authors of the paper; (d) excerpts are reported from the interviews that show evidence of the relation between codes and data.

Generalisability. In our study, experts were selected to have a sufficient coverage of three main dimensions (subdomain, geographical EU area, and background), as reported in Table 1. Therefore, their opinions, and our findings, mainly reflect their background. In particular, the results are representative for the subdomains of agriculture and rural communities in both southern and northern EU countries, and for forestry, but mostly in southern EU countries. Different results may be obtained if other continents are considered. We cannot claim generalisation of our catalogue to other domains. However, a similar approach to ours can be applied to identify analogous concepts in, e.g., smart cities or industrial areas.

5. Execution and results

Interviews were conducted between May 2020 and February 2021. Results were analysed between October 2020 and April 2021. This section reports the results with respect to the different RQs. Each RQ is associated to one of the main reference concepts of this paper, namely drivers, barriers and impacts. For each RQ, we report:

- a **summary table** with categories associated to the concept, themes within a category, and codes within a theme;
- a list of the main **categories** (e.g., social, technical, etc.) identified for the specific concept;
- a textual *explanation* of the themes within a category;
- a set of *fragments* that exemplify the themes, tagged with the specific code (in square brackets).

5.1. RQ1: What are the barriers hindering digitalisation in rural areas?

Barriers are reported in Table 3 and are categorised into socio-cultural, technical, economic, environmental, and regulatory-institutional. Below, we discuss the different categories and internal themes. We report fragments of the interviews together with the codes associated to them, to provide evidence of the relation between data and themes.

Socio-cultural barriers. Most of the barriers to digitalisation are rooted in the cultural, socio-demographic, and somewhat emotional aspects and inclinations of the individuals populating the rural communities. We identify six types of barriers:

1. *demographic*, related to age issues, the logistic isolation of rural communities, the sparse, low-density population, and the presence of seasonal work, which makes rural areas places in which there is a limited permanent human presence for large part of the year.
   [demographic[6]] *Main limitations of these sectors are the atomised structure, the harsh working conditions, the seasonal work and the sparse and aged rural population. All of them facilitate the social and economic isolation.*
2. *distrust*, which is oriented towards different players, from founders and regulators, to ICT suppliers and technology in general.
   [distrust of supplier] *[There is] lack of trust in partners who use the data, which can be ICT companies (who may use the data for profiling, or on the stock market or who may sell the data) or other partners in the value chain (for example, if the farmers and the slaughterhouse start to share data, who will then harvest the benefits: the farmer or the slaughterhouse?)*
3. *fear*, often based or real threats, such as the risk of dependency from technology, the presence of hidden costs such as those related to maintenance of installed technology, and the privacy concerns related to data sharing.
   [fear of dependency from technology] *Finally, there is also a fear of dependency and loss of control among some farmers. For example, by investing in monitoring systems farmers are increasing their dependence from management systems that need internet and electricity to successfully operate. Thus, sudden shocks like electricity loss might have devastating impacts on the farm.*
   [fear of hidden costs] *It might also be that the farmer decides not to implement the solution because of the challenges associated with the maintenance of the novelty.*
4. *values*, and in particular the attachment to traditional ways of working and identity.
   [attachment to tradition] *So far, many of them are reluctant to use a lot of technology as it does not fit to their image of being a farmer (e.g. working with the soil).*
5. *competence*, such as general lack of higher education, specific knowledge of technologies, as well as practical skills to deal with technology, and, when these aspects become endemic, the emergence of *digital debt* that increases the competence barrier to be covered.
   [lack of knowledge] *Another key challenge for farmers is to find staff that would have agricultural education yet would also have the knowledge regarding the cutting-edge farming software and hardware.*
   [digital debt] *Because of the poor material connectivity, people managed to cope without digital connectivity, and now they lack the "digital capital" to join the bigger leap in digitalisation.*
6. *complexity*, which deals with the relationship between the individual and the feeling of being overwhelmed by the complex systems of regulations, the complexity of technology, and the paradox of choice due to the wide variety of technological solutions available in the market.
   [paradox of choice] *As barriers: cost, complexity, skills and the fact that people are lost in the profusion of existing solutions. When farmers are talking about this to their advisors, the latter are sometimes as lost as farmers and limit themselves to propose solution they control.*

Technical barriers. These are related to four main quality aspects:

