Research and Innovation Action
HORIZON-CL6-2022-GOVERNANCE-01
TOPIC: HORIZON-CL6-2022-GOVERNANCE-01-11

AGRIDATAVALUE

Smart Farm and Agri-environmental Big Data Value

Deliverable D3.6
Smart Farming Use Cases Implementation & Validation V2

Authors	A. Zacepins (ZSA), I. Berzina (ZSA), N. Peiren (ILVO), P. Grzyś (UL), K. Dmochowska (UL), S. Bossuyt (Inagro), L. Berko (TEC), T. Van De Gucht (ILVO), S. Tsanakas (SYN), G. Athanasiou (SYN), N. Arvanitis (SYN), Vicky Inglezou (Nileas), Koen Wilhelm (Delphy), Christian van Os (Delphy), Francisco J. Lacueva (ITA), R. Del Hoyo (ITA), J. Sancho (SARGA), S. Sestili (Almaviva)
Nature	Report
Dissemination	PU-Public
Version	V1.0
Status	Draft
Delivery Date (DoA)	M36
Actual Delivery Date	31.01.2026

Keywords	Project Use cases, pilots, data collection, sensors, measurement systems, Longitudinal
Abstract	This Deliverable provides the AgriDataValue Use case implementation and validation description version 2. The technical Chairs of each pilot site have been coordinating the installation of the in-situ equipment as well as the installation and customization of the software components. This deliverable also describes developed models for the Use case implementation in the Pilots. In addition, the deliverable outlines an evaluation framework for the AGRIDATAVALUE project. It aims to assess the impact of technological interventions on agricultural practices and the quality of implemented systems. The framework proposes a longitudinal evaluation throughout the project lifecycle, focusing on user feedback and continuous improvement. Two primary areas are evaluated: the impact of interventions on farming practices and the quality of deployed systems, considering factors such as data quality, visualization, AI models, and overall system performance. To conduct this evaluation, both traditional methods like user surveys and usability testing, and technological approaches utilizing data from information and communication systems are combined. In essence, this framework provides a structured approach to measure the effectiveness and impact of AGRIDATAVALUE solutions, ensuring successful pilot implementation and continuous system improvement.

Funded by the European Union under Grant Agreement no. 101086461

ACKNOWLEDGEMENT

The AGRIDATAVALUE project is funded by the European Union under Grant Agreement No. 101086461. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency, while neither the European Union nor the granting authority can be held responsible for any use of this content.

	Participant organisation name	Short	Country
01	SYNELIXIS SOLUTIONS S.A.	SYN	EL
02	ATOS IT SOLUTIONS AND SERVICES IBERIA SL (Terminated)	ATOS	ES
03	SIXENSE ENGINEERING	SIXEN	FR
04	NETCOMPANY-INTRASOFT SA	INTRA	LU
05	SIEMENS SRL	SIEM	RO
06	SINERGISE LABORATORIJ ZA GEOGRAFSKEINFORMACIJSKE SISTEME DOO	SINER	SI
07	ALMAVIVA - THE ITALIAN INNOVATION COMPANY SPA	ALMA	IT
08	INTERNATIONAL DATA SPACES EV	IDSA	DE
09	SOFTWARE IMAGINATION & VISION SRL	SIMAVI	RO
10	SINGULARLOGIC S.A.	SLG	EL
11	EIGEN VERMOGEN VAN HET INSTITUUT VOOR LANDBOUW- EN VISSERIJONDERZOEK	EV ILVO	BE
12	ETHNIKO KAI KAPODISTRIAKO PANEPISTIMIO ATHINON	NKUA	EL
13	INAGRO, PROVINCIAAL EXTERNVERZELFSTANDIGD AGENTSCHAP IN PRIVAATRECHTELIJKE VORM VZW	InAgro	BE
14	UNIWERSYTET LODZKI	UL	PL
15	FUNDACION PARA LAS TECNOLOGIAS AUXILIARES DE LA AGRICULTURA	TEC	ES
16	DELPHY BV	Delphy	NL
17	INSTITUTO TECNOLOGICO DE ARAGON	ITAIN	ES
18	ZEMNIEKU SAEIMA	ZSA	LV
19	SOCIEDAD ARAGONESA DE GESTION AGROAMBIENTAL SL	SARGA	ES
20	AGROTIKOS KTINOTROFIKOS SYNETAIRISMOS KATOUNAS TO VIOLOGIKO AGROKTIMA	TBA	EL
21	SOCIETA ITALIANA DI VITICOLTURA ED ENOLOGIA	SIVE	IT
22	NILEAS-SYNETAIRISMOS PISTOPOIIMENON AGROTIKON PROIONTON DIMOU NESTOROS MESSINIAS	NILEAS	EL
23	CONSEIL DES VINS DE SAINT-EMILION	CVSE	FR
24	ASOCIATIA OPERATORILOR DIN AGRICULTURA ECOLOGICA BIO ROMANIA	BIORO	RO
25	RI.NOVA SOCIETA COOPERATIVA	RI.NO	IT
26	AGRO DIGITAL SOLUTIONS	AgroDS	LT
27	NATIONAL PAYING AGENCY	NPA	LT
28	AGENZIA PROVINCIALE PER I PAGAMENTIDELLA PROVINCIA AUTONOMA DI TRENTO	APPAG	IT
29	AGENTIA DE PLATI SI INTERVENTIE PENTRU AGRICULTURA	APIA	RO
30	QUEEN MARY UNIVERSITY OF LONDON	QMUL	UK

DISCLAIMER

Document History

Version	Date	Contributor(s)	Description
0.5	20/01/2025	ITA, SARGA	Draft version to be reviewed.
0.6	10/12/2025	ZSA	Updated draft version
0.61	05/01/2026	ILVO	Input pilots
0.62	15/01/2026	Inagro	Input pilots
0.7	20/01/2026	UL, Nileas, CVSE, BioRo	Input pilots
0.8	20/01/2026	Almaviva	Description of olive fruit fly monitoring models
0.91	22/01/2026	Delphy, TBA	Input pilot #2
0.92	27/01/2026	SIMAVI	Review comments are incorporated
0.96	30/01/2026	SIEM	Review #2 of the deliverable
0.97	30/01/2026	ZSA	Review #2 comments are incorporated

Document Reviewers

Date	Reviewer's name	Affiliation
26.01.2026	Alexandra Tudorascu	SIMAVI
30.01.2026	Iulia Ilie	SIEM

Table of Contents

Definitions, Acronyms and Abbreviations

ADS	Agri-Environment Data Space
AI	Artificial Intelligence
API	Application Programming Interface
BBCH	Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie scale
EC	European Commission
EU	European Union
DES	Differential Emotions Scale
DUI	Digital User Imprint
D&M	De Lone and McLean
ERP	Enterprise Resource Planning
ESM	Experience Sample Method
FML	Federated Machine Learning
HED/UT	Hedonic and Utilitarian Dimensions of User Experience
HMI	Human-Machine Interaction
HTTP	Hypertext Transfer Protocol
IA	Impact Analysis
IMGW-PIB	Institute of Meteorology and Water Management – National Research Institute, Poland
IS	Information System
IT	Information Technology
KNMI	Royal Netherlands Meteorological Institute
KM	Knowledge Management
KMS	Knowledge Management Systems
KPI	Key Performance Indicator
MES	Manufacturing Execution System
ML	Machine Learning
NWS	National weather service
PEOU	perceived ease of use
PGC	Pilots Governance Committee
PPP	Plant Protection Product
PU	Perceived Usefulness
QV	Quality Validation
TRL	Technology Readiness Levels
SIAR	Sistema de Información Agroclimática para el Regadío
SUS	System Usability Scale
TAM	Technology Acceptance Model
TL	Task Leader

TM	Technical Manager
TRL	Technology Readiness Levels
UC	Use Case
UDI	User (farmer) Digital Imprint
UI	User Interface
UMUX	User Experience Questionnaire
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
WP	Work Package
WPL	Work Package Lead
XAI	Explainable Artificial Intelligence
XDES	Differential Emotions Scale

Executive Summary

The project pilot sites play an essential role in AgriDataValue, as suppliers of data which are used, by the technology partners, to develop and train the various ML and AI models and realize the project Use Cases (UCs). This document summarizes the outcome of the work performed in T3.3 and T3.4 of AGRIDATAVALUE. It provides the final setup of the pilots. Deliverable summarizes an overview of the data tables associated with each project Pilot and Use Case. This overview is intended to support a clear understanding of the data landscape within each Pilot, facilitate cross-pilot comparability, and serve as a reference for subsequent data processing, model development, and evaluation tasks.

It also presents a **framework which aims to evaluate the impact of interventions (application deployments) and the quality of the deployed systems.** It builds upon an existing framework presented by Lacueva et al., adapted to the specific needs of the AGRIDATAVALUE project.

The framework presents the **evaluation process as longitudinal**, conducted throughout the pilot's lifecycle, with a focus on user feedback and continuous improvement. It proposed to evaluate 2 areas:

- **Impact Assessment (IA):** Measures the impact of interventions on farming practices.
- **Quality Validation (QV):** Evaluates the quality of deployed systems, including data quality, visualization, AI models, overall system performance, and knowledge transfer between use cases.

Within the quality Evaluation methods, the framework considers classical approaches such as user surveys (UMUX, UMUX-LITE, etc.), usability testing, user experience evaluation (UX), and analysis of system usage data. However, it also suggested to use **Technological approaches:** Utilize data logged from ICT systems to gather data for evaluation.

The document also provides a guide for setting the evaluation of each of the deployments of application to support AGRIDATAVALUE pilots. **In essence, the framework provides a structured approach to assess the effectiveness and impact of AGRIDATAVALUE solutions, ensuring continuous improvement and successful pilot implementation.**

This deliverable is a second version of the previous Deliverable D3.3 (submitted 30.09.2024). D3.3 deliverable provided the AgriDataValue Use case implementation and validation description version 1. The document summarized installed technologies, sensors, measurement and IoT systems within the project pilot sites, which are used for the use case implementation. It also described which data was already collected from the pilots and can be used for the model development to solve the use case. In this second version of the deliverable (D3.6), an updated version is created that incorporates the implementation of the use case model or goal for each pilot more in depth.

Work done within the WP3 provides a solid foundation for the project continuation, especially within the WP5 which is the logical step after the WP3.

1 Introduction

The first version of this deliverable (D3.3) included a large part on the implementation of sensors and technologies on pilot level in order to obtain data useable for the use cases with a very specific focus on the specific pilot situation. In this second version of the deliverable, an updated version is created that incorporates the implementation of the use case model or goal for each pilot more in depth. The specific use case goals and how they are obtained at each pilot using the available sensor data, observation data or other data and model creation are elaborated. At this point, the implementation of use cases is not only performed at pilot level, but also goes beyond specific pilot situations towards creating more general approaches and models for similar use cases. Hence, the elaboration of cross-pilot use case implementation is starting, thus indicating the transition from the tasks performed in WP3 towards the future work on the steady validation and adaptation in WP5. Future work on adaptation and customization and the definition and refinement of cross-pilot and cross-use case validation will hence continue the work performed in WP3.

The pilots are crucial to AgriDataValue, as they provide a large volume of on-site/in-situ data that the technology partners are using to develop and train various algorithms, machine learning models and implement the project's Use Cases (UCs). This diverse group of pilots offers a broad representation of use cases within different agricultural sectors across Europe.

The purpose of this Deliverable is to provide the AgriDataValue Use case implementation and validation description version 2.

