land

MDPI

Article

Assessing the Constraints to and Drivers for the Adoption and Diffusion of Smart XG, Last-Mile Connectivity and Edge Computing Solutions in Agriculture: The Case of Digital Shepherds in Flanders, Belgium

Max López-Maciel [1,*], Peter Roebeling [1], Katrine Soma [2] and Jeremie Haumont [3]

[1] Centre for Environmental and Marine Studies (CESAM), Department of Environment & Planning (DAO), University of Aveiro (UA), 3810-193 Aveiro, Portugal; peter.roebeling@ua.pt
[2] Wageningen Social & Economic Research, Wageningen University and Research (WUR), Droevendaalsesteeg 4, 6706 KN Wageningen, The Netherlands; katrine.soma@wur.nl
[3] Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Burgemeester van Gansberghelaan 115, 9820 Merelbeke, Belgium; haumontjeremie@hotmail.com
* Correspondence: max@ua.pt

Abstract: Advanced generations of mobile network technologies (XG), last-mile connectivity and edge computing solutions can offer invaluable support for farmers and agribusinesses, fostering sustainable development, though unequal access to these digital technologies may lead to a digital divide. It remains, however, unclear to what extent and why farmers are (not) ready to adopt digital technology solutions in agricultural production systems. Hence, this study identifies and assesses the constraints on and drivers for the adoption and diffusion of smart XG, last-mile connectivity and edge computing solutions in agricultural production systems, using the Adoption and Diffusion Outcome Prediction Tool (ADOPT) in a stakeholder workshop setting. Results for the case of the 'digital shepherd' in Flanders (Belgium) show that there is substantial potential for its adoption (~40% of the target population) and diffusion (~15 years to peak adoption). To motivate farmers to adopt the 'digital shepherd', its profitability, environmental benefits and management convenience are pivotal; to accelerate adoption of the 'digital shepherd', its trialability and evaluability, as well as farmers' skills and knowledge, are pivotal. Addressing these factors can significantly reduce the risk of a digital divide and, hence, allow policy makers to define corresponding strategies.

Keywords: adoption; diffusion; digital divide; XG; last-mile connectivity and edge computing solutions; prediction model; livestock production systems; stakeholder engagement

check for updates

Academic Editor: Hossein Azadi

Received: 8 January 2025
Revised: 26 February 2025
Accepted: 27 February 2025
Published: 5 March 2025

Citation: López-Maciel, M.; Roebeling, P.; Soma, K.; Haumont, J. Assessing the Constraints to and Drivers for the Adoption and Diffusion of Smart XG, Last-Mile Connectivity and Edge Computing Solutions in Agriculture: The Case of Digital Shepherds in Flanders, Belgium. *Land* **2025**, *14*, 543. https://doi.org/10.3390/land14030543

1. Introduction

Societies around the world are increasingly affected by the vast growth of information and new and rapid developments in technology, networks and social media. The Digital Age is characterised by enhanced opportunities for monitoring and control, for precision and efficiency, for maximising economic development and for minimising impacts on the environment By means of Artificial Intelligence (AI), robotics, and the Internet of Things (IoT), the latest technologies can offer invaluable support for farmers and agribusinesses. However, an issue of concern from a social sciences perspective is the risk of a digital divide—i.e., unequal access to and benefits from digital technology opportunities that are explained by contextual challenges.

Contextual challenges have been addressed in different ways. Weerabahu et al. [1] investigated the challenges of digital supply chains' (Industry 4.0) adoption by organisations. They found four categories of potential contextual obstacles, including (1) technical/technology factors, (2) financial, energy and legal factors, (3) inter-organisational factors and (4) intra-organisational factors. David et al. [2] studied the adoption challenges of digital technologies for various local government activities that potentially could enhance service efficiency, effectiveness and accountability. They found that some barriers were related to the lack of understanding of the effects of using these technologies, as well as the lower availability of public participation platforms, employees' skills and positive mindsets. Also, process-related aspects were found to be important, such as clearly recognised roles, aims, procedures and regulations and ways to receive user input. Contextual challenges were also investigated for education, which is a context where interactions traditionally take place face to face [3]. Whereas information accessibility beyond physical spaces is seen as important for inclusive learning environments, it is found that a one-size-fits-all approach does not work because of the diversity of learners and different abilities. Mhlanga et al. [4] conducted a study examining trends and rates of digital technological transformation in a typical African agricultural context with smallholder communities. In such contexts, resource scarcity, limited expertise and training, a lack of digital infrastructure, data privacy and security concerns and resistance by farmers were found to be the main challenges. To overcome these, efforts by the public and private sectors, as well as communities, are urgently needed. To explore contextual technological, environmental and organisational factors in developing countries, specifically in Bangladesh [5], influential factors were identified for the adoption of digital technologies among small and medium-sized enterprises. They found that relative advantage, complexity and observability factors were critically important, as well as competitive pressure, management support and governmental support. Al-Emran et al. [6] explain that digital technologies and innovative solutions play a crucial role in promoting sustainable development, although sustainability outcomes can be positive and negative. While these studies provide insights of relevance to this study, the contextual challenges and opportunities investigated in this study specifically address European farmers and the factors influencing their willingness to adopt new technologies.

New opportunities are provided by smart XG, last-mile connectivity and edge computing solutions. The next advanced generation of mobile network technologies, referred to as XG, allow higher internet speeds, lower latencies and a higher number of connected devices [7]. This allows individuals to better leverage the potential of novel technologies, such as IoT, robotics, drones and Artificial Intelligence (AI) in more remote areas and applications such as agriculture [7]. Currently, 4G is advancing to 5G, while 6G is about to evolve in the near future [8]. Last-mile connectivity refers to the final stretch of telecommunications networks that delivers corresponding services to end users' premises [9]. The efforts to cover the last stretches of land in a region, or to provide the highest quality connection to every household or access point, are typically vast, which is why this last-mile connectivity is a challenging endeavour. Even with enhanced connectivity provided to rural areas, human intervention appears to be equally essential to bridge the last mile, to provide knowledge and to avoid unintended consequences and opportunity costs [10]. At the edge of the network, close to the source of the data, edge computing can also provide a solution, as it allows computing, storage and other capabilities to provide intelligent services in close proximity to the data source [11]. For example, already analysed data can be transferred through the network, instead of raw data, requiring lower bandwidth consumption. Edge computing solutions refer to an innovative network paradigm, which pushes mobile computing and storage resources to the network edge, enhancing the trade-off between computation-intensive and latency-critical tasks [12]. XG and edge computing can result in the provision of connectivity to, for instance, remote areas suffering from disconnection to online services. This has a particularly interesting potential for agriculture, where in recent years there has been a booming development of precision agriculture and precision livestock farming applications [13,14]. However, the extent to which this is happening depends on farmers' willingness to adapt their existing practices to new ways of farming, making use of advancements in technologies and agricultural practices.

The Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) and the XGain project team [15] are conducting research on facilitating access by relevant stakeholders to a comprehensive inventory of smart XG, last-mile connectivity and edge computing solutions, so as to foster a sustainable, balanced and inclusive development of rural, coastal and urban areas. In Flanders, most livestock farms are family-run operations with, on average, ~28 hectares, and fields that are dispersed across neighbouring villages. Although connectivity is generally good in Flanders, there are differences between regions. In dairy production, unequal access to technologies can already be observed between intensive no-grazing production systems and more extensive grazing production systems [16]. The 'digital shepherd' is an important example of such a smart XG, last-mile connectivity and edge computing solution and is intended to support livestock farmers' daily operations [17]. Real-time monitoring services allow for animals to be observed on pastures, capturing relevant animal risk, health and welfare issues for the farmer, as well as generating targeted alerts. The 'digital shepherd' is expected to have a direct impact on the productivity and welfare of the livestock but also to reduce stress for the farmer. Cameras are installed at the border of the pasture, and with edge computing and AI, the location and behaviour of the animals is monitored at every moment, at a herd or individual-animal level (e.g., close monitoring of a potentially sick animal; [18]).

However, it remains unclear to what extent farmers are ready to adopt the 'digital shepherd'. The risk is that only the most wealthy or tech-savvy farmers will invest in the new technology, which in the long term would lead to an increased digital divide and inequalities within the agricultural sector in Europe [19,20]. It is acknowledged that with the right insights about how and when farmers will adopt these new technologies, it is possible to influence this by targeted measures [21,22]. Knowing which the factors contribute to increased uptake, and to what extent, can assist in transitioning towards a society with an enhanced inclusiveness of farmers that benefit from the Digital Age [23,24].