1. *connectivity*, as the absence of a communication infrastructure in rural areas is one of the issues mentioned most often by the interviewed experts.
   [connectivity] *In my research I have seen that rural communities have been, and still are, on the wrong side of a digital divide. Over the past two decades this was mainly a material matter, with a lack of connectivity as the prime issue.*
2. *dependability*, since, when present, technologies need to be dependable especially in particular environmental conditions such as those of fields and forests.
   [malfunctioning] *The agricultural environment is a relatively challenging environment. I have had that with the Near Infrared (NIR) sensors for manure tankers [...] And that is a challenging environment, especially manure is very corrosive.*
3. *usability*, as standards required by the usage of a mobile phone in a field are not the same as those of the same device for daily usage.
   [usability in the field] *[One of the promising technologies is the] use of natural languages recognition to facilitate the interactions with machine (e.g. manage crop operations and field log using voice interaction instead of manual entry).*
4. *scalability*, in terms of size and time complexity, since the amount of environmental data coming from monitoring systems is large, and need to be efficiently processed to take informed decisions in acceptable time, possibly profiting from edge computing solutions.
   [scalability] *Today our computer models are based on "cloud" which means that farmers are locally collecting information thanks to sensors, smartphones or computers. Then raw data are sent to a distant server which will treat them, make calculations, cartographies and recommendations. After that, those results are sent back to farmers' terminal. But cloud needs that raw information leave from the place they are so it needs a big communication effort between server and data collection area.*

Economic barriers. Economic barriers are mostly related to the difficulty in dedicating financially sustainable investments in technological solutions, when margins are already limited as it happens in the primary sector. Main themes are:

1. *costs*, including cost of technology but also cost of modernisation of the physical infrastructure of farms, low evidence of cost-effectiveness and the general lack of funds needed to afford the modernisation.
   [lack of funding, cost of technology] *By far the most significant barrier is funding. The technologies are expensive and not all farmers have the funds needed to cover the expenses.*
   [modernisation cost] *Another important barrier is related to the properties of infrastructure. Installation of hardware needed to gather data for management systems or to install milking robots requires that farms correspond to certain characteristics. This might mean that farm building is too small, the ceiling is too low [...] In these cases, the modernisation is just too expensive and might include complete reconstruction of the farm.*

[6] This fragment is associated to all the codes in the demographic theme.

Table 4
Drivers facilitating digitalisation in rural areas.

Socio-cultural drivers	
Practical demands	Demand for work flexibility, demand for workload reduction, demand for wealth, demand for employment, need to reduce isolation
Cultural tendencies	Cooperative spirit, solidarity spirit, need for inclusion, technological fascination, trust in technology
Technical drivers	
Quality	Simplicity of technology, specialisation of technology, proven reliability, proven efficiency
Service	More connectivity, availability of technology, data availability
Economic drivers	
Market demands	Competition, consumer health concerns, green company image, transparent company image, demand for certification, demand of organic products
Organisational	Presence of intermediary roles, collective forms of organisation, opportunity for cooperation
Business needs	Need for better control, need for simplification of legal compliance, need for process optimisation, need for better planning
Financial	Decreasing cost of technology, need for cost-effectiveness
Labour	Shortage of labour, cost of manual labour
Environmental drivers	
Impact reduction	Need to reduce environmental impacts, need to reduce fertilisers, need to reduce pesticides
Control	Need to decrease food waste, need to improve animal welfare, need to control natural disasters
Regulatory-institutional drivers	
Regulatory restrictions	Taxes, constraints, need for regulatory compliance
Economic incentives	Funding programmes, subsidies, incentives for technological adoption, support for cooperation
Educational support	Training programmes, technical mentorship, support of education, digital innovation centres
Promotional	Dissemination of results, promotion of digital entrepreneurship, promotion of digital innovation

2. *scale*, as rural communities in EU are normally small business and do not have the mass to invest in costly technological renewals.
   [small business size] *Margins are often rather small/thin in rural businesses (small and micro family businesses often dominate the business landscape in rural areas) and this means that businesses can be caught up in trying to make break-even.*
   [small market size] *High value enterprises such as milk production will justify the technology many years before low value sectors such as lamb production.*

Regulatory-institutional barriers. Institutions are also responsible for some barriers, as inadequate or unclear policies can hamper access to funds and technology. In particular, in relation to:

1. *data management*, which is often unclear in terms of who owns the data coming, e.g., from farm monitoring systems and how these are managed.
   [unclear data ownership] *"Data food consortium" [...] is about to develop a digital standard in order that all data can be integrated from one digital catalogue of products to another to decrease organisational costs and reinforce the control of data ownership. Farmers should only be able to give their agreement on data sharing for a precise and known use.*
2. *regulations*, which are frequently changing, and are sometimes not appropriate for rural contexts when it comes to grant schemes, which tend to privilege endeavours from large-size players.
   [inadequate grant schemes criteria] *The EU funds is an important mean to overcome the challenges associated with access to funds. However, not everybody corresponds the criteria set by the grant schemes.*
   [frequent change of regulations] *The legislative context is ultra-changing so the one who says he want to revolutionise the word of agriculture and food industry in general will not succeed.*

5.2. RQ2: What are the drivers facilitating digitalisation in rural areas?

Drivers are reported in Table 4, and are grouped into the same categories of barriers. The reader will notice that while for drivers we have most of the themes in the economic and regulatory-institutional categories, barriers are mostly socio-cultural and technical.