This deliverable presents the results of executing **Task 3.3: Use Case implementation and performance monitoring** and ***Task 3.4: Feedback-loop Collection and Scale-up Preparation***. This latter task focuses on coordinating and collecting feedback from end-users, ensuring secure and smooth operation of implemented use cases, and facilitating an iterative improvement approach. It is expected to involve at least 2-3 iterations for each use case.

This deliverable defines a framework of tools and a methodology for evaluating the deployed application. This framework supports the specific needs of each pilot implementing the use cases. It builds upon the framework introduced in the work of Lacueva et al. [1], adapted to the goals of the AGRIDATAVALUE project pilots and use cases. The framework identifies a set of tools to assess the impact of interventions (the deployment of created applications and technologies, and associated changes in farming practices) and to validate the deployed systems (IoT devices, applications, ML models, etc.).

The evaluation process is presented as longitudinal, conducted throughout the entire lifecycle of pilot development. During and immediately after the demonstration campaign, end-users will continuously evaluate the performance, usefulness, and benefits of the implemented solutions compared to their routine operations and decision-making. Collected feedback will be shared among the pilot and AGRIDATAVALUE governance boards to enable efficient technical improvement. This ensures timely responses to any failures in the pilot setup and implemented solutions, fostering user-driven innovation. This process will support the preparation of pilot scale-up, which will occur in WP5.

Regarding the evaluations, this deliverable introduces the facts to be considered when evaluating a Smart-farming environment supported in a data space. Although they will be deeply presented in Chapter 5, the validation of the applications must consider:

- Data: quality, value, etc.
- Visualization and interaction
- AI system XAI and trustworthiness
- Overall system performance
- Knowledge about other use cases/clusters (looking forward for scalability).

1.1 Document Structure

The deliverable is structured as follows:

- Chapter 1 provides the introduction of the deliverable
- Chapter 2 updates the information about the AgriDataValue pilot sites
- Chapter 3 summarizes the developed AI models
- Chapter 4 presents a background for evaluation framework
- Chapter 5 describes evaluation framework
- Chapter 6 explains preparation for the evaluation

The document is structured as follows: Chapter 1 introduces the deliverable and outlines its purpose and scope; Chapter 2 presents updated information on the AgriDataValue pilot sites, reflecting the latest developments and context; and Chapter 3 provides a concise summary of the AI models that have been developed, highlighting their main characteristics and outcomes. This deliverable is being created to be auto-contained in the sense of providing enough information without having to review the concepts which are the basement of the defined framework. Chapter ***4*** briefly introduces the theoretical background which supports the definition of the framework and provide the references to be followed by interested readers. Once the tools are presented (most of them are included as appendices of this document), the framework is introduced in chapter ***5 Evaluation Framework*.** This section defines the Impact Assessment (IA) and the Quality Validation (QV), which are their roles in the evaluation of the deployed (versions of the) applications, and how to interpret obtained results. Finally, section ***6 Evaluation Preparation*** presents a guide to prepare, to perform and to interpret the results obtained from each evaluation.

2 AgriDataValue Pilots

Pilots play a crucial role in the AgriDataValue project, and ensuring that all essential processes are fulfilled within the pilot sites is vital to the project's overall success. It should be remined that the Horizon Call focus and the main objective of the AgriDataValue project is to establish itself as the "Game Changer" in Smart Farming digital transformation and agri-environmental monitoring, and strengthen the smart-farming capacities, competitiveness and fair income by introducing an innovative, open source, intelligent and multi-technology, fully distributed Agri-Environment Data Space (ADS). Project pilots are considered as the main source of different data for the ADS. There are different types of data, like crop, livestock, and environmental data that are used for ML training. Still, during the project implementation there are minor changes in Pilot operation and in key personnel, thus it is important to update the Pilot table.

Table 1. List of the Pilots and Pilot leaders

#	Pilot partner	Pilot leaders	Additional pilot contact persons
1	UL	Patrycja Grzyś	Karolina Dmochowska, Paulina Tobiasz-Lis
2	Delphy	Milan Fransen	Koen Wilhelm
3	ZSA	Inga Berzina	Aleksejs Zacepins
4	TBA	Ioannis Katris	Spiros Karamplianis
5	Inagro	Sarah Bossuyt	-
6	TEC	Guadalupe Lopez	Lord Berko
7	Inagro	Emma Vandenbogaerde	Sarah Bossuyt
8	Inagro	Tim De Cuypere	Sarah Bossuyt
9	Inagro	Sarah Bossuyt	-
10	Inagro	Sarah Bossuyt	-
11	Delphy	Milan Fransen	Christina van Os
12	SARGA	Javier Sancho	-
13	TBA	Ioannis Katris	Spiros Karamplianis
14	CVSE	Nawel Aouadi	Franck Binard
15	RINO	Filippo Graziosi	-
16	NILEAS	Vicky Inglezou	Nikos Petoumenos
17	RINO	Filippo Graziosi	-
18	BioRO	Avraham Marian Cioceanu	Elena Ilie
19	EV ILVO	Nico Peiren	Tim Van De Gucht
20	ZSA	Aleksejs Zacepins	Inga Berzina
21	TBA	Ioannis Katris	Spiros Karamplianis
22	EVILVO	Nico Peiren	Tim Van De Gucht
23	TBA	Ioannis Katris	Spiros Karamplianis

Detailed information about project Pilots is provided in submitted deliverable D3.1: Smart Farming pilots & Data Management Plan (DMP) V1, in this deliverable D3.6 an update of the Pilot sites is provided, as there are some slight changes. As well in the Table 2 linkage of the pilots to Project Use Case scenarios is provided.

Table 2. Updated information about the Pilots and related Use case scenarios

#	Partner	Location	Crop / Livestock / Biogas	Use Case scenario
1	UL	Lodzkie, Poland	Apple orchard	1.1; 1.2; 1.3
2	Delphy	Flevoland, The Netherlands	Onions	1.1
3	ZSA	Zemgale, Latvia	Wheat	1.3
4	TBA	Etoloakarnania, Greece	Clovers and Corn	1.1; 1.2
5	Inagro	Flanders, Belgium	Vegetables and arable crops	1.2; 1.3; 2.1
6	TEC	Almeria, Spain	Greenhouse vegetables	2.1; 2.3; 2.4
7	Inagro	Flanders, Belgium	Endives	1.1; 5.4
8	Inagro	Flanders, Belgium	Leek	1.2; 2.1; 2.2
9	Inagro	Flanders, Belgium	Potato	1.4;
10	Inagro	Flanders, Belgium	Vegetables	1.2; 1.3; 2.1; 5.4
11	Delphy	Gelderland, The Netherlands	Apple orchard	1.3
12	SARGA	Aragon region, Spain	Non-Citrus Fruit Trees	1.3; 3.1
13	TBA	Etoloakarnania, Greece	Vineyards	3.3
14	CVSE	Saint-Emilion, France	Vineyards	3.2
15	RINO	Emilia-Romagna, Italy	Vineyards	3.1; 3.2
16	NILEAS	Messinia, Greece	Olive Trees	3.1; 3.2; 3.4
17	RINO	Emilia-Romagna region (N-E Italy).	Olive Trees	3.1; 3.4
18	BioRO	Romania	Arable crops	1.1
19	EV ILVO	Flanders, Belgium	Dairy barn	4.1; 4.2; 4.3; 4.4
20	ZSA	Zemgale, Latvia	Dairy barn	4.3; 4.4
21	TBA	Katouna, Etoloakarnania, Greece	Dairy Farn	4.3
22	EV ILVO	Flanders, Belgium	Pigs campus	4.1; 4.2; 4.3
23	TBA	Katouna, Etoloakarnania, Greece	Circular Economy	5.1

Below the list of the Use Cases is provided:

Table 3. List of AgriDataValue use cases

#	Title
1.1	Reduce Wasted irrigation water
1.2	Reduce Fertilizers
1.3	Reduce Pesticides
1.4	Increase potato production/quality
2.1	Precision open field/greenhouse Irrigation/Fertilization
2.2	Increase Leek /carrots/root crops production/quality
2.3	Optimization of Soluble Solids Content
2.4	Automatization of windows in greenhouses for climate control
2.5	Increase control of agri-environmental conditions
3.1	Fruit trees disease forecast/detection
3.2	Anti-frost control
3.3	Pest Control on Mediterranean Fruit Fly
3.4	Pest Control on Olive Fruit Fly
4.1	Reduce Greenhouse gas emissions
4.2	Reduce nitrogen deposition
4.3	Proactive cattle/pig health/welfare monitoring
4.4	Calving monitoring
5.1	Fully Circular ecosystem
5.2	Supply Chain transparency for Orchards/Vineyards
5.3	Supply Chain transparency for Meat
5.4	Increase farmers' digital independence

The project use cases address a broad range of agricultural, environmental, and supply-chain challenges. **Use cases 1.1–1.4** focus on improving resource efficiency and crop performance by reducing wasted irrigation water, fertilizers, and pesticides, while increasing potato production and quality. **Use cases 2.1–2.5** target precision agriculture and controlled environments, covering optimized irrigation and fertilization, improved production and quality of vegetables and root crops, enhancement of soluble solids content, greenhouse climate control through window automation, and better management of agri-environmental conditions. **Use cases 3.1–3.4** concentrate on crop protection, including disease forecasting and detection in fruit trees, anti-frost control, and pest management for Mediterranean and olive fruit flies. **Use cases 4.1–4.4** address sustainability and livestock management by reducing greenhouse gas emissions and nitrogen deposition, as well as enabling proactive monitoring of cattle and pig health, welfare, and calving processes. Finally, use cases **5.1–5.4** extend to system-level and socio-economic aspects, aiming at fully circular ecosystems, enhanced supply-chain transparency for orchards, vineyards, and meat production, and increased digital independence for farmers. Table below summarizes Use cases per pilot partner:

Table 4. List of the Use cases per pilot partners

Use Case	**UL**	**DELPHY**	**ZSA**	**TBA**	**Ri.NO**	**BioRO**	**InAgro**	**ILVO**	**TEC**	**SAGRA**	**CVSE**	**NILEAS**
1.1	X	X		X		X	X					
1.2	X			X			X					
1.3	X	X	X				X			X		
1.4							X					
2.1							X		X			
2.2							X					
2.3									X			
2.4									X			
2.5												
3.1					X					X		X
3.2					X					X	X	X
3.3					X							
3.4												X
4.1								X				
4.2								X				
4.3			X	X				X				
4.4			X					X				
5.1				X								
5.2				X								
5.3				X								
5.4							X					
UCs per partner	**3**	**2**	3	**6**	3	1	**7**	**4**	**3**	**3**	**1**	**3**

The table provides an overview of the allocation of use cases (UCs) across project partners. Each use case (from UC 1.1 to UC 5.4) is mapped to the partners involved, indicated by an “X”, illustrating the breadth of participation throughout the project. The distribution shows varying levels of engagement: InAgro is involved in the highest number of use cases (7), followed by TBA (6) and ILVO (4), while several partners such as Ri.NO and CVSE contribute to a more limited number of use cases. Overall, the table highlights a balanced yet differentiated collaboration structure, where specific partners play leading roles in multiple use cases while others provide targeted contributions aligned with their expertise.

As it is also underlined in section 3, in many cases the same UC has a totally different implementation based on the pilot and the actual crop. For example, UC1.1 that refers to the reduction of irrigation water is quite different if it is applied to Pilot #1 (Apple orchard), Pilot #2 (Onions), while it has similarities in case of Pilot #3 (Wheat), Pilot #4 (clovers, corn) and Pilot #7 (Endives). As a result, we consider the number of Use Cases to significantly increase to more than 30 different use cases, that require different treatment and validation.