Hence, the objective of this study is to identify and assess the main constraints on and drivers for the adoption and diffusion of smart XG, last-mile connectivity and edge computing solutions in agricultural production systems. To this end the Adoption and Diffusion Outcome Prediction Tool (ADOPT, [25]) is developed and applied in a workshop setting with participants from relevant industries, ministries, extension services and research and innovation. A case study is provided for the 'digital shepherd' in Flanders, Belgium, so as to not only obtain insights into the potential for adoption and diffusion of the 'digital shepherd' but also to assess the importance of the factors influencing the adoption and diffusion of the 'digital shepherd'.

This study contributes to previous studies by assessing to what extent farmers are ready to adopt smart XG, last-mile connectivity and edge computing solutions in agricultural production systems, thus pre-empting the potential risk of inequalities across the agricultural sector in Europe. The developed approach allows for (i) the early identification of factors contributing to a digital divide, such as financial constraints, education and access to support services and information; (ii) the assessment of the extent to which these factors constrain the adoption and diffusion potential of these high-tech solutions; and, hence, (iii) the prioritisation of actions and the definition of strategies to reduce the digital divide. Finally, as ADOPT addresses the environmental, social and economic sustainability dimensions of innovations that potentiate digital transitions, this approach can work as a tool to bridge understanding between the agricultural sector and policy makers.

The remainder of this paper is structured as follows. In Section 2, the ADOPT tool and sensitivity analysis methods are presented, followed by, in Section 3, the results for the adoption and diffusion of the 'digital shepherd' in Flanders, Belgium. In Section 4, the results are discussed, the main findings presented and caveats addressed. Finally, Section 5 provides some concluding remarks and policy recommendations.

2. Materials and Methods

The adoption and diffusion of innovations is influenced by a wide range of factors, most prominently and influentially classified in the diffusion of innovations (DoI) theory by Rogers [26]. In particular, Rogers conceives the following five main elements of diffusion:

- Characteristics of the adopters, including orientation, motivation and abilities/skills;
- Characteristics of the innovation, including its relative advantage, compatibility, complexity, trialability and observability;
- Communication channels, referring to the different means (from interpersonal to mass media) by which individuals receive messages from each other;
- Time needed to observe, learn and experiment with the innovation;
- Social system, described as the interrelationships between adopters looking to solve a common problem to reach a collective goal.

There are numerous studies that assess the wide range of factors influencing the adoption and diffusion of agricultural innovations (see, e.g., [21,27,28]), which form the basis for the Adoption and Diffusion Outcome Prediction Tool (ADOPT) that provides predictions of an innovation's level of adoption and rate of diffusion, as well as estimates as to the importance of the factors influencing adoption and diffusion (see [25]).

2.1. The Adoption and Diffusion Outcome Prediction Tool (ADOPT)

ADOPT is a web-based tool developed by the Commonwealth Scientific and Industrial Research Organisation (CISRO), along with other Australian laboratories and academic institutions (see [25]). It is, amongst others, based on concepts explained by the DoI theory [26], considering four categories (quadrants) that are of influence on adoption:

1. Relative advantage for the population (Quadrant Q1);
2. Learnability characteristics of the innovation (Quadrant Q2);
3. Population-specific influences on the ability to learn about the innovation (Quadrant Q3);
4. Relative advantage of the innovation (Quadrant Q4).

ADOPT uses different interaction variables, including those related to profit, risk and environmental outcomes, farmer networks, characteristics of the farm and the farmer and the ease and convenience of the innovation, which are captured in 22 variables divided over the abovementioned four main quadrants (see Figure 1; [25]). The corresponding 22 questions (described in Appendix A) are correlated, creating different intermediate variables, with the objective to reach two central values in the prediction scenario: the Peak Adoption Level (PAL) and the Time to Peak Adoption Level (TPAL).

The Peak Adoption Level (PAL) is dependent on the intermediate variable relative advantage, which is based on 14 independent variables in the two relative advantage quadrants, Q1 (relative advantage for the population) and Q4 (relative advantage of the innovation). Relative advantage is dependent on the profit advantage, environmental advantage, risk, ease and convenience and investment costs of the innovation, in combination with characteristics of the farm and the farmer.

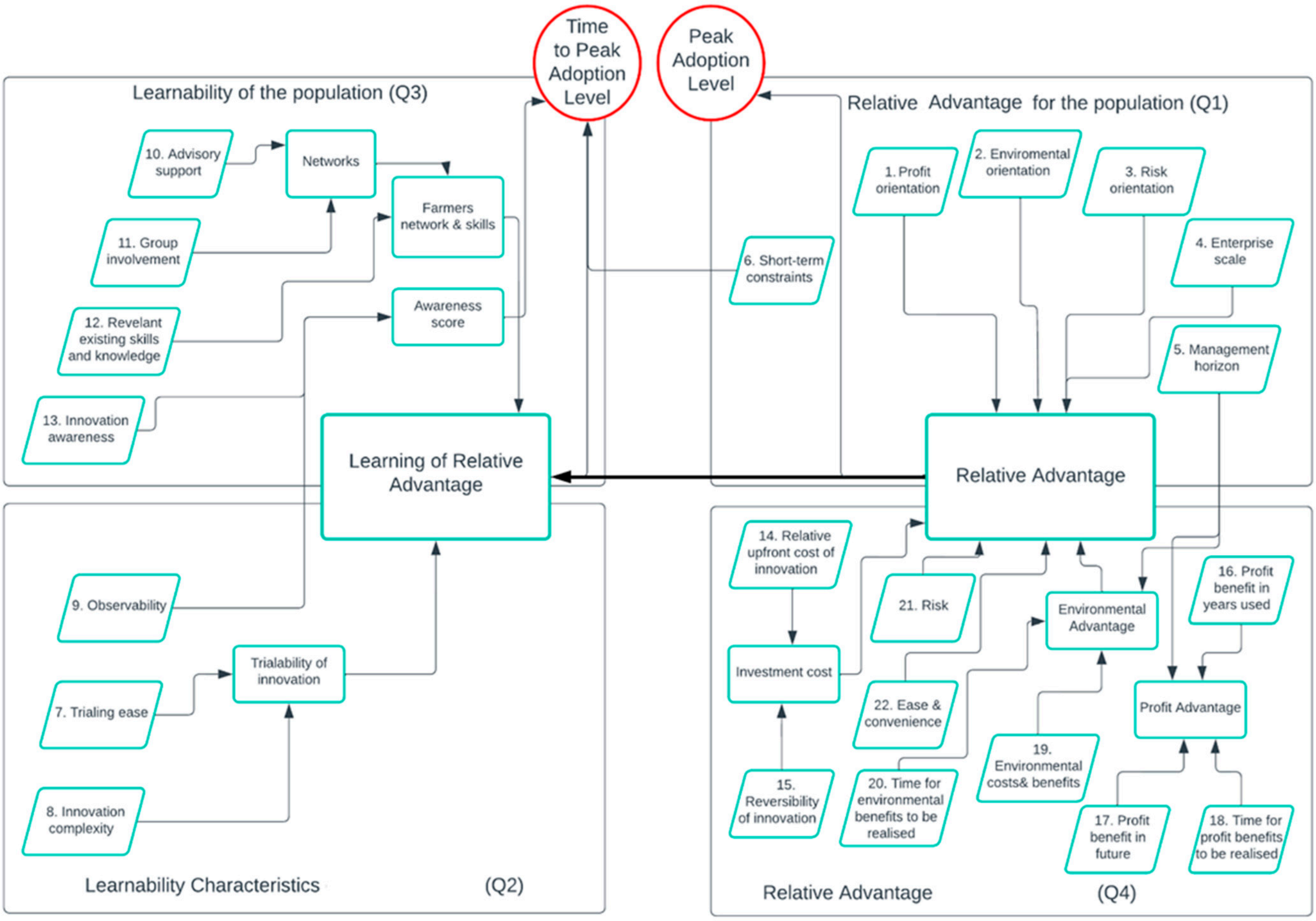

Figure 1. ADOPT quadrants, their relationships to the 22 questions and their influences on Peak Adoption Level and Time to Peak Adoption (source: Reprinted with permission from [29]; adapted from [25]).

The Time to Peak Adoption Level (TPAL) is dependent on the intermediate variables awareness, learning of relative advantage, relative upfront costs and short-term constraints, which are based on 9 independent variables in, mainly, the two learning quadrants, Q2 (learnability characteristics of the innovation) and Q3 (population-specific influences on the ability to learn about the innovation). Learning of the relative advantage is dependent on farmer networks and skills and the trialability of the innovation.