Socio-cultural drivers. Socio-cultural drivers include all those aspects that are related to the main social needs of rural communities and to the typical inclinations and tendencies of stakeholders. We identify the following themes:

1. *practical demands* represent the social needs, and are related to: (i) reduction of isolation through better communication that can allow to identify and strengthen the links between needs and potential supply; (ii) demand for lighter work, as automation is expected to reduce the manual labour that is typical of rural activities.
   [need to reduce isolation] *New technologies break the existing isolation in those areas, providing the necessary communication coverage. [...] So the technology allows you to mix and match, it allows you to identify where the needs are and where there is a potential supply and to improve the links between them.*
   [demand for workload reduction] *And from a social point of view [...] many technologies reduce the workload for everyone, [such as automatic] steering systems and these are the drivers.*
2. *cultural tendencies*, which include the natural cooperative and solidarity spirit of small communities, the need for inclusion in the "local vibe", but also the fascination that technology can create.
   [solidarity spirit] *Historically [...] there is solidarity among neighbours and people who live in rural areas, and what the digital does is to allow that natural resilience and solidarity to come out more.*
   [need for inclusion] *With community members [...] the driver seems to be to get included, to join others in (online) groups, and make sure one stays part of the local vibe. Social drivers such as inclusion, but also comparing with peers (other businesses) often turn out to be straightforward, and old-fashioned if you like, motivational factors.*
   [technological fascination] *When it comes to harvesting for big crops like barley, wheat etc there are these large scale harvesting machines that workers use for many days in a row. After interviewing farmers in Denmark, that have used yield monitoring tools on their machinery, they stated that their daily job has become more interesting.*

Technical drivers. A limited yet relevant part of the drivers is also technical, intended as relevant non-functional attributes of technology that can play a crucial role in facilitating digitalisation. We identify two main themes:

1. *quality*, intended as evidence about the proven quality of the technology in terms of simplicity, reliability, efficiency, and the possibility to specialise it to address the peculiarities of rural areas can convince rural community members to accept digital solutions.
   [simplicity of technology] *Acceptance is strongly driven by the simplicity or complexity in using the technology. E.g. simple smart phone applications are much easier accepted and used than complex systems requiring PC and specific training.*
   [specialisation of technology] *The uptake of the technology is also facilitated by the fact that there are new versions of technologies constantly being developed aimed at specific subgroups of farmers (e.g. small dairy farms).*
2. *service*, related to the availability of certain ICT service—e.g., basic connectivity or technology—, which can facilitate digitalisation just thanks to the mere possibility of being accessible by rural area stakeholders. Similarly, digitalisation can be fostered by the availability of new types of data about plants and crops that can be exploited for better monitoring and control.
   [data availability] *The last area that has emerged derived from the vast amount of data and images that we have collected from different crops, where we are trying with deep learning techniques to explain some of the features of this collected data.*

Economic drivers. The largest part of drivers is economic and business-related, and we identify five main themes in this category:

1. *market demands*, collecting drivers coming from customers' requests for healthy food and market trends, such as the need to have a "green" and transparent image. The demand, e.g., for organic products is related to health concerns, but becomes also a powerful market opportunity as "green" becomes fashionable.
   [consumer health concerns] *The consumer wants less inputs [fertilisers and pesticides] while we do need to be able to protect the crops, and we see a driving force for innovation there, driven by society.*
2. *organisational*, with drivers related to novel organisational structures. These includes collective forms of organisation such as cooperatives that can facilitate small players, but also technological hubs and intermediary roles, facilitating learning and access to technology.
   [presence of intermediary roles] *So, you have different types of digital hubs, you have co-working spaces, you have Fab Labs, you have virtual labs of different kinds. These intermediaries play a vital interface role between the people who are using the technology and the providers of it.*
3. *business needs*, including internal company needs, such as process optimisation.
   [need for better planning] *The adaptation of these technologies mainly depends on the economic possibilities of a particular farm. They are introduced to improve the efficiency of the farm—in terms of higher cow productivity, more efficient reproduction planning, reduced calf mortality and other calf related challenges.*
4. *financial*, collecting phenomena related to cost of assets and expected benefits. As advanced technology becomes less expensive, more subjects can take the risk of experimenting with technologies.
   [need for cost-effectiveness] *The use of Unmanned Aerial Vehicle (UAV) on-board solutions for the analysis of agro-environmental phenomena is also being implemented very quickly, due to the possibilities of use at a detailed scale and at an affordable cost compared to other traditional techniques.*
5. *labour-related*, including phenomena related to shortage or cost of labour, as, on one hand, rural areas tend to be scarcely populated, and on the other hand the cost of manual labour can be too high with respect to the typical revenues of the primary sector.
   [shortage of labour] *Milking robots are being installed to counter the labour shortages and to improve the efficiency of farms.*

Environmental drivers. Sustainability is strictly related with the needs of a silent stakeholder, namely the environment. Some drivers are therefore concerned with the relationship between the subject and the ecosystem. These are grouped into two somewhat mirror categories:

1. *impact reduction*, collecting drivers related to the need to reduce human impacts, in terms of reduced usage of fertilisers that can harm the soil in the long terms, and in terms of a reduced use of pesticides, which disrupt biodiversity.
   [need to reduce fertilisers] *Whereas before we gave more fertiliser than required, but now we see that this is no longer possible. And now the margin of fertiliser is reduced, and to prevent yield losses we need to efficiently apply fertiliser and drive the need for innovation.*
2. *control*, which are drivers concerned with the need to control the environment, such as the need to improve animal health, and control natural disasters.
   [need to improve animal welfare] *AMS may have significant potential in the prevention of adverse health outcomes in milking of dairy cows in comparison to conventional milking systems.*
   [control of natural disasters] *All the tools currently used [...] for the analysis and monitoring of environmental phenomena, such as satellite images, orthophotos [...] are very plastic solutions adapted to the control and monitoring of key parameters of different production systems and to the prevention and control of natural disasters.*

Regulatory-institutional drivers. Institutions are the actors that can contribute the most to the digital transformation, using different policy instruments that can steer the direction of the rural communities. The main instruments are:

1. *regulatory restrictions*, such as new regulations, with taxes and constraints associated to undesired behaviours, as, for example, the excessive use of nitrogen for fertilisation.
   [need for regulatory compliance] *Required reduction of the nitrogen balance in the new agricultural policy (AP 2020) will certainly increase the interest in carrying out nitrogen fertilisation more precisely and using the available nitrogen as optimally as possible.*
2. *economic incentives*, such as funding programmes, subsidies, incentives for the adoption sustainable technologies, and economic support for cooperation with digital players.
   [funding programmes] *In the forestry sector, the RDP funding is the main factor acting as a driver from both an economic and a social point of view.*
   [incentives for technological adoption] *Another important aspect is having policies that will incentivise people to adopt new technologies. These policies range from, public awareness, taxes and subsidies, training and education,*[7] *cohesion funds and in general policies that aim to shift the risk away from the technology user can become a driving force in ICT adoption.*
3. *educational support*, to facilitate the circulation of digital knowledge with training programmes, technical mentorship, and the creation of digital innovation centres.
   [digital innovation centres] *The creation and development of digital innovation centres, specifically in the agri-food sector (Agri-Food DIH) [are relevant drivers].*
4. *promotional*, with campaigns oriented to promote digital innovation and disseminate results of success stories.
   [promotion of digital entrepreneurship] *The promotion of digital entrepreneurship through conferences and seminars and demonstration activities.*

[7] This fragment has been coded also under the theme *educational*, with the code "training programmes".

Table 5
Impacts of digitalisation in rural areas according to the experts.

	Positive	Negative
Socio-cultural impacts		
Social (community)	Inclusion, reduction of disadvantages, involvement of consumers, improved attractiveness of rural areas	Exclusion
Quality of life (community)	More free time, increased access to external goods, improved well-being, relief from heavy work	Detachment from nature
Education (community)	Access to distant learning, increased education	Closing of local schools, loss of expertise
Socio-economic impacts		
Labour (workers, business owners)	Replacement of repetitive labour, replacement of seasonal labour, shift to technology-based labour, novel job opportunities, better access to skilled workforce, decentralisation of work structure	Unemployment, change in work profiles
Financial (business owners)	More profits, reduction of costs, improved productivity, benefits of scale	–
Management (*large* business owners)	Control at larger scale, optimisation of resources, increase of business choices, better management of process, logistic optimised, better management of production irregularity, improved measurability	Change of stakeholders, change in production models
Market (community, *small* business owners)	Improved tourism, novel energy-related services, attraction for technology players	Loss of independent companies, increased performance inequality, closing of local businesses, creation of monopolies, interest of large subjects, scale effects on small farms, increased dependency on global markets
Socio-political impacts		
Data (business owners)	Power control in data management, increased control of data ownership, improved transparency, improved trust, increased value of data	–
Institutional (community, institutions)	Improved food democracy, improved legality, facilitated regulatory compliance	–
Environmental impacts		
Environment (environment)	Reduction of human impacts, improved sustainability, reduction of carbon emission, improved animal welfare	–

5.3. RQ3: What is the potential impact of digitalisation in rural areas?

When asked about the potential impacts of digitalisation, the experts discussed cases of positive and negative ones. Table 5 summarises the results. We identify four main categories. Most of the identified themes and codes have a strong social angle, and we considered it appropriate to reflect this in the category names: socio-cultural, socio-economic, socio-political and environmental.

Each theme reported in Table 5 is also linked to the main stakeholders affected by a certain type of impacts. We identify five, non-exclusive, classes of stakeholders, namely:

- the **community** as a whole social subject;
- the **workers**, employed in farms and in other businesses;
- the **business owners**, distinguished into small and large, depending on the size of the business, as this has an effect on the type of impacts;
- the **institutions**, intended as municipalities, but also region, states, regulators and policy-makers in general;
- the **environment**, which is again a key stakeholder that sustainable development needs to take into account.