2.1 Pilot implementation and associated summarized data tables

The sub-chapters below provide a summarized overview of the implementation of use cases at the pilot level according with the data tables associated with each Pilot and Use Case. The approach to implementing the use case at pilot level is described concisely. The data tables describe the data type, data frequency, data time period, data access and availability for publishing, highlighting key entities, attributes, and relationships relevant to the corresponding analytical and machine learning activities. This overview is intended to support a clear understanding of the use case approach and data landscape within each Pilot, facilitate cross-pilot comparability, and serve as a reference for subsequent data processing, model development, and evaluation tasks.

2.1.1 Pilot #1: Lodz Heights Landscape Park, Poland/UC 1.1, 1.2, 1.3

Pilot #1 refers to the “Wiatrowy Sad” (Wind Orchard). It is a 17-hectare family-owned apple orchard located in Kałęczew, within the Lodz Heights Landscape Park (Lodz province) in Poland. The region is known for its rich agricultural history, with fruit cultivation gaining momentum after World War II, bolstered by the establishment of the Institute of Orchardery and Floriculture. This institute played a crucial role in spreading knowledge on modern apple-growing techniques, which the owner family utilized in developing their orchard. Wiatrowy Sad has been recognized with numerous awards for the quality of its products. It is known for its dedication to high standards, combining traditional methods with modern technology.

Figure 2. The orchard and the “Wind Orchard” fruit press

As part of the AgriDataValue project, Wiatrowy Sad integrates the SynField smart agriculture system, which includes a meteorological station and soil sensors to monitor real-time environmental data. This technology helps optimize orchard management by providing precise information on ambient temperature, humidity, wind speed, and soil conditions. Gathered data supports precision agriculture by allowing for more informed and sustainable decisions, optimizing fruit production and orchard management. The integration of this technology represents a step towards a digital orchard model, where data-driven solutions ensure efficiency and sustainability in response to market demands.

Figure 1. SynField installed in Pilot #1

Pilot #1 is related to four use cases: 1.1; 1.2; 1.3; and 2.5. However, following further assessment of data availability and added value, UC 2.5 “Agri-environmental conditions” was deprioritised and excluded from the pilot scope. The current implementation therefore focuses on three use cases: UC 1.1 (irrigation), UC 1.2 (fertilisation) and UC 1.3 (pesticide use).

Table 5. Summarized data table for Pilot#1

Data source	**Data type**	**Data frequency (minutes or days)**	**Data time period**	**Data access**	**Publishable**
IoT Data via connectors (automatically)	Synelixis weather station, soil sensor (soil moisture, soil temperature, air temperature, air humidity, precipitation)		09/2024 – ongoing (weather station) 09/2025 – ongoing (soil sensor)	Yes	Yes
Meteorological services data	Meteorological measurements from IMGW-PIB stations (air temperature, relative humidity, precipitation, wind speed and direction, atmospheric pressure, cloudiness, snow cover, radiation; data from synoptic, climatological, precipitation, and automatic stations)	Synoptic stations – every 1 hour (sometimes 3 hours) Climatological stations – daily Precipitation stations – daily Automatic stations – typically every 10 minutes	Historical – multi-year archives (many stations > 50–100 years) and ongoing data continuously updated	Yes	Yes
Other data	Orchard owner's documentation: *Plot and field metadata (parcel numbers, plot codes, varieties, field areas) *Fertilization plans, nutrient balances, and records of applied nitrogen, P_2O_5, K_2O, MgO, CaO (products, doses, dates) *Integrated Production observations (pest/disease monitoring, tools used, thresholds, weather notes, phenology, required IP documentation) *Plant protection treatments (all sprays: product, dose, water volume, plots, dates; records for weeds, pests, diseases) *Harvest records per plot and variety (start/end dates; quantities where provided) *On-farm infrastructure and equipment data (sprayers, calibration, hygiene facilities)	*Operational records: event-based, typically daily/weekly during the season (sprays, monitoring observations, fertilization) *Fertilization logs: per application date (several dates per season) *Harvest: per harvest window per variety/plot (1–several entries per season)	Historical: 2023 (season 2022/2023) and 2024 (season 2023/2024) fertilization plans and logs Current: Integrated Production notebook and full orchard records for 2025 (ongoing season)	Yes — internal documents provided directly by the orchard owner (private files shared in the project)	Yes* — with orchard owner's explicit consent and after anonymization (removal of personal data, address and parcel numbers, as these are private records). (Not public data by default; publication requires de-identification.)

Below an example of orchard owner's documentation about plant protection methods used against diseases and pests is presented:

Date	Register of agrotechnical, biological and chemical plant protection treatments				
	plant protection product or agrotechnical method used			Lp.	1 2 3 4 5 6 7 8 9 10
	name and recommendation of the decision support system and indication of the ordinal number of observation specified in Table XII.1	name [19]	dose kg(l)/ha or pcsm² (amount of usable liquid)		By the Pole
24.03.2025	1. Weather forecast	Nordox 75 WG	1.0 (500l/ha)	tick the right box	1-3
30.03.2025	2. Magnifier	Treol 770 EC	0.015 (1000l/ha)		1-3
04.04.2025	3. Thermometer	Miedzian 50 WP	1.5 (500l/ha)		1-3
10.04.2025	4. Forecasting models	Delan 700 WG	0.5 (500l/ha)		1-3
16.04.2025	5. Magnifying glass	Teppeki 50 WG	0.14 (500l/ha)		1-3
22,04.2025	6. Thermometer	Chorus Next	1.0 (500l/ha)		1-3
25.04.2025	7. Magnifier	Delan 700 WG	0.5 (500l/ha)		1-3
02.05.2025	8. Thermometer	Luna Experience 400 SC	0.75 (500l/ha)		1-3
05.05.2025	9. Magnifier	Siltac EC	0,1 % (500)		1-3
08.05.2025	10. Rain gauge	Captan 80 WDG*11/15/25	1.9 (750l/ha)		1-3
08.05.2025	11. Rain gauge	Difo 250 EC	0.2 (500l/ha)		1-3
15.05.2025	12. Weather forecast	Therefore 50 WG*06/30/25	0.2 (500l/ha)		1-3
19.05.2025	13. Weather forecast	Revyona	2.0 (500l/ha)		1-3

[19] The name of the plant protection product or the biological or agrotechnical method used must be indicated.

Figure 3. Example of orchard owner's documentation within Pilot#1

2.1.2 Pilot #2: Swifterbant, Flevoland, The Netherlands / Use case 1.1

Pilot 2 is situated at an arable farm in Swifterbant, Flevoland, The Netherlands. The involved partner is Delphy. The pilot is being conducted in onion cultivation. The trial field contains 5 objects in 4 replications, i.e. 20 plots. These 5 objects all have an RMA-soil sensor (data via API) and a different irrigation strategy. We can provide the following data: the crop yield per object (average over 4 replications) and the mm of irrigation per object (average over 4 replications) per season.

Figure 4. Location of the Pilot #2

Figure 5. Irrigation system at the Pilot #2

Pilot #2 focuses on reduce wasted irrigation water while ensuring healthy crop growth and stable yields. For these purposes all the required data streams are established. Results of this Pilot can be verified through a combination of quantitative measurements, comparative analysis, and agronomic validation that jointly demonstrate reduced water use without negative impacts on crop performance.

Figure 6. Sensor installation at the Pilot #2

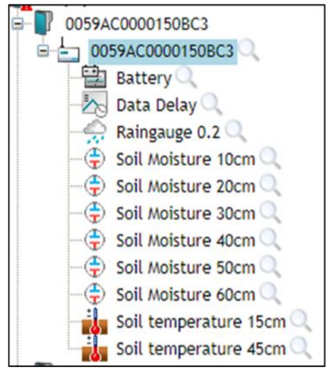


Figure 7. Overview of the measurements at the Pilot #2

Table 6. Summarized data table for Pilot#2

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Weather data soil data	Daily Daily	04/2026 – ongoing 04/2026 - ongoing	Yes	No
Activity log data	Field observations	On events	04/2026 - ongoing	Yes	No

Example of automatically record of the soil data is demonstrated below:

```
Date,VWC,EC,Temp,Depth,Cultivation,Type
2024-06-17T08:50:06Z,34.44862,0.34446722,16.116405,15,15D Zaaiuien 2024,Archived
2024-06-17T09:26:06Z,34.56325,0.34211108,16.573437,15,15D Zaaiuien 2024,Archived
2024-06-17T10:02:06Z,34.638542,0.3403663,16.867188,15,15D Zaaiuien 2024,Archived
2024-06-17T10:38:06Z,34.692417,0.33941713,17.002344,15,15D Zaaiuien 2024,Archived
2024-06-17T11:14:06Z,34.71943,0.33910006,16.916407,15,15D Zaaiuien 2024,Archived
2024-06-17T11:50:06Z,34.72297,0.33902323,17.004688,15,15D Zaaiuien 2024,Archived
2024-06-17T12:26:06Z,34.713646,0.33896187,17.002344,15,15D Zaaiuien 2024,Archived
2024-06-17T13:02:06Z,34.70299,0.33882385,16.934376,15,15D Zaaiuien 2024,Archived
2024-06-17T13:38:06Z,34.69588,0.33863688,17.259375,15,15D Zaaiuien 2024,Archived
2024-06-17T14:14:06Z,34.69455,0.33838555,17.4625,15,15D Zaaiuien 2024,Archived
2024-06-17T14:50:05Z,34.70742,0.3381098,17.702343,15,15D Zaaiuien 2024,Archived
2024-06-17T15:26:05Z,34.718964,0.3379076,17.775782,15,15D Zaaiuien 2024,Archived
2024-06-17T16:02:05Z,34.730064,0.33779436,18.054688,15,15D Zaaiuien 2024,Archived
2024-06-17T16:38:05Z,34.739403,0.3377546,17.9375,15,15D Zaaiuien 2024,Archived
2024-06-17T17:14:05Z,34.746517,0.3377791,18.059376,15,15D Zaaiuien 2024,Archived
2024-06-17T17:50:05Z,34.75364,0.33789235,17.785938,15,15D Zaaiuien 2024,Archived
2024-06-17T18:26:05Z,34.764324,0.33806685,17.741405,15,15D Zaaiuien 2024,Archived
2024-06-17T19:02:05Z,34.769222,0.33835492,17.508595,15,15D Zaaiuien 2024,Archived
2024-06-17T19:38:05Z,34.769222,0.33875692,17.224218,15,15D Zaaiuien 2024,Archived
2024-06-17T20:14:05Z,34.763885,0.33931315,16.735157,15,15D Zaaiuien 2024,Archived
2024-06-17T20:50:04Z,34.750988,0.34007105,16.5875,15,15D Zaaiuien 2024,Archived
2024-06-17T21:26:04Z,34.730976,0.3411094,16.217968,15,15D Zaaiuien 2024,Archived
```

Figure 8. Example of the soil data in Pilot#2

2.1.3 Pilot #3: Zemgale, Latvia / Use case 1.3

Pilot #3 is situated at an arable farm in Zemgale, Latvia. Responsible partner for this pilot is ZSA, which is the biggest agricultural organisation of producers in Latvia. Wheat and hard wheat are grown on the field. The main subcase of this pilot is managing the winter wheat leaf diseases.