ADOPT (Version 2.1) has been validated using six specific agricultural innovations and populations with known complete or near-complete adoption outcomes (see [25]). The model shows a good fit (predicted vs. actual) for PAL and TPAL.

ADOPT is intended to be used before or during the early stages of the adoption and diffusion process and is generally applied in a workshop setting, with professionals working with farmers. Participants discuss each question and justify their responses, particularly for those questions where consensus is low. Questions that show a low consensus are identified, and sensitivity analyses are performed to assess how different possible responses may affect adoption and diffusion outcomes.

2.2. Sensitivity Analysis

To assess the extent to which the PAL and TPAL are sensitive to changes in the 22 ADOPT question scores, a sensitivity analysis is performed (following [29]). Thus, scores for each question are decreased/increased one level, and corresponding changes in PAL and TPAL recorded. Consequently, the effect of this decrease/increase in the response for each variable shows the effect on PAL and TPAL with all other variables unchanged.

3. Results

On 18 April 2023 a 'livestock and farming mutual learning and co-creation workshop' was organised at the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) in Merelbeke (Belgium), including participants (19) from the Ministry of Agriculture and Fisheries in Flanders (2), farmer advisory services (2), technology and IT companies (2), ILVO (6), Wageningen Research (1), the University of Aveiro (2), and other research and education organisations (incl. universities) (4). The workshop programme included sessions on (i) sharing knowledge about technological innovations, (ii) assessing barriers to the adoption of technological innovations (ADOPT session) and (iii) building a community for technological innovations. The ADOPT session was organised in two parts: the first part (75 min) providing an introduction to ADOPT (10 min) and discussing and responding to the ADOPT questions (65 min); the second part (45 min) presenting and discussing the preliminary results based on the responses obtained in the first part. The ADOPT variable, question and answer descriptions by quadrant, as used during the workshop, are provided in Appendix B. This section provides the case study description (Section 3.1), descriptive statistics (Section 3.2) and workshop results (Section 3.3).

3.1. Case Study Description

The innovation considered in this ADOPT workshop was related to livestock farming in Flanders, Belgium. Flanders is a densely populated area, with communication infrastructure in place. However, even within Flanders, there are differences in connectivity between different areas, providers and devices. Traditionally, Flanders is very active in the farming industry, but the available arable lands and pastures of each farmer are spread across multiple smaller fields in the same, or neighbouring, villages. Already, a digital divide can be observed between extensive and intensive livestock farming. The XGain scope aims to address this void by developing a 'digital shepherd' (i.e., the innovation), in the form of a camera system in the field that monitors the herd on pastures of a relatively small size in densely populated and relatively well-connected areas.

The 'digital shepherd' will support the farmers' daily operation (e.g., livestock monitoring), considering areas with both strong and poor network coverage. Real-time monitoring services will ensure animals (cows/sheep) are always observed, capturing relevant events with a risk of health and welfare issues, as well as generating targeted alerts for the farmer. Cameras at the borders of fields will monitor the behaviour of the animals at every moment with AI algorithms running on edge processing units. Successful implementation of the 'digital shepherd' will improve livestock health and welfare and result in a reduction in animal and farmers' stress.

3.2. Descriptive Statistics

The workshop participants' answers (average; standard deviation) to the 22 ADOPT multiple choice questions are shown in Table 1. From the responses to quadrant Q1 (relative advantage for the population), it can be observed that the majority of livestock farmers are considered to be profit/utility maximisers and about half are considered to be risk minimisers, have a long-term planning horizon and hold a major enterprise that could benefit from the innovation, while only a minority are considered to face severe short-term financial constraints or have protection of the environment as a strong motivation. From the responses to quadrant Q2 (learnability characteristics of the innovation), it can be observed that the innovation is considered to be moderately trialable, evaluable and observable. From the responses to quadrant Q3 (population-specific influences on the ability to learn about the innovation), it can be observed that about half of the livestock farmers are considered to use relevant advisors, are involved in relevant farmer-based groups and would need new skills/knowledge; only a minority are considered to be aware of the use/trialling of the innovation. Finally, from quadrant Q4 (relative advantage of the innovation), it can be observed that the innovation is considered to provide small recurrent and future profit and environmental benefits, management ease and convenience, and a reduction in risk.

Table 1. ADOPT questions, answers and standard deviation (Std. dev.).

	Question	Answer	Std. Dev.
Relative advantage for the population (Q1)			
1.	What proportion of the target population has maximizing profit as a strong motivation?	4. A majority have maximizing profit/utility as a strong motivation	0.6
2.	What proportion of the target population has protecting the natural environment as a strong motivation?	2. A minority have protection of the environment as a strong motivation	0.6
3.	What proportion of the target population has risk minimisation as a strong motivation?	3. About half have risk minimisation as a strong motivation	0.6
4.	On what proportion of the farms is there a major enterprise that could benefit from the 'digital shepherd'?	3. About half of the target population has a major enterprise that could benefit	0.8
5.	What proportion of the target population has a long-term (more than 10 years) planning horizon for their farm?	3. About a half have a long-term planning horizon	0.8
6.	What proportion of the target population is under conditions of severe short-term financial constraints?	4. A minority currently have severe short-term financial constraints	0.6
Learnability characteristics of the innovation (Q2)			
7.	How easily can the 'digital shepherd' (or significant components of it) be trialled on a small scale before a decision is made to adopt it on a larger scale?	3. Moderately trialable	1.1
8.	Does the complexity of the 'digital shepherd' allow effects of its use to be easily evaluated when it is used?	3. Moderately difficult to evaluate effects of use due to complexity	0.8
9.	To what extent would the 'digital shepherd' be observable to farmers who are yet to adopt it when used in their area?	3. Moderately observable	1.2
Population-specific influences on the ability to learn about the innovation (Q3)			
10.	What proportion of the target population uses paid advisors capable of providing advice relevant to the 'digital shepherd'?	3. About a half use a relevant advisor	1.0
11.	What proportion of the target population participates in farmer-based groups that discuss this type of innovation ('digital shepherds')?	3. About half are involved with a group that discusses 'digital shepherds'	0.9
12.	What proportion of the target population will need to develop substantial new skills and knowledge to use the 'digital shepherd'?	3. About half will need new skills and knowledge	0.8
13.	What proportion of the target population would be aware of the use or trialling of 'digital shepherds' in their area?	2. A minority are aware that it has been used or trialled in their area	1.2

Table 1. *Cont.*

	Question	Answer	Std. Dev.
Relative advantage of the innovation (Q4)			
14.	What is the size of the up-front cost of the investment relative to the potential annual benefit from using the 'digital shepherd'?	3. Moderate initial investment	0.4
15.	To what extent is the adoption of the 'digital shepherd' able to be reversed?	4. Easily reversed	1.0
16.	To what extent is the use of the 'digital shepherd' likely to affect the profitability of the farm in the years during its implementation and use?	5. Small profit advantage in the years that it is used	0.8
17.	To what extent is the use of the 'digital shepherd' likely to have additional effects on the future profitability of the farm?	5. Small profit advantage in the future	0.8
18.	How long after the 'digital shepherd' is first adopted would it take for effects on future profitability to be realised?	4. 1 to 2 years	0.7
19.	To what extent would the use of the 'digital shepherd' have net environmental benefits or costs?	5. Small environmental advantage	1.5
20.	How long after the 'digital shepherd' is first adopted would it take for the expected environmental benefits or costs to be realised?	5. Immediately	1.1
21.	To what extent would the use of the 'digital shepherd' affect the net exposure of the farm to risk?	5. Small reduction in risk	1.0
22.	To what extent would the use of the 'digital shepherd' affect the ease and convenience of the management of the farm in the years that it is used?	5. Small increase in ease and convenience	1.5

The standard deviation analysis revealed considerable degrees of disagreement in relation to the following: (1) the extent to which the 'digital shepherd' is observable to farmers who are yet to adopt it when used in their area (question 9), (2) the proportion of the target population that would be aware of the use or trialling of the innovation in their area (question 13), (3) the extent to which the use of the 'digital shepherd' has net environmental benefits or costs (question 19), and (4) the extent to which the use of the innovation will affect the ease and convenience of the management of the farm in the years that it is used (question 22). From the corresponding discussion with workshop participants, it became clear that the 'digital shepherd' is in the early stages of the adoption and diffusion process—with currently only very limited experimental trials (at ILVO grounds) and little concrete insights on the environmental, economic and management advantages, costs and benefits.