The analysis of impacts is multi-dimensional, as it accounts for positive and negative impacts, as well as different stakeholders. Therefore, to highlight relevant relationships across dimensions, we discuss our findings for this RQ is an argumentative manner, instead of linearly summarising each single theme. We report representative fragments at the bottom of the description of each category.

Socio-cultural impacts. Expected impacts on the community as a whole are concerned with three main themes: *social* and relational aspects, with higher inclusion of rural areas into the society at large, and improved attractiveness of rural areas; *quality of life*, due to the relief from heavy work that can give access to more free time, but also to the possibility of accessing goods from distant areas through online purchases; *education*, with the availability of distant learning and increased education driven by the need to learn the technology itself.

Digitalisation comes also with its negative impacts, such as the exclusion of those subjects who cannot keep the pace of technological change, but also the detachment from nature, since the relationship between workers, fields and animals is increasingly mediated by computers and robot. Furthermore, access to distant learning can lead to the closing of local schools, while the increase in digital automation can lead farmers to lose their expertise and intuition, as they would rely more and more on data analysis and decision making systems. Fragments exemplifying these positive and negative impacts are reported in the following.

[social: inclusion] *And I think this [technological intermediaries] helps people to step up in a progressive way. So there is the trends, the digital journey, if you like. And then the idea that rural areas are not alone. They are part of something bigger, and they need to work out how they link in with them.*

[social: exclusion] *There is a real need of farmers' education about the use of digital and increased intelligence. But tools must also be reliable, ergonomic, trusted and couple together with a training for their use. A farmer who will be excluded from digital will be excluded from the system.*

[quality of life: more free time] *Finally, these solutions simplify the daily life of farmers and, presumably increases their quality of life. Many of these farmers did not have time for anything before they modernised the farm. Modernisation was a way to ensure that there is time for off-farm activities.*

[quality of life: detachment from nature] *[A risk is] less human attention to animals and plants. Too much to rely on programming and machinery—not all situations can be predicted and programmed.*

[education: access to distant learning, closing of local schools] *it is clear that distant learning can be of help to students in villages and in* *more rural areas, but at the same time it can provide an excuse to closing down the village school and concentrate the village schools in other places*

[education: loss of expertise] *it could lead to a loss of expertise and common knowledge of farmers if robots are more used to determine production decisions.*

Socio-economic impacts. The largest part of the discussed themes are related to the socio-economic impacts of digitalisation, and in particular concerning four main aspects that affect workers, business owners, and the community. Impacts in this category are mostly positive for what concerns *labour*, *financial* and *management* aspects, while more disruptive changes affect the *market* models, especially when considering effects on small players.

Concerning *labour*, positive impact is the replacement of repetitive and seasonal labour, the presence of novel job opportunities associated with the usage of new technologies, but also the possibility of exploiting the network to gain access to a skilled workforce and decentralise the work structure. Undesired impact is mainly the possibility of unemployment, but also the need to cope with the change in work profiles.

[labour: replacement of repetitive labour] *And especially you will see a shift between low-skilled, repetitive labour to more technology-based labour where the dirty work is done by the machine. And the oversight and interpretation is still a task for people. That also means that the education becomes more and more important.*

[labour: unemployment] *We can think that robots will be able to alleviate heavy work and to overcome the difficulty to find working force when they will be more accessible. But on the other hand, some employees will not have work anymore.*

Financial aspects are generally positive for business owners, with more profits, reduction of costs, improved productivity especially thanks to the usage of data acquisition and monitoring systems, and the possibility of leveraging technology to scale-up with the same amount of labour.

[financial: improved productivity] *About the question of performances, a study was made few years ago on the use of milking robots. This work shows [...] that a great productivity gain was made with the intensive use of the digital data and a pretty modest gain for those who used it as a simple milking tool.*

From the *management* standpoint, the main beneficiaries are the large business owners, who can achieve better control at larger scale, optimise their resources and processes, deal with production irregularity thanks to the improved measurability granted by the sensing and monitoring technologies as well as the farm management platforms. Negative aspects are again concerned with the need to deal with change in terms of production models, and in terms of involved stakeholders.

[management: control at larger scale] *Also the monitoring is automated with this technology. And that will mean, that when farms get bigger they can still keep an overview of the farm.*

[management: better management of production irregularities] *Digital can help to manage production irregularity. If the farmer has an alert all along the production's process, he can adjust his position on the sector with more adapted specifications and better valorise his product on the final market.*

[management: change of stakeholders, change of production models] *Digital technologies are not just "tools" added to a farm; they thoroughly change farm management and practice. They demand therefore a revision of the actions of farmers and the interaction with stakeholders around it. Moreover, it also changes the types of stakeholders who are part of the social network around farms.*

Finally, the *market* also sees positive changes thanks to the availability of online booking services and the birth of novel energy-related services, e.g., with the usage of renewable sources. However, the effect on the market can be particularly negative for small business owners, with the closing of local business who cannot compete on the global market, the increased performance inequality with respect to large players who can profit from technology, and the creation of monopolies, as the digital world is characterised by a tendency towards these types of centralised market models.