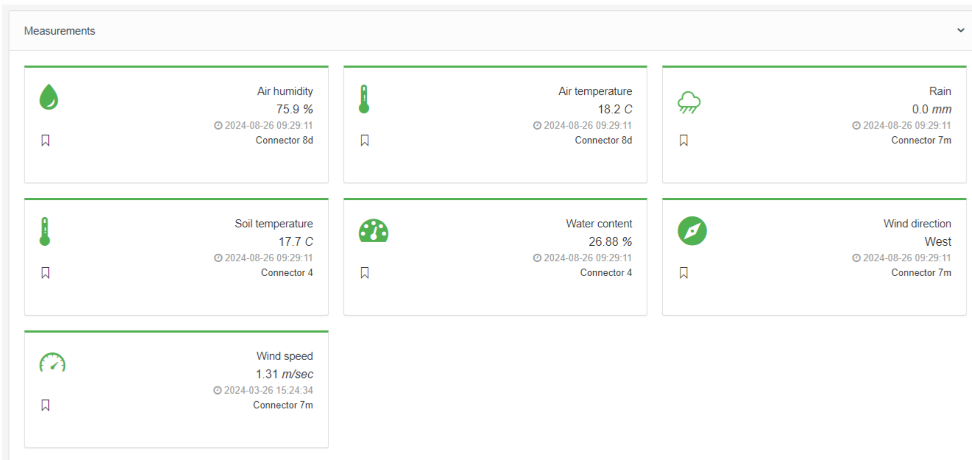


Figure 9. Weather station measurements in the online system

Figure 10. Installed Weather station in the Pilot #3

Pilot 3 focuses on reduction of the usage of pesticides by identification of wheat leaf diseases. For these purposes all the required data streams are established.

Table 7. Summarized data table for Pilot#3

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Synelixis weather station, soil sensor	Every 20 min.	02/2024 - ongoing	Yes	Yes
Activity log data	Field observations	On-request (each week)	02/2024 - ongoing	Yes	No

Example of manual record is demonstrated below:

Datums	Kviešu BBCH	Dzeltenpl.%	Pelēkpl.%	Miltrasa%	Br.rūsa%	Dz.rūsa%	Plēkšņu plank	Fuzarioze
					0	0	0	0
10.05.2023.	AS 32	0,04	0,05	0	0	0	0	0
17.05.2023.	AS 32	0,67	0,04	0	0	0	0	0
24.05.2023.	AS 37	0,21	0	0	0	0	0	0
01.06.2023	AS 45	0,21	0	0	0	0	0	0
08.06.2023.	AS 51	0,13	0	0	0	0	0	0
14.06.2023.	AS 61	0,13	0	Ascra Xpr	0	0	0	0
21.06.2023.				0	0	0	0	0
28.06.2023.				0	0	0	0	0
05.07.2023	AS 72	11,83	0,04	0	0	0	0	0
12.07.2023.	AS 75	15,63	0	0	0	0	79,17	0

Figure 11. Example of manual record for the disease monitoring within Pilot #3

For the implementation of the use case 1.3 within Pilot#3 wheat disease monitoring methodology is developed. Methodology describes required actions during different seasons and wheat growing stages.

Autumn / Demonstration setup, field selection, soil preparation, variety selection.
Usual set-up in Latvia:

- Soil cultivation = No-till
- Crop = Winter wheat
- Wheat variety = (Skagen, Ceylon, Zeppelin, Brons, Creator, Fenomen, Mariboss, KWS Malibu, Patras)
- Field observations = 3 times (Second week after sowing, 1 month after sowing, before wintering)

Spring / When the vegetation resumes, mark the boundaries of the variants (experiment scenario: Control, Owner opinion, System "Vesels Augs") in the field

Spring – Summer / Observations and disease records are performed once a week

- Starting from BBCH 30, the % of the development degree of all diseases is counted on the leaves of the entire plant (in each variant on 25 leaves)
- Starting from BBCH 39, the stages of development of all diseases are listed on the 3 upper leaves of the plant (in each variant on 25 leaves)
- In option 2, disease control is carried out according to the veselsaugs.lv disease risk assessment. If this is not carried out (it is not possible to carry out due to the absence of a weather station), then disease control is carried out according to the principles of integrated cultivation with a single fungicide treatment when the degree of disease development (for one or more diseases together) reaches 5% according to wheat BBCH 39.
- Take photographs of all the collected plant leaves, each variant, on a white background.
- The counted data is recorded in an Excel table.

Linking observations to the decision support program "Vesels augs"

- Perform the "Vesels Augs" disease calculator test every week and save the results for analysis (if meteorological data from stations is available)
- Using meteorological data in decision-making
- Choosing the time for fungicide treatment for option 2 according to the disease risk assessment recommended by "Vesels Augs" or according to the principles of integrated cultivation.

Summer

Harvest monitoring and analysis

- Record the yield of each scenario
- Determination of the yield quality of each scenario

Results:

- Economic evaluation of fungicide use (in relation to yield and crop quality)
- Comparison of different disease development rates over the years (relationship with meteorological data)
- Calculation of the effectiveness of fungicide use of all scenarios compared to the control option.

2.1.4 Pilot #4: Agrinio, Greece / Use case 1.1, 1.2

Pilot #4 is located in Agrinio, Etoloakarnania (Greece), and covers forages, i.e. clovers and corn crops for livestock feeding. This pilot is owned by TBA and directly involves 15 farmers.

Figure 12. SynField installations in Pilot #4

Table 8. Summarized data table for Pilot#3

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Synelixis weather station, soil sensor	Every 20 min.	04/2021 - ongoing	Yes	Yes
Activity log data	Field observations	On-request (each week)	06/2024 - ongoing	Yes	No

Data collection for Pilot #4 is conducted via SynField devices which collect the measurements from the deployed sensors and forward them to SynField platform. From there, the measurements are extracted periodically and saved in the STORE component of AgriDataValue. Figure 13 depicts an instance of the measurements collected.

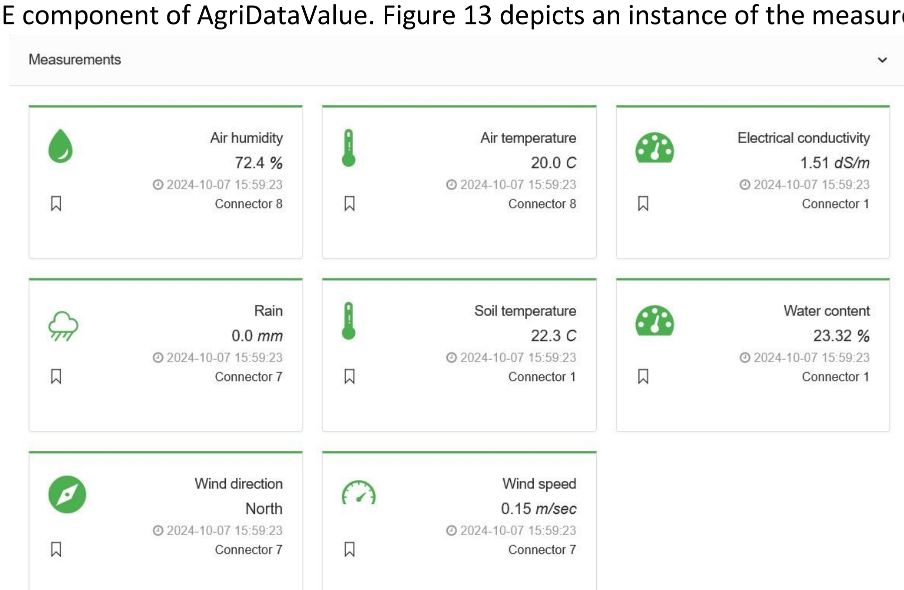


Figure 13. Overview of SynField measurements for Pilot #4

2.1.5 Pilot #5: Optifarm, Belgium / Use case 1.2, 1.3, 2.1

This pilot #5 takes place on a demonstration field of InAgro in Belgium that consists of multiple sections that have a crop rotation of both vegetables and arable crops. This demonstration field can be used to try out the newest innovations in agriculture in an environment that simulates an actual agricultural field without any risks to farmers.

Pilot#5 delivers data of Inagro's fields, mainly the Optifarm field containing multiple crops with a rotation of both arable crops and vegetables. The RGB data can be used to detect weeds, to create a model for spot-spraying which reduces pesticide usage. Yield data can be used for biomass estimation and nitrogen uptake modelling.

Figure 14. Example of the field scan by the soil scanner

Table 9. Summarized data table for Pilot#5

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
Meteorological services data	Belgian weather station data	Daily	2022-ongoing	Closed	No
Activity log data	Field activities	On events	2022-ongoing	Closed	No
Other data	Drone data (multispectral) Drone data (RGB) Laboratory data Soil scans Penetrologging Yield Satellite imagery	14 flights available Yearly Yearly One time only One time only Yearly Depends on cloud cover	2022-ongoing	Closed	No