3.3. Results on Adoption Metrics

3.3.1. Peak Adoption Level and Time to Peak Adoption Level

Based on the workshop participants' answers (see Table 1), which were analysed using ADOPT, the Peak Adoption Level (PAL) is estimated at 40% of the target population (see Figure 2). The Time to Peak Adoption Level (TPAL) is estimated at 15 years.

To comprehend the PAL, the ADOPT quadrants Q1 (relative advantage for the population) and Q4 (relative advantage of the innovation) need to be analysed (see Figure 1). Regarding the 'relative advantage for the population' (Q1), this relates to the motivations and orientations of the target population, which are generally difficult to change in the short run. It is, however, clear that profitability and risk are important considerations for farmers, and that there is considerable potential to implement the 'digital shepherd' on their farms. Regarding the 'relative advantage of the innovation' (Q4), positive, though small, profit, environmental, risk and farm management benefits from the 'digital shepherd' are expected. The combination of these aspects explain the average (40%) PAL.

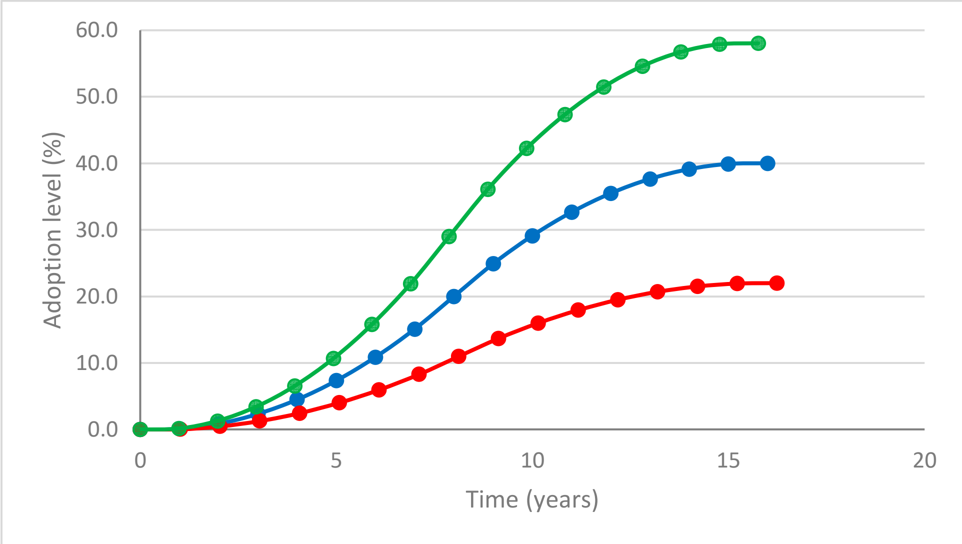

Figure 2. Adoption level curve from ADOPT for original (blue) and single step-up (green) and step-down (red) for the most sensitive question (question 16).

To comprehend the TPAL, in particular the ADOPT quadrants Q2 (learnability characteristics of the innovation) and Q3 (population-specific influences on the ability to learn about the innovation) need to be analysed (see Figure 1). Regarding the 'learnability characteristics of the innovation' (Q2), the moderate trialability, evaluability and observability of the 'digital shepherd' by farmers is noted. Regarding 'population-specific influences on the ability to learn about the innovation' (Q3), about half of all farmers are considered to use advisory services, are involved in relevant farm-based groups and will need new skills, while only a minority of farmers are considered to be aware of the use or trialling of the 'digital shepherd'. Both these aspects explain the relatively long (15 years) TPAL.

3.3.2. Interpretation of Sensitivity Analysis

The sensitivity analysis on all questions shows that the Peak Adoption Level (PAL) is mostly influenced by the following (see Figure 3):

- Question 16 (To what extent is the use of the 'digital shepherd' likely to affect the profitability of the farm in the years during its implementation and use?): up to +20%-point increase in PAL;
- Question 17 (To what extent is the use of the 'digital shepherd' likely to have additional effects on the future profitability of the farm?): up to +18%-point increase in PAL;
- Question 19 (To what extent would the use of the 'digital shepherd' have net environmental benefits or costs?): up to +16%-point increase in PAL;
- Question 4 (On what proportion of the farms is there a major enterprise that could benefit from the 'digital shepherd'?): up to +15%-point increase in PAL;
- Question 22 (To what extent would the use of the 'digital shepherd' affect the ease and convenience of the management of the farm in the years that it is used?): up to +15%-point increase in PAL;
- Question 21 (To what extent would the use of the 'digital shepherd' affect the net exposure of the farm to risk?): up to +15%-point increase in PAL.

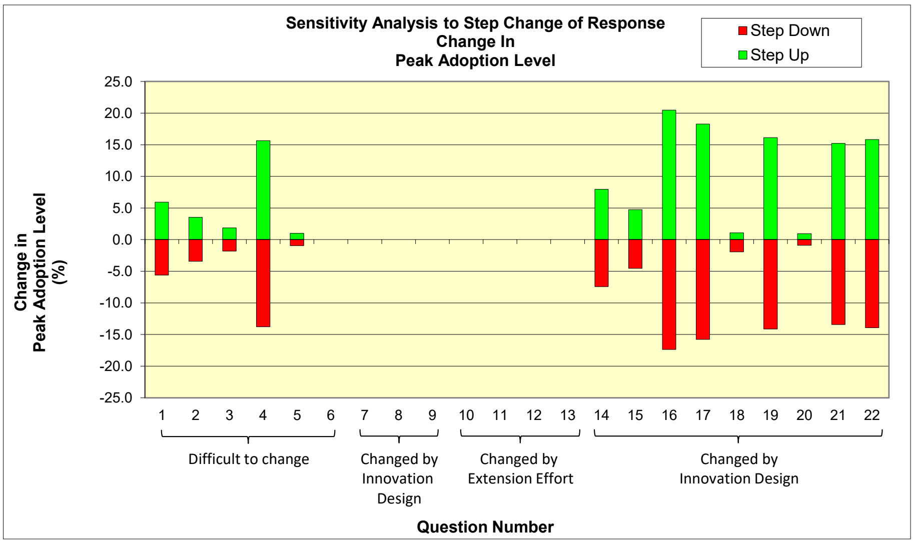

Figure 3. Sensitivity analysis for Peak Adoption Level of single step-up (green) and step-down (red) changes for all questions (Image generated by ADOPT_v2.1).

Note that the questions relevant for the PAL for which considerable levels of disagreement were observed in the standard deviation analysis (namely questions 19 and 22; see Section 3.2) have a significant impact on the PAL of the 'digital shepherd' (+16%-point and +15%-point increase in PAL, respectively).

Hence, it can be concluded that recurrent and future profit and environmental benefits (questions 16, 17 and 19), the potential size of innovation implementation on the farm (question 4), management ease and convenience (question 22) and reduction in risk (question 21) are critical aspects to be addressed when wider adoption of the 'digital shepherd' is considered—potentially leading, on a stand-alone basis, to a 15–20%-point increase in the Peak Adoption Level of the 'digital shepherd'.

The sensitivity analysis on all questions shows that the Time to Peak Adoption Level (TPAL) is mostly influenced by the following (see Figure 4):

- Question 7 (How easily can the 'digital shepherd' (or significant components of it) be trialled on a small scale before a decision is made to adopt it on a larger scale?): up to a 1.5 year decrease in TPAL;
- Question 8 (Does the complexity of the 'digital shepherd' allow the effects of its use to be easily evaluated when it is used?): up to a 1.5 year decrease in TPAL;
- Question 12 (What proportion of the target population will need to develop substantial new skills and knowledge to use the 'digital shepherd'?): up to a 1.5 year decrease in TPAL.

Note that the questions relevant for the TPAL for which considerable levels of disagreement were observed in the standard deviation analysis (namely, questions 9 and 13; see Section 3.2) have a relatively small impact on the TPAL of the 'digital shepherd' (0.7 and 0.5 year decrease in TPAL, respectively).

Hence, the trialability of the innovation (question 7), the ability to assess its effects (question 8) and relevant skills and knowledge (question 12) are crucial factors to be addressed when acceleration of the adoption process of the 'digital shepherd' is considered—potentially leading, on a stand-alone basis, to a 1.5 year decrease in the Time to Peak Adoption Level of the 'digital shepherd'. Also note that an increase in the size of the upfront cost relative to the potential annual benefit (question 14) could significantly slow down the diffusion process (by over 1 year).