[market: closing of local businesses] *online shopping can help rural communities obtain lots of goods without travelling, that they would not have been able to do beforehand, but at the same time it can mean that a shop in the village loses customers and has to close down.*

[market: creation of monopolies] *In addition, digital platforms as part of those ecosystems are usually having a disruptive impact as they follow a "first player wins the whole market" scenario, which is usually disruptive for other branches.*

Socio-political impacts. The socio-political impacts are all related to positive effects. They consider the following stakeholders: business owners, for what concerns aspects related to data, their value and control; the community and institutions, with improved legality thanks to mechanisms that facilitate transparency and regulatory compliance (e.g., blockchain, dematerialisation, process standardisation).

[data: improved transparency] *Blockchain is not revolutionary but it secures data access. It is a tool and all the issue is to give the feeling of protection, data security, monetarize it and give access.*

[institutional: improved legality] *In case of adoption of these new technologies (i.e., blockchain), as a consequence companies from these Countries could enter new (legal) markets thanks to their compliance with the European Union Timber Regulation (EUTR).*

Environmental impacts. The environment is assumed to benefit from the introduction of digitalisation and technological solutions, with reduction of human impacts, carbon emissions and improved animal welfare. No risks were explicitly discussed by the experts. The expected environmental impacts are strictly linked to the environmental drivers, which were previously discussed. We thus report only one fragment in this theme.

[reduction of carbon emission] *Digital allows to bring data together and sharing them optimise logistic and limit carbon emissions, cost and mobility.*

6. Discussion

Our results represent a catalogue of drivers, barriers and impacts, elicited from experts belonging to the ICT and social sectors. RE practitioners involved in the development of technological applications in the domain of rural areas should consider the list of themes and codes identified, and incorporate them in their RE activities, e.g., in the form of checklists to make evident which sustainability concerns are considered in the requirements specifications, or by mapping them into interview scripts for the elicitation of sustainability requirements. Our catalogue can be particularly useful in feasibility studies and to support fit-gap analysis. Given a digital technology, e.g., a smart irrigation system, to be applied in a rural context, the requirements analyst will first consult the catalogue of barriers and will check which ones apply to its case, e.g., *are demographic issues relevant? How is connectivity in the area?* Then, they will check which drivers could be leveraged, e.g., *is there funding that can be exploited?* Finally, they will evaluate the impact of the technology, e.g., *to what extent can my system improve regulatory compliance?* Once impacts are identified, an explicit connection between these and the Sustainable Development Goals (SDGs) of the United Nations (UN)[8]—as done, e.g., by Herrero et al. [10]—can form a clear argument for the promotion of the technology itself.

The catalogue can be used also for the design of a novel solution. For example, in one of the DESIRA Living Labs, we aim to co-design a system to involve citizens and business owners in the ordinary maintenance of a mountain area in Tuscany, Italy. Before getting into the use case workshops in which co-design is carried out (Section 2),

[8] SDGs described at: https://sdgs.un.org/goals

we first perform domain analysis. In this activity, we consider the list of barriers, and interview stakeholders to confirm those that are applicable to the context (e.g., *sparse population, connectivity*), exclude those that are not relevant for our case (e.g., *paradox of choice*), and identify specific ones (e.g., *competition between business owners*). By consulting the list of potential negative impacts (e.g., *loss of expertise, change in work profiles*), we can also plan for the long term evolution of the product, while expected positive impacts (e.g., *inclusion*) can be used to claim funding.

A specific RE method with detailed guidelines is out of the scope of the current paper, as is part of future work. In the following, instead, we summarise identified barriers, drivers and impacts, and we relate them with previous literature.

Barriers. Barriers to digitalisation in rural areas are mostly *socio-cultural*, and in particular demographic issues related to aging and sparse population. Technology requires skilled users that are less frequent among older people, as well as exchange of technological knowledge, which is made difficult in a highly distributed and scarcely populated context. Demographic factors were already observed to be crucial aspects for technology adoption by the literature review on precision agriculture by Pierpaoli et al. [51], as well as the more recent survey by Paustian et al. [52].

Rural communities also tend to rely on traditional values, and having negative sentiments towards novelty. These sentiments include *distrust*— especially towards all those parties that are regarded as external to the rural environment, namely funders, regulators, and ICT suppliers—and *fear*. This is directed towards the concrete possibility of becoming dependent from the technology, but also of unknown angles, such as hidden costs of technology and data ownership. Negative sentiments are not helped by the inherent complexity of technology and regulations, and by the lack of ICT skills in rural areas. The relevance of traditional values and their potential negative influence on technology adoption was confirmed by Regan [53] in an interview study with smart farming experts in Ireland. Educational barriers in terms of lack of training were also noted in the past, e.g., by Robertson et al. [54] in a study on precision agriculture, and still appear to be relevant according to our experts. Finally, the need to address trust issues were remarked by Van der Burg et al. [55] in a study about ethics in smart farming.