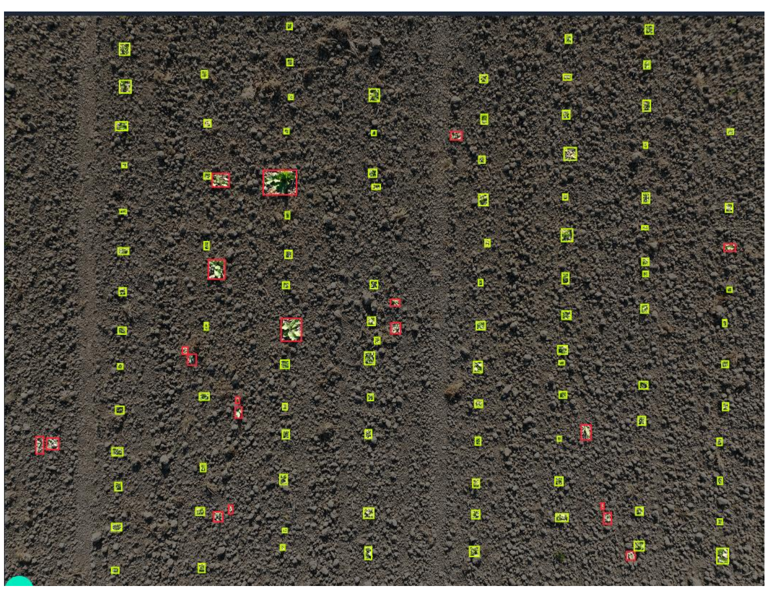


Figure 15. RGB drone image with celeriac (green) and weeds (red) labelled

Parallel	Object	marketable yield (kg/ha)	number of marketable plants	Average plant weight (g)	Waste (%)	Dropout %	Too small %	% < 2 cm)	% 2-3 cm	% 3-4 cm	% >4 cm	11/07/2024 NDVI	24/07/2024 NDVI	08/08/2024 NDVI	19/08/2024 NDVI	03/09/2024 NDVI	20/09/2024 NDVI	19/10/2024 NDVI
1	1	29300	93,33334	235,4464	0,8333333	5,833333	0,8333333	4,69875	42,40242	52,82304	0	0,2544678	0,2364431	0,4639251	0,4681664	0,5525398	0,6337196	0,697625
1	2	29777,78	92,5	241,4414	0,8333333	6,666667	0,8333333	2,982849	41,79716	55,14541	0	0,2654595	0,2426757	0,4873296	0,4785605	0,5640864	0,6717445	0,7131354
1	3	24788,89	90	206,5741	1,666667	8,333333	1,666667	5,503356	52,97539	41,34228	0	0,2508733	0,2332729	0,4585392	0,4499733	0,5424864	0,6512178	0,7050484
1	4	27144,45	90,83334	224,1284	0,8333333	8,333333	0,8333333	3,394683	40,818	55,70552	0	0,254064	0,2365313	0,4770373	0,4815129	0,5703774	0,6693907	0,7118551
1	5	29255,55	95,83334	228,9565	1,666667	2,5	1,666667	2,501895	42,53222	54,77634	0	0,2653217	0,2491153	0,4709411	0,4752379	0,5827166	0,6705703	0,7221195
1	6	28688,89	95	226,4912	1,666667	3,333333	0,8333333	2,929838	46,0293	50,57826	0	0,2570547	0,2429866	0,4550468	0,4628869	0,5634418	0,6775438	0,7202972
1	7	25822,22	92,5	209,3694	1,666667	5,833333	1,666667	8,161512	44,07217	47,5945	0	0,2573981	0,2336445	0,4524262	0,4495511	0,5436941	0,6455553	0,6990964
1	8	28422,22	90	236,8519	1,666667	8,333333	1,666667	3,864169	40,20296	55,77674	0	0,2615118	0,2347904	0,4634239	0,456048	0,556083	0,6707375	0,7163235
1	9	27977,78	87,5	239,8095	3,333333	9,166667	3,333333	4,707278	39,63607	55,26107	0	0,2584416	0,2344024	0,4508372	0,442125	0,5347164	0,6540877	0,7008528
2	1	28677,78	91,66666	234,6364	0,8333333	7,5	0,8333333	4,916763	40,22454	54,78126	0	0,2420002	0,2210954	0,4181088	0,424466	0,5427531	0,6609101	0,6964377
2	2	27377,78	94,16666	218,0531	0	5,833333	0	5,113636	40,25974	54,62663	0	0,2542771	0,2340258	0,4372794	0,4291834	0,5277813	0,6374425	0,7082591
2	3	29722,22	95	234,6491	0	5	0	3,214953	36,03738	58,28037	2,46729	0,2536741	0,2337235	0,4723102	0,4697583	0,5879006	0,681598	0,721663
2	4	28311,11	90	235,9259	3,333333	6,666667	3,333333	2,267396	42,10321	55,23847	0	0,2491957	0,2247409	0,4516946	0,4430345	0,5502303	0,6665951	0,7127069
2	5	28744,45	92,5	233,0631	0,8333333	6,666667	0,8333333	3,553496	39,51332	56,85593	0	0,2515563	0,2283669	0,4665027	0,4499006	0,5621639	0,6782047	0,7146521
2	6	29033,33	96,66666	225,2586	0	3,333333	0	4,554152	38,15538	57,29047	0	0,2502825	0,2257827	0,4661629	0,4649767	0,564899	0,6651438	0,7151612
2	7	30388,89	93,33334	244,1964	0	6,666667	0	2,486289	37,9159	59,59781	0	0,2503775	0,2301607	0,4565391	0,4568766	0,5673062	0,6773583	0,7152737
2	8	28722,22	90,83334	237,156	4,166667	5	4,166667	3,041971	39,08356	57,4124	0	0,2434625	0,2247382	0,457877	0,4542306	0,5587575	0,6645357	0,7181282
2	9	29833,33	96,66666	231,4655	0	3,333333	0	4,506518	41,41527	54,07821	0	0,2504829	0,2327164	0,4433193	0,4562597	0,5686708	0,6686932	0,7112893
3	1	28933,33	90,83334	238,8991	2,5	6,666667	2,5	5,287356	37,70115	56,78161	0	0,2470428	0,2281574	0,4542682	0,4399748	0,5400025	0,643463	0,6978523
3	2	27844,45	94,16666	221,7699	2,5	3,333333	2,5	3,105096	47,01433	49,64172	0	0,2449273	0,2218484	0,4639421	0,4585401	0,5647626	0,6674178	0,7149476
3	3	27377,78	90,83334	226,055	1,666667	7,5	0,8333333	3,26087	44,92754	51,00644	0	0,2488674	0,2237519	0,4267298	0,424028	0,5310531	0,6573179	0,7123312
3	4	25877,78	82,5	235,2525	5,833333	11,66667	5,833333	2,812101	35,23647	61,18449	0	0,2411684	0,2169626	0,4261891	0,4166307	0,5244302	0,6581356	0,7032222
3	5	28133,33	95,83334	220,1739	1,666667	2,5	1,666667	5,402208	54,10094	40,33912	0	0,2608736	0,2347093	0,4492437	0,4347237	0,5442318	0,6493176	0,7219232
3	6	27377,78	91,66666	224	3,333333	5	3,333333	4,688763	50,32336	44,58367	0	0,257269	0,2259818	0,4336254	0,4326087	0,5400144	0,6597141	0,7180765
3	7	28433,33	95	224,4737	0	5	0	2,461899	40,17194	57,36616	0	0,2457495	0,2194877	0,461367	0,4508602	0,5642992	0,6717236	0,7156981
3	8	29111,11	92,5	236,036	1,666667	5,833333	1,666667	1,829268	45,23628	52,78201	0	0,2594242	0,2319382	0,4588352	0,4561835	0,5611613	0,6586555	0,7322779
3	9	31322,22	94,16666	249,469	0,8333333	5	0,8333333	2,410493	39,91492	54,94505	2,658632	0,244335	0,2258503	0,4480871	0,4404847	0,5437934	0,652408	0,7070796
4	1	26188,89	90,83334	216,2385	0	9,166667	0	2,969877	39,62664	57,40348	0	0,253964	0,230081	0,460685	0,454188	0,5500199	0,6531261	0,7037217

Figure 16. Yield and drone data

2.1.6 Pilot #6: Almeria, Spain / Use case 2.1, 2.3 & 2.4

Pilot#6 focuses on the optimization and predictive management of greenhouse vegetable production (tomato and cucumber) under Mediterranean conditions in Almería (Spain). The responsible partner for this pilot is Tecnova, an Andalusian Technological Centre for the Agricultural Industry, comprising approximately 125 private companies. In this pilot, tomatoes and cucumbers are grown in a greenhouse environment. The main objective of this subcase is to optimize the management of crop development.

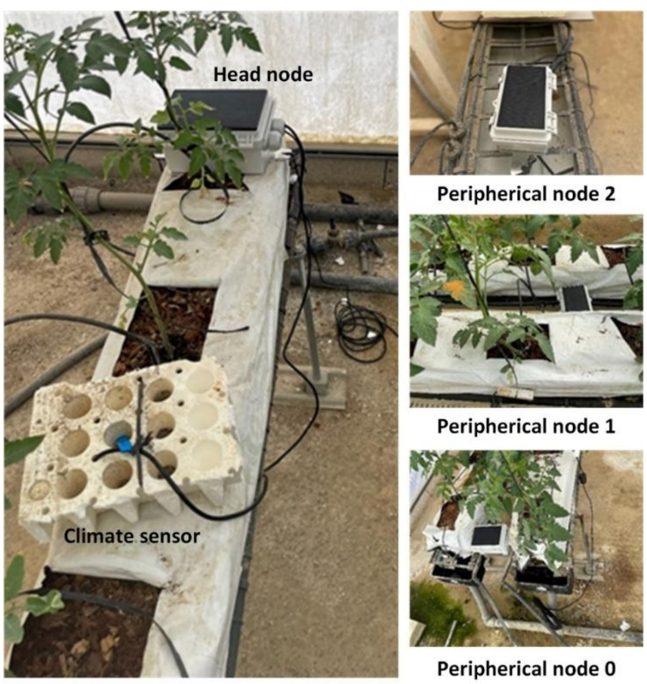


Figure 17. Environmental and edaphology station

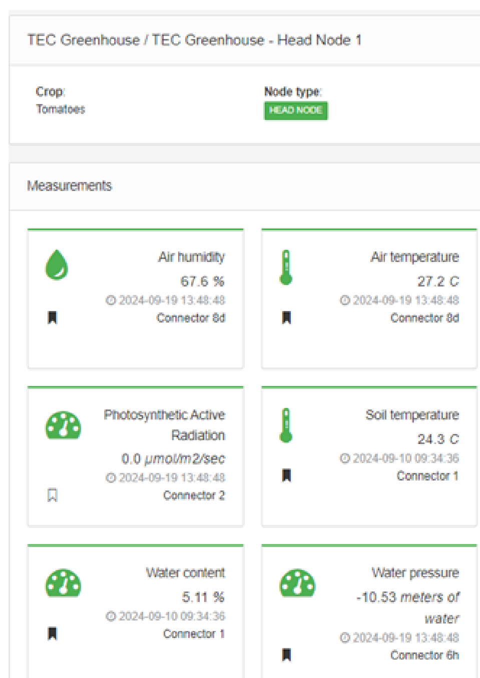


Figure 18. Data in the SynField platform for the Pilot #6

The pilot addresses three complementary use cases: precision irrigation and fertilization management, quality prediction through soluble solids content (ºBrix), and automated climate control via greenhouse window management. For these purposes, all the required data streams are established and integrated at pilot level.

Table 10. Summarized data table for Pilot6

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Soil moisture, soil temperature, soil electrical conductivity, air temperature, air relative humidity, air pressure	10–15 min	02.26 – ongoing	Closed	No
Meteorological services data	External weather data (temperature, humidity, radiation, precipitation)	60 min	02.26 – ongoing	Open	Yes
IoT Data (manually)	Hyperspectral images (Specim FX10), image labelling	Campaign-based	02.26 – ongoing	Closed	Partial
Activity log data	Crop management records (irrigation events, fertigation recipes, phenological stage, window opening actions)	On events	02.26 – ongoing	Closed	No
Other data	Physiological parameters (leaf temperature), yield and quality measurements (ºBrix)	Campaign-based	02.26 – ongoing	Closed	No

Excerpt of the data used for model development:

The data used for model development include continuous time-series data from soil and climate sensors deployed in the greenhouse, complemented by hyperspectral image datasets and crop management logs. These datasets are used to train and validate predictive models for fertigation optimization, fruit quality estimation, and climate control actions.

Intended model

- **Use case 2.1:** Predictive models for precision irrigation and fertilization management aimed at reducing water and nutrient inputs while maintaining or increasing crop productivity.
- **Use case 2.3:** Machine learning models for the estimation of tomato soluble solids content (ºBrix) based on hyperspectral imagery.
- **Use case 2.4:** Decision-support and predictive models for automated greenhouse window control to optimize internal climate conditions and energy efficiency.

2.1.7 Pilot #7: West-Flanders, Belgium / Use case 1.1, 5.4

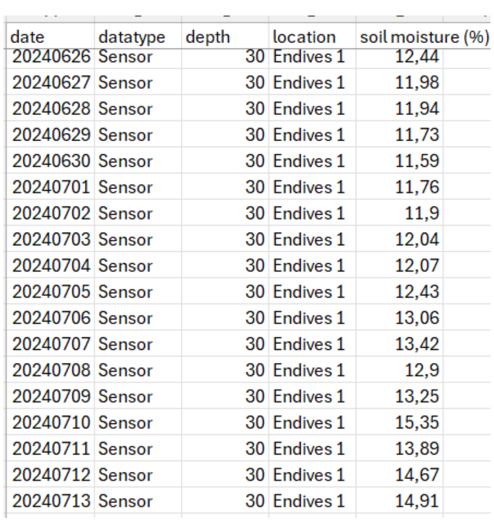
Pilot#7 is situated in West-Flanders in Belgium with InAgro as responsible partner. The pilot is focused on vegetables such as Belgian Endives, potatoes, spinach and beans. Sufficient soil moisture is of great importance in these crops, for Belgian Endives especially around the time of seed emergence. These seeds are expensive, and a good emergence is essential to qualitive product. Soil moisture can be measured in field with sensors, but these sensors are often expensive and require proper installation and maintenance. Some commercial websites offer a soil moisture estimation based on satellite imagery. IOT GEOBAS weather stations were installed. These weather stations can measure soil moisture, soil temperature, water potential, precipitation, relative humidity and air temperature. However, the pilot mainly focusses on soil moisture estimations through satellite imagery.