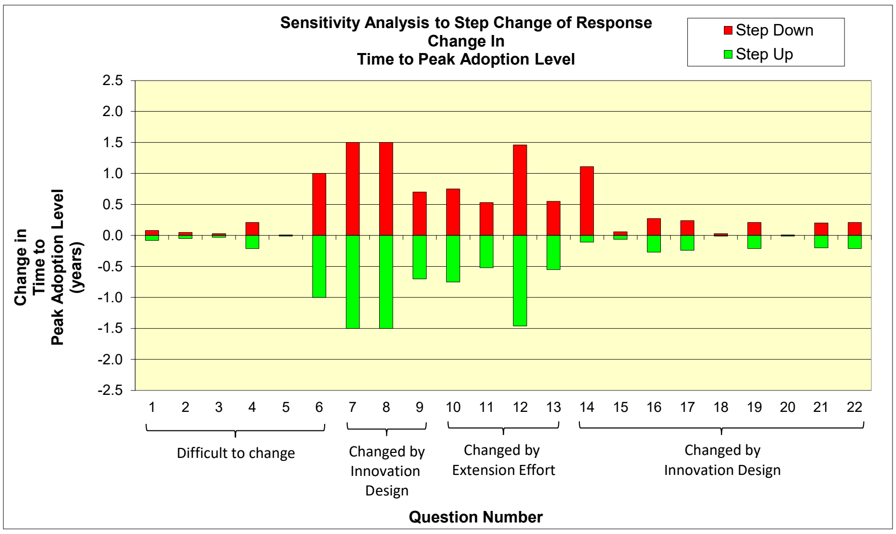

Figure 4. Sensitivity analysis for Time to Peak Adoption Level of single step-up (green) and step-down (red) changes for all questions (Image generated by ADOPT_v2.1).

4. Discussion

The Digital Age has shown an increased uptake by means of Artificial Intelligence (AI), robotics and the Internet of Things (IoT), among others, which can offer invaluable support for farmers and agribusiness development. These technologies can substantially increase effectiveness by enhanced connectivity, creating new opportunities for collecting data to increase farmers' performance, by 4G advancing to 5G and, further, to 6G in the near future [8]. It remains unclear to what extent farmers are ready to adopt advanced technologies, with a risk that only the most wealthy or prepared farmers will invest in the new technology, which in the long term could lead to an increased digital divide and inequalities across the agricultural sector in Europe. Therefore, this study assessed the potential for the adoption and diffusion of the 'digital shepherd' among livestock farmers in Flanders, Belgium.

The results show that the estimated Peak Adoption Level (PAL) of the 'digital shepherd' among livestock farmers in Flanders is 40% of the target population, and that the estimated Time to Peak Adoption Level (TPAL) is 15 years. These results are in line with those for the adoption of solar photovoltaic systems for water pumping by sugarcane farmers in Australia (50% PAL and 10 years TPAL; [30]), though well below those for geographic positioning system (GPS) guidance in tractors by grain growers in Australia (83% PAL and 15 years TPAL; [25]) and for energy management systems in automated dairy cattle barns in Germany (98% PAL and 8 years TPAL; [31]). A larger adoption of GPS guidance in tractors is expected because of the larger proportion of the farm that could benefit (question 4) and because of the larger increase in ease and convenience (question 22). A larger adoption of energy management systems in automated dairy cattle barns is expected because of the (far) larger profit (questions 16 and 17), environmental (question 19), risk (question 21) and ease and convenience (question 22) benefits.

Results from the sensitivity analysis further show that the Peak Adoption Level of the 'digital shepherd' can be significantly increased by addressing recurrent and future profit and environmental benefits, the potential size of innovation implementation on the farm, management ease and convenience, and reductions in risk. The Time to Peak Adoption Level of the 'digital shepherd' can be somewhat reduced by addressing the trialability of the innovation, the ability to assess its effects and relevant skills and knowledge. It is widely acknowledged that these factors influence the adoption and diffusion of innovations in agriculture (see, e.g., [32,33])—in this, study we also provide insights into the extent to which addressing these factors may increase the Peak Adoption Level (per factor, by up to +20%-points) and decrease the Time to Peak Adoption Level (per factor, by up to 1.5 years).

Access to digitisation is addressed in the literature as an opportunity to improve quality of life [34]. A digital divide appears when some people benefit from this and others not, such as due to the gender gap [35] and inequalities across geographical space [36]. Further, the literature refers to a digital divide by people not having access to public services, such as health care [37], financial services [38] and public administration [39], and not having a fair data collection and distribution system to avoid imbalances in analyses and representation [40]. Moreover, lack of the appropriate education can lead to digital exclusion [41], among others. With ADOPT, these factors can be identified at the early stages, can be assessed according to their adoption potential and, finally, can be prioritised—hence allowing policy makers to define appropriate strategies to reduce the digital divide.

Transition takes place at multiple levels, including in the forms of information construction in policy processes, new relationships, transparency implications in environmental governance, new global arrangements and public engagement in the Information Age [42]. Through ADOPT, it is believed that the criteria explained during the workshop phase about the adoption of high-tech by farmers will stimulate a more equal and fair transition towards a future that is more inclusive, environmentally friendly, effective and economically viable. This responds to the desire to contribute to economic, social and environmental sustainability. A new high-tech society must ensure directionality and policy coordination, including coherencies across national, regional, sectoral and technological levels. Notably, with extensive use of high-tech approaches in ever more digitalised contexts across the agricultural sector in Europe, new challenges must be dealt with [43]: (1) infrastructure, including online and physical, transport of information, goods, energy and people; (2) institutions, including regulation, standards and legislation as well as cultures, norms and values; (3) interactions and networks that will not overflow nor weaken existing actors' connections; and (4) the capabilities of people to know how to invest and how to reach specific goals. Although farmers increasingly take responsibility for sustainability, which often results in reduced profit margins in the short term [44], policy makers should safeguard the long-term sustainability impacts [45] as, as yet, farmers will not take full responsibility for the broad spectrum of ecosystem services, including regulating and maintenance and cultural ecosystem services [46]. As ADOPT addresses the environmental, social and economic sustainability dimensions of innovations that potentiate digital transitions, it can work as a tool to bridge understanding between the agricultural sector and policy makers. Moreover, ADOPT provides critical information about how to develop policy measures that facilitate this digital transition towards sustainable futures.

This study on 'digital shepherds' in Flanders, Belgium, represents a good approach to assess the potential for the adoption and diffusion of farming innovation. However, the followed approach may not capture all the contextual nuances specific to Flanders' agricultural sector. The workshop responses likely do not fully represent the totality of the diverse range of farmers and their objectives, skills, networks, constraints and opportunities, which should be complemented with parallel approaches—such as a survey-based application of ADOPT across the entire population of potential adopters (following López-Maciel et al. [29]. For instance, even if our findings suggest that profitability and environmental benefits are significant drivers of adoption, there may be underlying socio-cultural factors and local market conditions influencing these perceptions. For example, Flemish farms are mostly characterised by having many dispersed fields, and hence the extent to which the fields are dispersed could influence willingness to adopt technologies to monitor farm operations across those fields. Future research should also consider a mixed-method approach, incorporating qualitative insights to complement the quantitative results from ADOPT—such as through feedback and discussion on answers to ADOPT questions, as well as through discussion on ADOPT results with workshop participants (as in this study) or through discussion with a focus group of experts (e.g., [30]. Moreover, longitudinal studies tracking the actual adoption and performance of the 'digital shepherd' over time would provide better insights into its long-term viability and impact (following, e.g., Kuehne et al., [25]). Expanding the research to include comparisons with other regions or similar innovations could also highlight best practices and potential improvements. This holistic approach would help refine strategies to promote digital farming technologies across different agricultural communities.

5. Conclusions

In this study, we identify and assess the main constraints on and drivers for the adoption and diffusion of smart XG, last-mile connectivity and edge computing solutions in agricultural production systems, with a case study for 'digital shepherds' in Flanders, Belgium. The developed approach contributes to previous studies by assessing the extent to which farmers are ready to adopt smart XG, last-mile connectivity and edge computing solutions in agricultural production systems—thus pre-empting the potential risk of a digital divide and inequalities in the agricultural sector. Factors contributing to a digital divide are identified and assessed regarding the extent to which they constrain the adoption and diffusion potential of these high-tech solutions, such that strategies to reduce the digital divide can be defined. Moreover, the environmental, social and economic sustainability dimensions of innovations that potentiate digital transition are addressed, and hence the approach can work as a tool to bridge understanding between the agricultural sector and policy makers.