Technological barriers are also particularly relevant, and, most of all, *connectivity*. Without Internet connection, isolation is amplified as well as the possibility of using all those sensing technologies that rely on connectivity to properly function, such as cloud-based sensor networks and IoT platforms in general, as observed by Bacco et al. [8] in a survey of digital technologies for smart farming. Other relevant technical barriers are to the need to adapt technologies to ergonomic requirements of fields and forests. These require rugged devices that can be operated with gloves, possibly through voice interaction, and that resist to corrosion and adverse environmental conditions in general. While studies exist on ergonomics for agriculture that take into account physical tools and machines (see, e.g., the recent survey by Benos et al. [56]), we are not aware of similar works in RE for digital systems.

Economic barriers are the *costs* of technology adoption, as well as scarce evidence of cost-effectiveness of certain solutions. Rural areas are often characterised by small players and atomised business structures, which cannot take advantage of the economies of scale favoured by the deployment of a technological infrastructure. The challenge of cost was also highlighted by Barnes et al. [57], who identify it as first barrier for the adoption of precision agriculture. Instead, the need to provide evidence of the return of investment in specific contexts was noted by an earlier study of Barnes et al. [58] and by Regan et al. [53].

Finally, barriers are also *regulatory-institutional*, especially in relation to data management. Issues around data ownership were widely discussed also by previous literature focused on smart farming and the agrifood sector in general [53,55,58–61]. As observed by Van der Burg et al. [55], farm data are not personal data in strict sense, still they are valued so by farmers because farm business and household are traditionally viewed as 'one-and-the-same economic unit'. The data ownership concerns of farmers, and their observed distrust towards regulators and ICT providers, are indeed exacerbated by the absence of clear policies for the management of farm data that can be collected by digital platforms. Carbonnell et al. [62] suggests to adopt open data policies, as a way to respect the people's right to access information. Still, Schroeder et al. [60] remarks the need for transparent data policies, in which the usage of data is made clear to farmers, and technology providers are accountable for how they use them.

> The main barriers for adoption of digital technologies are socio-cultural, and especially demographic and educational issues. Connectivity is the most important technical concern. Cost of technology adoption is the main economic barrier. Unclear data ownership is the main regulatory-institutional challenge.

Drivers. While the majority of barriers are socio-cultural, main drivers are *economic*. The primary relevance of economic aspects was also observed in previous studies focused on precision agriculture [57], and it is evident also from the analysis of policy documents by Lajoie-O'Malley et al. [63]. Technology is expected to facilitate access to fine-grained information about resources, e.g., soil, plants and animals, to address *business needs* such as greater control of production, better optimisation and better planning. On the other hand, technology is pushed also by external factors, such as *market demands* for higher competition, but also for greener and transparent image. This can be facilitated by precision agriculture oriented to use less fertilisers, and other digital means, e.g., blockchain, to support food and wood traceability. Other important drivers are *organisational*, as there are forms of organisation such as cooperatives that can facilitate small players in sharing the cost of technological change. In addition to that, technology mediators can facilitate access to novel digital solutions. The relevance of mediators, and in particular advisory services, was observed to be crucial by Busse et al. [64] in an interview study on precision farming in Germany.

Economic drivers are complemented by *regulatory-institutional* ones, as restrictions on the usage of certain fertilisers, together with the need for product certification, pushes farmers to introduce technologies that provide evidence that regulations are respected. Economic incentives for technology adoption coming from institutions are also key enablers, paired with educational support. The importance of subsidies and taxation as main enablers was also observed by Barnes et al. [57], and the role of institutions in general is remarked also in a recent book by Shroeder et al. [60] focused on digitalisation in agrifood.

Regulatory-institutional drivers are tightly connected with *environmental* ones, with the need of reducing the impact of the human footprint, counterbalanced by the urge to better control the environment, for example from natural disasters. Overall, environmental drivers have been observed to be considered as secondary aspects, as primary concerns are related to profitability for farmers [58], and even for policy makers [63].

Some important factors are also *socio-cultural*. As observed, some people resist to change, while others are technological enthusiasts, and can play the role of 'technology sponsors', which can be effective in a community where the need for inclusion is high. The presence of these enthusiast is confirmed by the study of Paustian and Theuvsen [52], who performed a questionnaire with German farmers, and showed that people with low experience in crop farming—less than 5 years, supposedly younger people—were more inclined to adopt smart farming technologies. Practical needs such as reducing heavy workload and improve work flexibility are also drivers for the technological change.

💡 Main drivers are economic, and the need to increase revenue and control of production. They are paired with regulatory-institutional drivers, including taxes, subsidies, economic incentives and the diffusion of digital innovation centres. Socio-cultural drivers come from young technology enthusiast. Less explicit are environmental drivers.