Figure 19. GEOBAS weather station on the field

Table 11. Summarized data table for Pilot#7

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Weather station data (incl soil moisture)-	hourly	2024- ongoing-	Closed	No
Meteorological services data	Belgian weather station data	60 min	2011- ongoing	Closed	No
Activity log data	Irrigation	On events	2011-ongoing	Closed	No
Other data	Soil moisture labanalyses Irriwatch Emergence data	On events Daily On events	2024- ongoing 2024- ongoing 2011- ongoing	Closed	No

Excerpt of the data used for model development:



date	datatype	depth	location	soil moisture (%)
20240626	Sensor	30	Endives 1	12,44
20240627	Sensor	30	Endives 1	11,98
20240628	Sensor	30	Endives 1	11,94
20240629	Sensor	30	Endives 1	11,73
20240630	Sensor	30	Endives 1	11,59
20240701	Sensor	30	Endives 1	11,76
20240702	Sensor	30	Endives 1	11,9
20240703	Sensor	30	Endives 1	12,04
20240704	Sensor	30	Endives 1	12,07
20240705	Sensor	30	Endives 1	12,43
20240706	Sensor	30	Endives 1	13,06
20240707	Sensor	30	Endives 1	13,42
20240708	Sensor	30	Endives 1	12,9
20240709	Sensor	30	Endives 1	13,25
20240710	Sensor	30	Endives 1	15,35
20240711	Sensor	30	Endives 1	13,89
20240712	Sensor	30	Endives 1	14,67
20240713	Sensor	30	Endives 1	14,91

Figure 20. Dataset with irriwatch/sensor and lab soil moisture

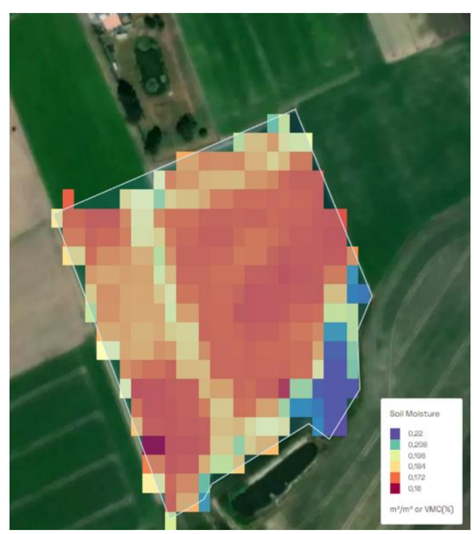


Figure 21. Example of the soil moisture calculations

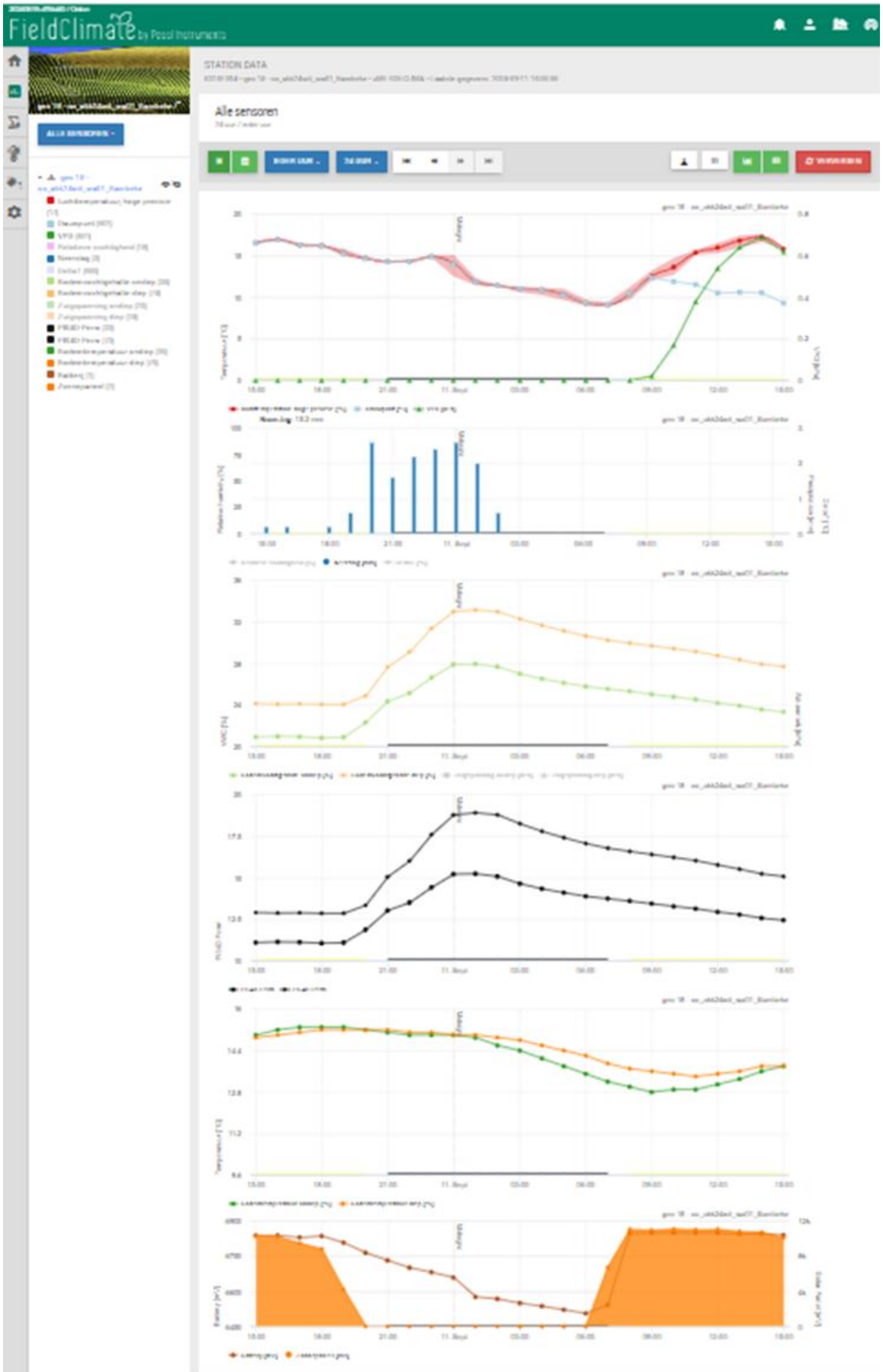


Figure 22. Screenshot from the FieldClimate

Year	Date	Days after sowing	Variety type	nr	volgnr	rowID	emergence per m²	seeds/ ha	emergence %	Location shapefile	Sowing date
2011	2011-06-09	18	early	11	1	2011.11.1	11,4	38,1	30	2011 Menen	2011-05-22
2011	2011-06-09	18	early	15	5	2011.15.5	20,7	38,1	54,38	2011 Menen	2011-05-22
2011	2011-06-09	18	early	19	9	2011.19.9		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	winter	32	14	2011.32.1	27,1	38,1	71,25	2011 Menen	2011-05-22
2011	2011-06-09	18	winter	36	18	2011.36.18		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	winter	40	22	2011.40.2	5	38,1	13,13	2011 Menen	2011-05-22
2011	2011-06-09	18	late	53	27	2011.53.2	3,6	38,1	9,38	2011 Menen	2011-05-22
2011	2011-06-09	18	late	57	31	2011.57.3	27,9	38,1	73,13	2011 Menen	2011-05-22
2011	2011-06-09	18	late	61	35	2011.61.3	10	38,1	26,25	2011 Menen	2011-05-22
2011	2011-06-09	18	very late	74	40	2011.74.4	2,1	38,1	5,63	2011 Menen	2011-05-22
2011	2011-06-09	18	very late	78	44	2011.78.4	8,6	38,1	22,5	2011 Menen	2011-05-22
2011	2011-06-09	18	early	11	45	2011.11.4	4,3	38,1	11,25	2011 Menen	2011-05-22
2011	2011-06-09	18	early	15	49	2011.15.49		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	early	19	53	2011.19.5	2,1	38,1	5,63	2011 Menen	2011-05-22
2011	2011-06-09	18	winter	32	58	2011.32.5	12,1	38,1	31,88	2011 Menen	2011-05-22
2011	2011-06-09	18	winter	36	62	2011.36.6	20	38,1	52,5	2011 Menen	2011-05-22
2011	2011-06-09	18	winter	40	66	2011.40.66		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	late	53	71	2011.53.7	2,1	38,1	5,63	2011 Menen	2011-05-22
2011	2011-06-09	18	late	57	75	2011.57.7	22,9	38,1	60	2011 Menen	2011-05-22
2011	2011-06-09	18	late	61	79	2011.61.7	12,1	38,1	31,88	2011 Menen	2011-05-22
2011	2011-06-09	18	very late	74	84	2011.74.8	0	38,1	0	2011 Menen	2011-05-22
2011	2011-06-09	18	very late	78	88	2011.78.8	6,4	38,1	16,88	2011 Menen	2011-05-22
2011	2011-06-09	18	early	11	89	2011.11.8	8,6	38,1	22,5	2011 Menen	2011-05-22
2011	2011-06-09	18	early	15	93	2011.15.9	12,9	38,1	33,75	2011 Menen	2011-05-22
2011	2011-06-09	18	early	19	97	2011.19.97		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	winter	32	102	2011.32.1	18,6	38,1	48,75	2011 Menen	2011-05-22
2011	2011-06-09	18	winter	36	106	2011.36.106		38,1		2011 Menen	2011-05-22
2011	2011-06-09	18	winter	40	110	2011.40.1	12,1	38,1	31,88	2011 Menen	2011-05-22
2011	2011-06-09	18	late	53	115	2011.53.1	11,4	38,1	30	2011 Menen	2011-05-22

Figure 23. Dataset with Belgian endive emergence

2.1.8 Pilot #8: Flanders, Belgium / Use case 1.2, 2.1, 2.2

Pilot#8 on leeks, a model to estimate nitrogen uptake will be made. It is the intention of optimizing the nitrogen fertilization by determining the nitrogen uptake over time by the crop. This will allow the farmers to reduce fertilization by using precision farming techniques. A correctly timed and dosed fertilization will also increase the leek yield and/or quality. Data was acquired by GEOBAS weather stations. This weather stations can measure soil moisture, soil temperature, water potential, precipitation, relative humidity and air temperature.