There is substantial potential for the adoption (~40% of the target population) and diffusion (~15 years to peak adoption) of the 'digital shepherd' in Flanders. This study highlights critical factors influencing the adoption and diffusion process. The key drivers for adoption are economic, environmental and management benefits (or information about these and the perception thereof), as well as the potential size of innovation implementation (leading, on a stand-alone basis, to a 15–20%-point increase in adoption). Key drivers for diffusion are the possibility of trialling and assessing effects, as well as the development of relevant new skills and knowledge (leading, on a stand-alone basis, to a 1.5 year decrease in adoption time). These findings reveal that profitability, both immediate and future, alongside environmental benefits and management convenience, are pivotal in motivating farmers to adopt the 'digital shepherd'. Moreover, larger farms are more likely to adopt it due to their resource availability and operational flexibility, emphasizing the need for targeted strategies to support smaller farms. These findings also underscore the importance of addressing trialability, evaluability and the development of relevant skills and knowledge among farmers to accelerate adoption of the 'digital shepherd'.

This study provides a robust framework for understanding the adoption and diffusion dynamics of smart XG, last-mile connectivity and edge computing solutions in agricultural settings. It highlights the necessity of continuous support and clear communication regarding the benefits and practical implementation of such innovations. Key policy recommendations for enhancing the adoption of high-tech solutions such as the 'digital shepherd' include the following: providing financial incentives for small farmers, improving rural digital infrastructure, offering targeted training and extension programmes, establishing clear regulatory frameworks for data privacy and cybersecurity, investing in research and development and public–private partnerships, and raising awareness through effective communication channels. These measures aim to foster sustainable and inclusive digital transformation in agriculture.

Author Contributions: Conceptualisation, M.L.-M., P.R. and K.S.; methodology, P.R. and M.L.-M.; case study development, J.H., K.S., P.R. and M.L.-M.; writing—original draft preparation, M.L.-M., P.R. and K.S.; writing—review and editing, M.L.-M., P.R., K.S. and J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the XGain project (Enhancing Competitiveness, Resilience and Sustainability of Remote Farming, Forestry and Rural Areas through Holistic Assessment of Smart XG, Last-Mile and Edge Solutions' Gains; Grant Agreement No. 101060294). We also acknowledge the support of the Portuguese Foundation for Science and Technology—FCT under the grant PRT/BD/154933/2023. Finally, we acknowledge financial support from CESAM (UIDB/50017/2020+UIDP/50017/2020), FCT/MCTES through national funds and co-funding by the FEDER, within the PT2020 Partnership Agreement and Compete 2020. Funded by the European Union. The views and opinions expressed are, however, those of the author(s) and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA) (the granting authority). Neither the European Union nor the granting authority can be held responsible for them.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study according to the UA Regulation for the Protection of Data.

Data Availability Statement: Data will be made available upon request to the first author.

Acknowledgments: We thank Jarissa Maselyne from the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) for her support in reviewing the data and providing valuable suggestions that improved the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. ADOPT quadrant, variable and question descriptions (source: [25]).

Quadrant	Variable	Question
Relative advantage for the population	1. Profit orientation	What proportion of the target population has maximising profit as a strong motivation?
(Q1)	2. Environmental orientation	What proportion of the target population has protecting the natural environment as a strong motivation?
	3. Risk orientation	What proportion of the target population has risk minimisation as a strong motivation?
	4. Enterprise scale	On what proportion of the target farms is there a major enterprise that could benefit from the innovation?
	5. Management horizon	What proportion of the target population has a long-term (greater than 10 years) management horizon for their farm?
	6. Short-term constraints	What proportion of the target population is under conditions of severe short-term financial constraints?
Learnability characteristics of the innovation	7. Trialling ease	How easily can the innovation (or significant components of it) be trialled on a limited basis before a decision is made to adopt it on a larger scale?
(Q2)	8. Innovation complexity	Does the complexity of the innovation allow the effects of its use to be easily evaluated when it is used?
	9. Observability	To what extent would the innovation be observable to farmers who are yet to adopt it when used in their area?
Population-specific influences on the	10. Advisory support	What proportion of the target population uses paid advisors capable of providing advice relevant to the innovation?

Table A1. *Cont.*

Quadrant	Variable	Question
ability to learn about the	11. Group involvement	What proportion of the target population participates in farmer-based groups that discuss this type of innovation?
Innovation (Q3)	12. Relevant existing skills and knowledge	What proportion of the target population will need to develop substantial new skills and knowledge to use the innovation?
	13. Innovation awareness	What proportion of the target population would be aware of the use or trialling of the innovation in their area?
Relative advantage of the innovation	14. Relative upfront cost of the innovation	What is the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation?
(Q4)	15. Reversibility of the innovation	To what extent is the adoption of the innovation able to be reversed?
	16. Profit benefit in years that it is used	To what extent is the use of the innovation likely to affect the profitability of the farm business in the years that it is used?
	17. Profit benefit in future	To what extent is the use of the innovation likely to have additional effects on the future profitability of the farm?
	18. Time for profit benefit to be realised	How long after the innovation is first adopted would it take for effects on future profitability to be realised?
	19. Environmental impact	To what extent would the use of the innovation have net environmental benefits or costs?
	20. Time for env. impacts to be realised	How long after the innovation is first adopted would it take for the expected environmental benefits or costs to be realised?
	21. Risk	To what extent would the use of the innovation affect the net exposure of the farm business to risk?
	22. Ease and convenience	To what extent would the use of the innovation affect the ease and convenience of the management of the farm in the years that it is used?

Appendix B

Table A2. ADOPT variable, question and answer descriptions by quadrant, as used during the ADOPT workshop on 18 April 2023 at the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) in Flanders, Belgium.

Variable	Question	Answers
Relative advantage for the population (Q1)		
1. Profit orientation	What proportion of the target population has maximising profit as a strong motivation?	1. Almost none have maximising profit/utility as a strong motivation 2. A minority have maximising profit/utility as a strong motivation 3. About a half have maximising profit/utility as a strong motivation 4. A majority have maximising profit/utility as a strong motivation 5. Almost all have maximising profit/utility as a strong motivation

Table A2. *Cont.*

Variable	Question	Answers
2. Environmental orientation	What proportion of the target population has protecting the natural environment as a strong motivation?	1. Almost none have protection of the environment as a strong motivation 2. A minority have protection of the environment as a strong motivation 3. About a half have protection of the environment as a strong motivation 4. A majority have protection of the environment as a strong motivation 5. Almost all have protection of the environment as a strong motivation
3. Risk orientation	What proportion of the target population has risk minimisation as a strong motivation?	1. Almost none have risk minimisation as a strong motivation (risk takers) 2. A minority have risk minimisation as a strong motivation 3. About half have risk minimisation as a strong motivation 4. A majority have risk minimisation as a strong motivation 5. Almost all have risk minimisation as a strong motivation (risk averse)
4. Enterprise scale	On what proportion of the farms is there a major enterprise that could benefit from the 'digital shepherd'?	1. Almost none of the target population has a major enterprise that could benefit 2. A minority of the target population has a major enterprise that could benefit 3. About half of the target population has a major enterprise that could benefit 4. A majority of the target population has a major enterprise that could benefit 5. Almost all of the target population has a major enterprise that could benefit
5. Management horizon	What proportion of the target population has a long-term (more than 10 years) planning horizon for their farm?	1. Almost none have a long-term planning horizon 2. A minority have a long-term planning horizon 3. About a half have a long-term planning horizon 4. A majority have a long-term planning horizon 5. Almost all have a long-term planning horizon
6. Short-term constraints	What proportion of the target population is under conditions of severe financial constraints?	1. Almost all currently have severe short-term financial constraints 2. A majority currently have severe short-term financial constraints 3. About half currently have severe short-term financial constraints 4. A minority currently have severe short-term financial constraints 5. Almost none have severe short-term financial constraints