Impacts and entities. Discussed impacts have a strong social dimension, with *socio-economic* aspects dominating the scene. Business owners can improve their productivity by achieving better management of their processes, and by lowering the costs of labour through the replacement of manual activities with automatic ones. Large business owners can also take advantage of the economies of scale facilitated by technological infrastructures. On the other hand, while large players tend to be privileged by digitalisation, small ones risk to be ruled-out by a market in which they cannot compete, or to be incorporated by larger companies. Communities can suffer from these phenomena with the closing of local businesses, and with unemployment. The disparity between small and big players, accompanied by the risk of inequitable development is a topic of discussion in the literature [53,59]. The size of a farm was observed to positively influence the adoption of precision agriculture [51], and the logistic regression analysis by Paustian et al. [52] empirically confirmed this intuition, showing that technology adopters tend to have more than 500 hectares of arable lands.

From the *socio-cultural* perspective, positive expected impacts affect the rural communities as a whole. Among these positive impacts are the increased inclusion, mostly driven by connectivity, and the greater well-being due to more free time and less heavy work. The mere presence of Internet connection can make rural areas more attractive, and can facilitate access to distant learning to acquire the missing skills needed to introduce novel technologies. On the other hand, the risk of exclusion for those subjects who cannot or do not want to use technology is high. In addition, a community that uses digital means as interface to the environment risks losing expertise and detaching from nature. Positive socio-cultural impacts are confirmed by the survey of Regan [53], especially in terms of greater well-being achieved by reduction of burdensome jobs, and improved time management. The same study also confirms our findings that negative impacts include the over-reliance on technology, with consequent loss of skills, as well as the potential distancing and isolation of farmers from animals and community.

Other observed impacts are at the *socio-political* level. These favour large business owners, the community and institutions alike. For example, improved control on data about a certain farm, or about the origin of wood, can facilitate assessment by government and thus improve legality, as remarked by other studies [60]. Finally, from the *environmental* standpoint, technology facilitates precision and control, thus reducing the human impact on vegetation and animals in the long-term. The positive impact on the environment and animals was also observed by other works, especially in relation to IoT technologies [17,65].

💡 Main impacts are socio-economic, with replacement of manual work and the possibility to leverage economies of scale. Socio-cultural impacts include greater well-being, improved technical skills, but also loss of practical expertise due to dependency from technology. Positively impacted entities are large business owners, the natural environment, and institutions. Negatively impacted ones are small players and manual workers who risk unemployment.

7. Conclusion

Sustainability requirements are quality concerns that requirements engineers shall take into account when transforming existing socio-cyber–physical contexts through the introduction of novel digital technologies. These requirements involve mid- to long-term effects that the system can have on the context in which it is deployed. In this paper, we perform an interview study involving 30 sustainability-aware experts with background in ICT and social-science in the domain of rural areas. Our study aims to elicit *drivers*, *barriers* and *impacts* of digitalisation in rural areas, considered according to different sustainability dimensions. These concepts are regarded as having a wider temporal perspective with respect to stakeholders' goals normally discussed in RE, and we consider them to be the right lenses to analyse sustainability aspects. From the analysis of the interviews, we classify 14 barriers, 15 drivers, and 10 types of impact, divided into different sustainability categories adapted from previous literature [4,26,36,44], e.g., socio-cultural, economic, regulatory-institutional, environmental, *etc.* According to the experts, the main barriers are socio-cultural, drivers are mostly economic, and impacts are balanced between social and economic aspects. Our findings can be useful to RE practitioners that deal with system development in rural areas, such as applications in digital farming [8], smart villages [7], and smart forestry [66].

This paper is part of a larger endeavour carried out within the H2020 DESIRA project. In future work, we plan to confirm and extend the provided conceptual meta-model through the analysis of interviews and focus groups coming from the DESIRA Living Labs, which involve farmers and other rural area stakeholders. This analysis will help to identify *patterns* of driver, barriers and impacts, to go beyond the catalogue presented in this paper, and consolidate the meta-model as a whole. Particular attention will be devoted to the identification of *negative impacts* and *environmental* aspects in general, and accounting also for ambivalent factors [67]. At this stage, the general discussion with experts only touched upon these issues, while we believe that a more concrete perspective, such as the one available in the Living Labs, can facilitate the enrichment of the framework in this direction. As part of future work, we also aim to develop an RE method specifically designed with sustainability as a primary concern. To this end, we plan to extend existing goal-oriented RE approaches to incorporate the concepts of drivers, barriers and impacts, and their explicit tracing with the UN Sustainable Development Goals (SDGs).

CRediT authorship contribution statement

Alessio Ferrari: Conceptualisation, Methodology, Formal analysis, Writing – original draft, Project administration. **Manlio Bacco:** Writing – original draft, Methodology, Supervision, Project administration. **Kirsten Gaber:** Writing – review & editing, Validation, Investigation. **Andreas Jedlitschka:** Writing – original draft, Investigation. **Steffen Hess:** Writing – review & editing, Investigation. **Jouni Kaipainen:** Writing – review & editing, Investigation. **Panagiota Koltsida:** Writing – review & editing, Investigation. **Eleni Toli:** Writing – review & editing, Investigation. **Gianluca Brunori:** Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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