Figure 24. GEOBAS weather station installed on Pilot #8

Table 12. Summarized data table for Pilot#8

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Weather station data (incl soil moisture)-	hourly-	2020	Closed	No
Meteorological services data	Belgian weather station data	daily	2019-2022	Closed	No
IoT Data (manually)	-	-	-	-	No
Activity log data	Field activities (fertilization)	On events	2019-2022	Closed	No
Other data	Drone data (multispectral) Yield data Soil samples Dry matter Nitrogen uptake Satellite imagery	On events Yearly Yearly Yearly Yearly Depends on cloud cover	2019-2022	Closed	No

Excerpt of the data used for model development:

ID	Harvesting date (dd/mm/yyyy)	Flandria-quality(% of net yield)	A1-quality (% of net yield)	% < 2 cm)	% 2-3 cm	% 3-4 cm	% >4 cm	Dry matter plants harvested (%)	DM-yield (g DM/plant) calculated on total bioma
WIKI-2020-A.1.1.1	19/01/2021	97,6	2,4	1,4	74,4	22,0	2,1	11,19	39,14
WIKI-2020-A.1.1.2	19/01/2021	88,6	11,4	2,3	64,9	32,8	0,0	10,51	36,10
WIKI-2020-A.1.1.3	19/01/2021	95,1	3,6	0,7	47,5	50,5	0,0	11,38	46,78
WIKI-2020-A.1.1.4	19/01/2021	99,1	0,9	1,3	57,3	38,3	3,2	11,60	42,06
WIKI-2020-A.2.1.1	19/01/2021	96,4	3,6	3,0	63,8	33,3	0,0	11,67	37,07
WIKI-2020-A.2.1.2	19/01/2021	96,2	3,8	3,3	62,5	34,2	0,0	11,55	41,41
WIKI-2020-A.2.1.3	19/01/2021	97,2	2,8	2,7	53,4	43,9	0,0	11,84	38,18
WIKI-2020-A.2.1.4	19/01/2021	95,2	4,8	2,0	51,3	41,7	5,0	11,33	46,65
WIKI-2020-A.3.1.1	19/01/2021	96,4	3,6	3,2	67,0	29,8	0,0	11,69	39,69
WIKI-2020-A.3.1.2	19/01/2021	94,6	5,4	3,6	59,9	36,5	0,0	11,02	40,91
WIKI-2020-A.3.1.3	19/01/2021	97,9	2,1	2,7	56,5	37,5	3,3	11,33	44,95
WIKI-2020-A.3.1.4	19/01/2021	95,6	4,4	5,0	70,3	24,8	0,0	12,01	44,98
WIKI-2020-A.4.1.1	19/01/2021	95,9	4,1	3,8	64,5	31,7	0,0	12,36	37,91
WIKI-2020-A.4.1.2	19/01/2021	100,0	0,0	3,2	61,6	31,3	3,9	12,19	43,18
WIKI-2020-A.4.1.3	19/01/2021	97,2	2,8	2,7	70,9	26,4	0,0	10,45	34,66
WIKI-2020-A.4.1.4	19/01/2021	95,9	4,1	3,4	65,9	30,7	0,0	10,61	32,24
WIKI-2020-C.1.1.1	7/12/2020	100,0	0,0	12,8	38,2	49,0	0,0	12,86	48,52
WIKI-2020-C.1.1.2	7/12/2020	100,0	0,0	34,4	32,8	32,8	0,0	10,60	44,67
WIKI-2020-C.1.1.3	7/12/2020	100,0	0,0	13,4	38,0	48,6	0,0	10,68	41,92
WIKI-2020-C.1.1.4	7/12/2020	100,0	0,0	10,2	37,6	52,2	0,0	10,05	44,77
WIKI-2020-C.2.1.2	7/12/2020	100,0	0,0	15,6	38,5	45,9	0,0	10,88	46,08
WIKI-2020-C.2.1.4	7/12/2020	100,0	0,0	19,5	34,6	45,9	0,0	10,57	43,82
WIKI-2020-C.2.1.1	7/12/2020	100,0	0,0	16,1	46,0	38,0	0,0	10,20	37,91
WIKI-2020-C.2.1.3	7/12/2020	100,0	0,0	12,4	38,2	49,4	0,0	10,22	40,70
WIKI-2020-C.3.1.3	7/12/2020	100,0	0,0	9,4	40,6	50,0	0,0	10,85	50,40
WIKI-2020-C.3.1.4	7/12/2020	100,0	0,0	8,4	36,3	55,3	0,0	10,18	47,52
WIKI-2020-C.3.1.1	7/12/2020	100,0	0,0	10,2	33,7	56,1	0,0	11,55	50,09
WIKI-2020-C.3.1.2	7/12/2020	100,0	0,0	10,0	33,5	56,6	0,0	10,19	46,27
WIKI-2020-C.4.1.3	7/12/2020	100,0	0,0	8,6	40,1	51,2	0,0	10,50	48,32

Figure 25: Collected yield data of the leeks

2.1.9 Pilot #9: Flanders, Belgium / Use case 1.4

Pilot#9 focusses on post-harvest potato quality. A classification model will be created that will use hyperspectral images of potatoes to detect defects such as black spot.

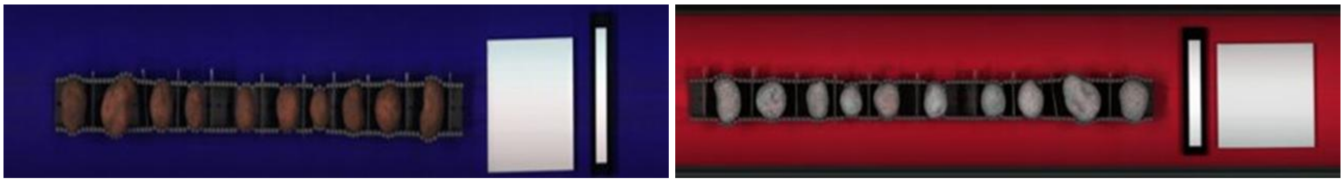


Figure 26. Example of a potato scanning process

Table 13. Summarized data table for Pilot#9

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
Other data	Hyperspectral data Defect scores Dry matter content	-	-	Closed	No

Excerpt of the data used for model development:

Batch	ID	Scab score	Blackspot	% DM
1	0	6	5	27,3224
1	1	3	5	22,74602
1	2	2	5	23,57398
1	3	4	5	23,55795
1	4	4	5	
1	5	3	5	
1	6	4	5	
1	7	3	5	
1	8	4	5	
1	9	3	5	
1	10	4	5	
1	11	4	5	
1	12	3	5	
1	13	3	5	
1	14	2	5	
2	0	3	5	
2	1	3	5	
2	2	2	5	
2	3	3	5	
2	4	2	5	
2	5	4	5	
2	6	2	5	
2	7	2	4	
2	8	3	5	
2	9	4	5	
2	10	3	5	
2	11	3	5	

Figure 27: manual scores of the quality defects in potatoes

2.1.10 Pilot #10 Flanders, Belgium/ Use case 5.4 (formerly also 1.2, 1.3 and 2.1)

Pilot#10 created a learning network of farmers willing to do experiments on reducing fertilizers with open field precision fertilization and reducing pesticides. Above all the goal is to increase farmers' digital independence. There will no longer be a model created in this pilot so further data collection is suspended. The pilot will from now on solely focus on increasing farmers' digital independence.

Figure 28: InAgro's ''Open company day'' event

Table 14. Summarized data table for Pilot#20

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
Meteorological services data	Belgian weather station data	Daily	2022-2025	Closed	No
Other data	Fertilization map Plant counts Satellite data Yield data + quality sorting Soil analyses	On events	2022-2025	Closed	No

Excerpt of the data used for model development:

Field	Date	Treatment	Begin depth	End depth	Nitrate kg/ha NO3-N DS	Dry matter %
OO_AKK22AAR_BM01	19/09/2022 15:27	1	0	30	91,43	87,37
OO_AKK22AAR_BM01	19/09/2022 15:27	1	30	60	9,63	90,12
OO_AKK22AAR_BM01	19/09/2022 15:27	2	0	30	82,45	86,36
OO_AKK22AAR_BM01	19/09/2022 15:28	3	0	30	71,47	88,12
OO_AKK22AAR_BM01	19/09/2022 15:28	4	0	30	103,42	86,78
OO_AKK22AAR_BM01	19/09/2022 15:28	5	0	30	80,09	88,98
OO_AKK22AAR_BM01	19/09/2022 15:28	6	0	30	72,19	86,18
OO_AKK22AAR_BM01	19/09/2022 15:27	6	30	60	48,51	86,54
OO_AKK22AAR_BM01	19/09/2022 15:27	6	60	90	63,5	84,53
OO_AKK22AAR_BM01	7/06/2022 15:07	1	0	30	105,59	86,84
OO_AKK22AAR_BM01	7/06/2022 15:07	1	30	60	23,81	85,11
OO_AKK22AAR_BM01	7/06/2022 15:07	2	0	30	92,06	85,92
OO_AKK22AAR_BM01	7/06/2022 15:07	2	30	60	34,25	83,89
OO_AKK22AAR_BM01	7/06/2022 15:07	3	0	30	117,74	87,54
OO_AKK22AAR_BM01	7/06/2022 15:08	3	30	60	64,92	87,3
OO_AKK22AAR_BM01	7/06/2022 15:06	4	0	30	104,31	86,94
OO_AKK22AAR_BM01	7/06/2022 15:06	4	30	60	75,02	85,96
OO_AKK22AAR_BM01	7/06/2022 15:08	5	0	30	73,6	88,19
OO_AKK22AAR_BM01	7/06/2022 15:08	5	30	60	57,68	87,82
OO_AKK22AAR_BM01	7/06/2022 15:06	6	0	30	96,64	86,18
OO_AKK22AAR_BM01	7/06/2022 15:06	6	30	60	28,83	85,09
OO_AKK23AAR_BM05	02/10/2023 13:54	1	0	30	7,97	88,75

Figure 29: nitrogen residues before and after fertilizer reduction by open field precision fertilization.

2.1.11Pilot #11: Gelderland, The Netherlands /Use case 1.3

Pilot#11 is based in The Netherlands and will focus on the crop off apple. A model will be made for determining the crop load levels to achieve the highest yield without risking an off year for the next. Another model will predict the fruit size.

Figure 30. Location of the Pilot #11

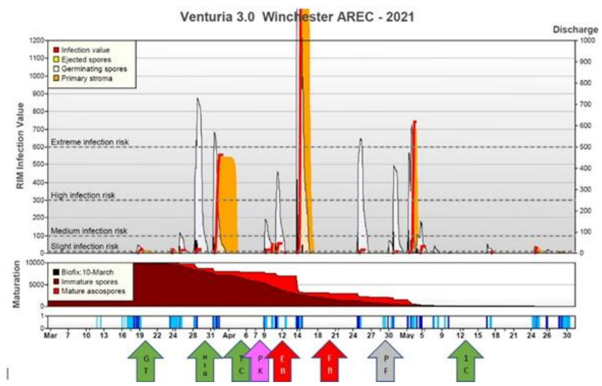


Figure 31. Weather information at the Pilot #11

Table 15. Summarized data table for Pilot#11

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
Camera systems	Flowering density, vigour density, cropload/fruitsize	2 to 3 times pro season	2025-2028	No	No/partly
Meteorological services data	Weather Data KNMI	Hourly based	2023-2028	Yes	Yes
Manual control	Flower numbers, vigour levels, cropload and fruitzis.	On-demand	2023-2028	Yes	Yes

Figures below demonstrates examples of data and shapefiles, which are used in the Pilot#11.

	id	vegetation_height_m	canopy
1	0	2,07	1,04
2	1	2,37	1,29

Figure 32. Data example for Pilot#11

	id	image_id	blossom_cluster_count
1	7246	d9467e5f-8057-...	147
2	5749	2b83926d-3088...	146
3	7245	2b6489bf-d50f-...	145
4	5330	916cd87d-935d...	143

Figure 33. Shapefile used in Pilot#11

2.1.12Pilot #12: Aragon, Spain /Use case 1.3; 3.1

Pilot 12 is being implemented on stone and pome fruit farms in Aragon, northeastern Spain. It combines meteorological data from the SIAR network with field observations on phenology and pest prevalence from the Aragon Phytosanitary Network (Red FARA). Using Big Data and AI under the guidance of government agronomists, the project develops Machine Learning models to predict phenological stages and disease risk for each plot. Accurate forecasts help farmers optimize the timing and necessity of phytosanitary treatments, whose effectiveness depends on crop stage. This approach supports Use Cases 3.1 and 1.3 through iterative refinement of predictive models. Table 16 shows the description of the data sources considered for creating the dataset used to train and use the models. The resulting dataset has already uploaded at zenodo repository, and it is available at: ***https://doi.org/10.5281/zenodo.17975075***

Figure 34. RedFAra monitoring points at the Pilot #12

Table 16. Summarized data table for Pilot#12

Data source	**Data type**	**Data frequency (minutes or days)**	**Data time period**	**Data access**	**Publishable**
SIAR Meteorological Stations Network	Numerical time series (T, RH, P, etc.)	30'	2009	Restricted	Yes (under recognition of SIAR)
Ref FARA phenological field observations	Qualitative (BBCH scale)	Weekly (+/-3 days)	2009	Restricted	Yes (but transformed and under recognition of Red FARA)
Ref FARA phenological field observations	Qualitative (BBCH scale)	Weekly (+/-3 days)	2009	Restricted	Yes (but transformed and under recognition of Red FARA)

2.1.13 Pilot #13: Etoloakarnania, Greece/ Use Case 3.3

Pilot #13 is located in Amfilochia, Etoloakarnania, Greece. The focus of Pilot #13 will be UC3.3 - Pest Control on Mediterranean Fruit Fly. In the context of Pilot #13, an SynField X5 device has been installed, along with:

- a meteorological station for the collection of environmental measurements (e.g. wind speed and direction, temperature, relative humidity, rainfall),
- a soil sensor for the collection of soil-related measurements (temperature, volumetric water content, electrical conductivity),
- a leaf wetness sensor, and
- a pyranometer for the measurement of solar radiation.