Table A2. *Cont.*

Variable	Question	Answers
Learnability characteristics (Q2)		
7. Trialling ease	How easily can the 'digital shepherd' (or significant components of it) be trialled on a small scale before a decision is made to adopt it on a larger scale?	1. Not trialable at all 2. Difficult to trial 3. Moderately trialable 4. Easily trialable 5. Very easily trialable
8. Innovation complexity	Does the complexity of the 'digital shepherd' allow effects of its use to be easily evaluated when it is used?	1. Very difficult to evaluate effects of use due to complexity 2. Difficult to evaluate effects of use due to complexity 3. Moderately difficult to evaluate effects of use due to complexity 4. Slightly difficult to evaluate effects of use due to complexity 5. Not at all difficult to evaluate effects of use due to complexity
9. Observability	To what extent would the 'digital shepherd' be observable to farmers who are yet to adopt it when used in their area?	1. Not observable at all 2. Difficult to observe 3. Moderately observable 4. Easy observable 5. Very easy observable
Learnability of the population (Q3)		
10. Advisory support	What proportion of the target population uses paid advisors capable of providing advice relevant to the 'digital shepherd'?	1. Almost none use a relevant advisor 2. A minority use a relevant advisor 3. About a half use a relevant advisor 4. A majority use a relevant advisor 5. Almost all use a relevant advisor
11. Group involvement	What proportion of the target population participates in farmer-based groups that discuss this type of innovation ('digital shepherds')?	1. Almost none are involved with a group that discusses 'digital shepherds' 2. A minority are involved with a group that discusses 'digital shepherds' 3. About half are involved with a group that discusses 'digital shepherds' 4. A majority are involved with a group that discusses 'digital shepherds' 5. Almost all are involved with a group that discusses 'digital shepherds'
12. Relevant existing skills and knowledge	What proportion of the target population will need to develop substantial new skills and knowledge to use the 'digital shepherd'?	1. Almost all need new skills and knowledge 2. A majority need new skills and knowledge 3. About half will need new skills and knowledge 4. A minority will need new skills and knowledge 5. Almost none will need new skills or knowledge

Table A2. *Cont.*

Variable	Question	Answers
13. Innovation awareness	What proportion of the target population would be aware of the use or trialling of 'digital shepherds' in their area?	1. It has never been used or trialled in their area 2. A minority are aware that it has been used or trialled in their area 3. About a half are aware that it has been used or trialled in their area 4. A majority are aware that it has been used or trialled in their area 5. Almost all are aware that it has been used or trialled in their area
Relative advantage (Q4)		
14. Relative upfront cost of the innovation	What is the size of the up-front cost of the investment relative to the potential annual benefit from using the 'digital shepherd'?	1. Very large initial investment 2. Large initial investment 3. Moderate initial investment 4. Minor initial investment 5. No initial investment required
15. Reversibility of the innovation	To what extent is the adoption of the 'digital shepherd' able to be reversed?	1. Not reversible at all 2. Difficult to reverse 3. Moderately difficult to reverse 4. Easily reversed 5. Very easily reversed
16. Profit benefit in years that it is used	To what extent is the use of the 'digital shepherd' likely to affect theprofitability of the farm in the years during its implementation and use?	1. Large profit disadvantage in years that it is used 2. Moderate profit disadvantage in years that it is used 3. Small profit disadvantage in the years that it is used 4. No profit advantage or disadvantage in the years that it is used 5. Small profit advantage in the years that it is used 6. Moderate profit advantage in the years that it is used 7. Large profit advantage in the years that it is used 8. Very large profit advantage in the years that it is used
17. Profit benefit in future	To what extent is the use of the 'digital shepherd' likely to have additional effects on the future profitability of the farm?	1. Large profit disadvantage in the future 2. Moderate profit disadvantage in the future 3. Small profit disadvantage in the future 4. No profit advantage or disadvantage in the future 5. Small profit advantage in the future 6. Moderate profit advantage in the future 7. Large profit advantage in the future 8. Very large profit advantage in the future

Table A2. *Cont.*

Variable	Question	Answers
18. Time for profit benefit to be realised	How long after the 'digital shepherd' is first adopted would it take for the effects on future profitability to be realised?	1. More than 10 years. 2. 6 to 10 years 3. 3 to 5 years 4. 1 to 2 years 5. Immediately 6. Not applicable
19. Environmental impact	To what extent would the use of the 'digital shepherd' have net environmental benefits or costs?	1. Large environmental disadvantage 2. Moderate environmental disadvantage 3. Small environmental disadvantage 4. No net environmental effects 5. Small environmental advantage 6. Moderate environmental advantage 7. Large environmental advantage 8. Very large environmental advantage
20. Time for environmental impacts to be realised	How long after the 'digital shepherd' is first adopted would it take for the expected environmental benefits or costs to be realised?	1. More than 10 years 2. 6 to 10 years 3. 3 to 5 years 4. 1 to 2 years 5. Immediately 6. Not applicable
21. Risk	To what extent would the use of the 'digital shepherd' affect the net exposure of the farm to risk?	1. Large increase in risk 2. Moderate increase in risk 3. Small increase in risk 4. No increase in risk 5. Small reduction in risk 6. Moderate reduction in risk 7. Large reduction in risk 8. Very large reduction in risk
22. Ease and convenience	To what extent would the use of the 'digital shepherd' affect the ease and convenience of the management of the farm in the years that it is used?	1. Large decrease in ease and convenience 2. Moderate decrease in ease and convenience 3. Small decrease in ease and convenience 4. No decrease in ease and convenience 5. Small increase in ease and convenience 6. Moderate increase in ease and convenience 7. Large increase in ease and convenience 8. Very large increase in ease and convenience

References

1. Weerabahu, W.M.S.K.; Samaranayake, P.; Nakandala, D.; Hurriyet, H. Digital supply chain research trends: A systematic review and a maturity model for adoption. *Benchmarking* **2023**, *30*, 3040–3066. [CrossRef]
2. David, A.; Yigitcanlar, T.; Li RY, M.; Corchado, J.M.; Cheong, P.H.; Mossberger, K.; Mehmood, R. Understanding Local Government Digital Technology Adoption Strategies: A PRISMA Review. *Sustainability* **2023**, *15*, 9645. [CrossRef]
3. Mhlongo, S.; Mbatha, K.; Ramatsetse, B.; Dlamini, R. Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review. *Heliyon* **2023**, *9*, e16348. [CrossRef]
4. Mhlanga, D.; Ndhlovu, E. Digital Technology Adoption in the Agriculture Sector: Challenges and Complexities in Africa. *Hum. Behav. Emerg. Technol.* **2023**, *2023*, 6951879. [CrossRef]
5. Shahadat, M.M.H.; Nekmahmud, M.; Ebrahimi, P.; Fekete-Farkas, M. *Digital Technology Adoption in SMEs: What Technological, Environmental and Organizational Factors Influence in Emerging Countries?*; SAGE Journals: Los Angeles, CA, USA, 2023. [CrossRef]

6. Al-Emran, M.; Griffy-Brown, C. The role of technology adoption in sustainable development: Overview, opportunities, challenges, and future research agendas. *Technol. Soc.* **2023**, *73*, 102240. [CrossRef]
7. van Hilten, M.; Wolfert, S. 5G in agri-food—A review on current status, opportunities and challenges. *Comput. Electron. Agric.* **2022**, *201*, 107291. [CrossRef]
8. Dogra, A.; Jha, R.K.; Jain, S. A Survey on beyond 5G Network with the Advent of 6G: Architecture and Emerging Technologies. *IEEE Access* **2021**, *9*, 67512–67547. [CrossRef]
9. Kostas, C.; Tanel, J.; Marinos, C.; Roumeliotis Anargyros, J.; August, B.; Adrián, P.; Dimitrios, K.; Konstantinos, S.; Ioannis, N.; Leonardo, A.; et al. Enhancing Competitiveness, Resilience and Sustainability of Remote Farming, Forestry and Rural Areas Through Holistic Assessment of Smart XG, Last-Mile and Edge Solutions' Gains. 2023. Available online: https://xgain-project.eu/public-deliverables/ (accessed on 1 January 2025).
10. European Commission. *Communication from the Commission to the European Parliament, THE COUNCIL, THE EUROPEAN Economic and Social Committee and the Committee of the Regions a Long-Term Vision for the EU's Rural Areas—Towards Stronger, Connected, Resilient and Prosperous Rural Areas by 2040*; EU-Document 52021DC0345; European Comission: Brussels, Belgium, 2021. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021DC0345 (accessed on 1 January 2025).
11. Zhang, Y.; Yu, H.; Zhou, W.; Man, M. Application and Research of IoT Architecture for End-Net-Cloud Edge Computing. *Electronics* **2022**, *12*, 1. [CrossRef]
12. Chen, Z.; He, Q.; Liu, L.; Lan, D.; Chung, H.M.; Mao, Z. An artificial intelligence perspective on mobile edge computing. In Proceedings of the 2019 IEEE International Conference on Smart Internet of Things, Tianjin, China, 9–11 August 2019; pp. 100–106. [CrossRef]
13. Monteiro, A.; Santos, S.; Gonçalves, P. Precision Agriculture for Crop and Livestock Farming—Brief Review. *Animals* **2021**, *11*, 2345. [CrossRef]
14. Sathya, D.; Thangamani, R.; Balaji, B.S. The Revolution of Edge Computing in Smart Farming. *Signals Commun. Technol.* **2024**, *2461*, 351–389. [CrossRef]
15. Xgain. XGain Project. 2023. Available online: https://xgain-project.eu/about/ (accessed on 1 January 2025).
16. Landbouw and Visserij. Landbouw Rapport. 2024. Available online: https://landbouwcijfers.vlaanderen.be/landbouwrapport-2024-lara (accessed on 1 January 2025).
17. Waldmuller, J.; Llukmani, F.; Bartar, P. Key Stakeholders Mapping and Functional Requirements Elicitation and Analysis. XGain Project Deliverable D2.1. 2023. Available online: https://xgain-project.eu/wp-content/uploads/2024/01/XGain_D2.1_Key-stakeholders-mapping-and-functional-requirements-elicitation-and-analysis.pdf (accessed on 4 March 2025).
18. Haumont, J.; De Temmerman, P.-J.; Vangeyte, J.; Maselyne, J. *Localization of Grazing Cows Using Yolov8 Object Detection and Known Landmarks*; ILVO: Merelbeke, Belgium, 2024. Available online: https://pureportal.ilvo.be/en/publications/localization-of-grazing-cows-using-yolov8-object-detection-and-kn (accessed on 1 January 2025).
19. Deganis, I.; Haghian, P.Z.; Tagashira, M.; Alberti, A. Leveraging Digital Technologies for Social Inclusion. In *United Nations Department of Economic and Social Affairs*; United Nations: New York, NY, USA, 2021. Available online: https://www.un.org/development/desa/dpad/publication/un-desa-policy-brief-92-leveraging-digital-technologies-for-social-inclusion/ (accessed on 1 January 2025).
20. Kwilinski, A.; Vyshnevskyi, O.; Dzwigol, H. Digitalization of the EU Economies and People at Risk of Poverty or Social Exclusion. *J. Risk Financ. Manag.* **2020**, *13*, 142. [CrossRef]
21. Feder, G.; Umali, D.L. The adoption of agricultural innovations: A review. *Technol. Forecast. Soc. Chang.* **1993**, *43*, 215–239. [CrossRef]
22. Serebrennikov, D.; Thorne, F.; Kallas, Z.; McCarthy, S.N. Factors Influencing Adoption of Sustainable Farming Practices in Europe: A Systemic Review of Empirical Literature. *Sustainability* **2020**, *12*, 9719. [CrossRef]
23. Menz, M.; Kunisch, S.; Birkinshaw, J.; Collis, D.J.; Foss, N.J.; Hoskisson, R.E.; Prescott, J.E. Corporate Strategy and the Theory of the Firm in the Digital Age. *J. Manag. Stud.* **2021**, *58*, 1695–1720. [CrossRef]
24. van Kessel, R.; Wong, B.L.H.; Rubinić, I.; O'Nuallain, E.; Czabanowska, K. Is Europe prepared to go digital? making the case for developing digital capacity: An exploratory analysis of Eurostat survey data. *PLoS Digit. Health* **2022**, *1*, e0000013. [CrossRef]
25. Kuehne, G.; Llewellyn, R.; Pannell, D.J.; Wilkinson, R.; Dolling, P.; Ouzman, J.; Ewing, M. Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy. *Agric. Syst.* **2017**, *156*, 115–125. [CrossRef]
26. Rogers, E.M. *Diffusion of Innovations*, 5th ed.; The Free Press: Los Angeles, CA, USA, 2003. Available online: https://www.simonandschuster.com (accessed on 1 January 2025).
27. Pannell, D.J.; Marshall, G.R.; Barr, N.; Curtis, A.; Vanclay, F.; Wilkinson, R. Understanding and promoting adoption of conservation practices by rural landholders. *Aust. J. Exp. Agric.* **2006**, *46*, 1407–1424. [CrossRef]
28. Knowler, D.; Bradshaw, B. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* **2007**, *32*, 25–48. [CrossRef]

29. López-Maciel, M.; Roebeling, P.; Llewellyn, R.; Figueiredo, E.; Matos, F.A.; Mendonça, R.; Bastos, M.I.; Mendes, R.; Postmes, L.; van Dinter, M. Adoption and Diffusion of Nature-Based Solutions by Property Owners in Urban Areas: The Case of Green Roofs in Eindhoven, The Netherlands. *Resources* **2023**, *12*, 133. [CrossRef]
30. Powell, J.W.; Welsh, J.M.; Pannell, D.; Kingwell, R. Factors Influencing the Adoption of Solar Photovoltaic Systems for Water Pumping by Australian Sugarcane Irrigators. In Proceedings of the 42nd Australian Society of Sugar Cane Technologists Conference, Bundaberg West, Australia, 20–23 April 2021. Available online: https://research-repository.uwa.edu.au/en/publications/factors-influencing-the-adoption-of-solar-photovoltaic-systems-fo (accessed on 1 January 2025).
31. Bader, C.; Stumpenhausen, J.; Bernhardt, H. Prediction of the Spatial and Temporal Adoption of an Energy Management System in Automated Dairy Cattle Barns in Bavaria—"CowEnergySystem". *Energies* **2024**, *17*, 435. [CrossRef]
32. Wang, L.; Tang, J.; Tang, M.; Su, M.; Guo, L. Scale of Operation, Financial Support, and Agricultural Green Total Factor Productivity: Evidence from China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9043. [CrossRef] [PubMed]
33. De Pinto, A. *The Economic Advantage: Assessing the Value of Climate-Change Actions in Agriculture*; IFAD: Rome, Italy, 2016. Available online: https://www.researchgate.net/publication/310047905_The_Economic_Advantage_Assessing_the_value_of_climate-change_actions_in_agriculture (accessed on 1 January 2025).
34. Pinto, F.; Macadar, M.A.; Pereira, G.V. The potential of eParticipation in enlarging individual capabilities: A conceptual framework. *Inf. Technol. Dev.* **2023**, *29*, 276–298. [CrossRef]
35. MacAya, J.F.M.; Ribeiro, M.M.; Jereissati, T.; Dos Reis Lima, C.; Cunha, M.A. Gendering the digital divide: The use of electronic government services and implications for the digital gender gap. *Inf. Polity* **2021**, *26*, 131–146. [CrossRef]
36. Szeles, M.R.; Simionescu, M. Regional Patterns and Drivers of the EU Digital Economy. *Soc. Indic. Res. Int. Interdiscip. J. Qual. Life Meas.* **2020**, *150*, 95–119. [CrossRef]
37. Tirado-Morueta, R.; Rodríguez-Martín, A.; Álvarez-Arregui, E.; Ortíz-Sobrino, M.Á.; Aguaded-Gómez, J.I. The digital inclusion of older people in Spain: Technological support services for seniors as predictor. *Ageing Soc.* **2023**, *43*, 1409–1435. [CrossRef]
38. Vasile, V.; Panait, M.; Apostu, S.A. Financial Inclusion Paradigm Shift in the Postpandemic Period. Digital-Divide and Gender Gap. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10938. [CrossRef]
39. Ranchordás, S. The Digitization of Government and Digital Exclusion: Setting the Scene. *Law Gov. Technol. Ser.* **2022**, *49*, 125–148. [CrossRef]
40. McAuliffe, M.; Blower, J.; Beduschi, A. Digitalization and Artificial Intelligence in Migration and Mobility: Transnational Implications of the COVID-19 Pandemic. *Societies* **2021**, *11*, 135. [CrossRef]
41. Zarouali, B.; Helberger, N.; de Vreese, C.H. Investigating Algorithmic Misconceptions in a Media Context: Source of a New Digital Divide? *Media Commun.* **2021**, *9*, 134–144. [CrossRef]
42. Soma, K.; MacDonald, B.H.; Termeer CJA, M.; Opdam, P. Introduction article: Informational governance and environmental sustainability. *Curr. Opin. Environ. Sustain.* **2016**, *18*, 131–139. [CrossRef]
43. Weber, K.M.; Rohracher, H. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. *Research Policy* **2012**, *41*, 1037–1047. [CrossRef]
44. Niehoff, S. Aligning digitalisation and sustainable development? Evidence from the analysis of worldviews in sustainability reports. *Bus. Strategy Environ.* **2022**, *31*, 2546–2567. [CrossRef]
45. Janssen, M.; Wimmer, M.A. Introduction to Policy-Making in the Digital Age. In *Public Administration and Information Technology*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 1–14. [CrossRef]
46. Oostindie, H. Unpacking Dutch multifunctional agrarian pathways as processes of peasantisation and agrarianisation. *J. Rural. Stud.* **2018**, *61*, 255–264. [CrossRef]