Figure 35: SynField SynTrap

Moreover, a SynTrap nodes has been implemented and installed in the pilot. Synelixis SynTrap has integrated computer vision and AI to enhance pest monitoring and control. At the core of the system is an embedded high-resolution micro-camera integrated with a SynNano device (used for providing connectivity) and a conventional pheromone/bait-based trap. The embedded optical sensor is equipped with lens providing a horizontal field of view (HFOV) of 75 degrees, enabling wide-angle coverage of the trap's interior. Periodically, the camera captures images of insects attracted to the trap and transmits them to the SynField cloud server, where advanced AI algorithms, process these images, automatically distinguishing the target species from non-relevant insects based on morphological features.

Data collection in the context of Pilot #13 is conducted via SynField devices collecting data from the deployed sensors. These measurements are periodically extracted and saved in the STORE component of AgriDataValue. The following figures depict the measurements that are collected in the context of Pilot #13.

2.1.14 Pilot#14: Saint-Émilion, France/ Use case 3.2

Pilot#14 is located in the Saint-Émilion vineyard (France) and is involved in one use case (UC 3.2). The objective of this use case is the early detection and prediction of frost events, in order to support winegrowers in optimising their active frost protection systems. The Saint-Émilion vineyard covers approximately 7,500 hectares and is equipped with a large network of weather stations, enabling the exploitation of historical meteorological data (air temperature, air and soil humidity, soil temperature, wind, etc.), particularly during the past frost periods. Satellite data are also available and will be used to carry out a model for the prediction of frost events. Moreover, the following SynField devices have been installed (Figure 37):

- 2 SynField X5 Head Nodes
- 2 SynOdos Peripheral Nodes
- 2 weather stations
- 4 leaf wetness sensors
- 4 soil moisture sensors
- 1 pyranometer

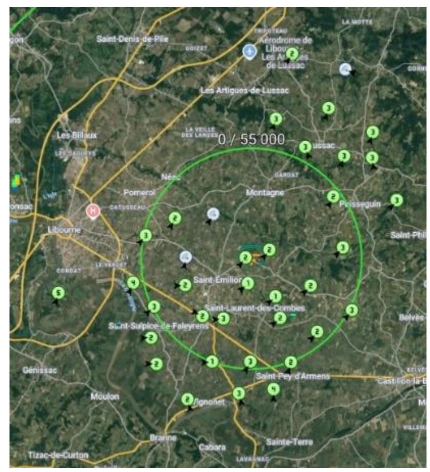


Figure 36. Location of the 37 weather stations provided by SELERYS

The aim is to measure the air temperature and humidity in two frost-sensitive areas in the Pilot #14 and to study their impact on the frost risk. The first is located in the northeast and the second one in the south (Figure 38).

Figure 37. Air and soil sensors installed in Pilot #14

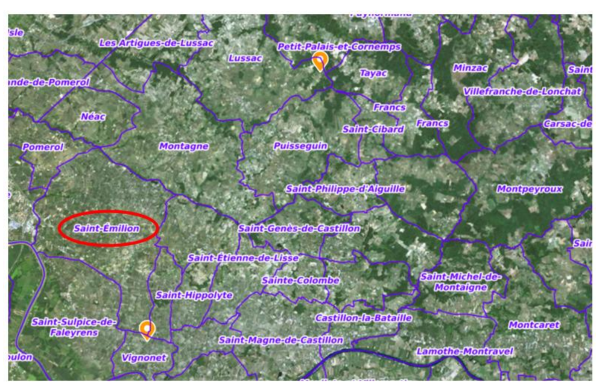


Figure 38. Location of the two fields in the Pilot #14 where the sensors were installed

A federated machine learning model is under development for Pilot 14 by Synelixis, with support from SIXENS for data labelling, and applied to pilots 15 and 16, which address similar challenges.

Table 17. Summarized data table for Pilot#14

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	SENCROP weather stations (historical) SynField sensors (real time data)	Variable (hourly/daily)	2017-2024 2024- 2028	Yes Yes	Yes Yes
Satellite data	Optical imagery (MODIS, LANDSAT, SENTINEL)	6-16 days	1986- 2028	Yes	Yes
Meteorological services data	MeteoFrance API	Daily and sub-daily data	1986 – 2028	Yes	Yes
Activity log data	Climate models (ERA5, CMIP6, etc.) Field observations (i.e. phenological stage, frost damage assessment)	Yearly Observations before and after the frost event	1990-2028 2027-2028	Yes No	Yes No
Other data	Topography & pedology	-	2025-2028	Yes	Yes

ID	time	mean_wind_speed	wind_direction	wind_gust	air_temperature	dew_point	air_pressure	sea_pressure	precip_intensity	precip_amount	synop_code	Brightness	humidity	wet_bulb
667302	01/01/2023 00:00	20.9	105.9	30.6	12.2	10.4	1014.49	1019.43	0	0	0	0	88.8	11.2
667303	01/01/2023 00:01	20.9	105.5	30.6	12.2	10.4	1014.5	1019.44	0	0	0	0	88.8	11.2
667304	01/01/2023 00:02	20.5	104.8	30.6	12.2	10.4	1014.51	1019.45	0	0	0	0	88.8	11.2
667305	01/01/2023 00:03	20.5	104.8	31.3	12.2	10.4	1014.52	1019.46	0	0	0	0	88.8	11.2
667306	01/01/2023 00:04	19.8	104.6	31.3	12.2	10.4	1014.52	1019.46	0	0	0	0	88.8	11.2
667307	01/01/2023 00:05	19.4	104.8	31.3	12.2	10.4	1014.54	1019.48	0	0	0	0	88.8	11.2
667308	01/01/2023 00:06	19.1	104.8	31.3	12	10.3	1014.55	1019.49	0	0	0	0	89.3	11.1
667309	01/01/2023 00:07	19.1	105.4	31.3	12	10.3	1014.55	1019.49	0	0	0	0	89.3	11.1
667310	01/01/2023 00:08	18.4	105.4	31.3	12	10.3	1014.56	1019.5	0	0	0	0	89.3	11.1
667311	01/01/2023 00:09	18.4	105.5	31.3	12	10.3	1014.56	1019.5	0	0	0	0	89.3	11.1
667312	01/01/2023 00:10	18.4	105.5	31.3	12	10.3	1014.56	1019.5	0	0	0	0	89.3	11.1
667313	01/01/2023 00:11	18.4	105.4	31.3	12	10.3	1014.55	1019.49	0	0	0	0	89.3	11.1
667314	01/01/2023 00:12	18.4	105.7	31.3	11.9	10.3	1014.54	1019.48	0	0	0	0	89.9	11.0
667315	01/01/2023 00:13	18.4	105.5	26.6	11.9	10.2	1014.53	1019.47	0	0	0	0	89.3	11.0
667316	01/01/2023 00:14	19.1	106.1	31.3	11.9	10.2	1014.52	1019.46	0	0	0	0	89.3	11.0
667317	01/01/2023 00:15	19.4	106.6	31.3	11.9	10.2	1014.51	1019.45	0	0	0	0	89.3	11.0

Figure 39. Example of measurements provided by the weather station of the SELERYS system

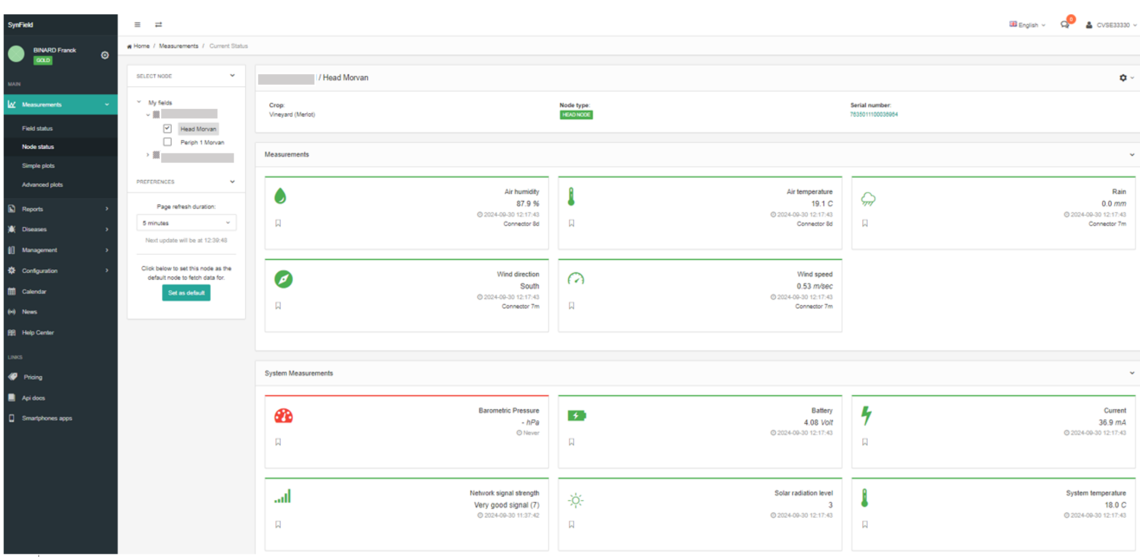


Figure 40. SynField head node measurement overview

For **Pilots 14, 15, and 16**, a federated machine learning model (FML) will be developed by Synelixis, with support from Sixens, to address these shared challenges across the pilots. This model will integrate distributed sensor data and on-farm inputs to improve predictive capabilities while protecting data privacy.

- UC 3.1: Data is available and a machine learning model ML is in progress.
- UC 3.2: For Pilots 14, 15, and 16, a federated machine learning model (FML) will be developed by Synelixis, with support from Sixens.
- UC 3.4: For Pilots 16 and 17 a federated machine model (FML) is already developed.

Table 18. Summarized data table for Pilot#16

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Soil moisture and temperature, rainfall, air humidity and temperature and Digital pheromone trap data, Duration of leaf wetness	Every 60 min	02/2022 - 01/2029	Yes	Yes
Satellite data *	Climatic data (prediction “white frost” vs. “black frost”)			Yes	Yes
Meteorological services data	National Weather Service (NWS) (Greek: EMY)	Every 6 hours	Yearly	Yes	Yes
IoT Data (manually)	Duration of last sunshine, Cloud cover, Cultivation, Trap Monitoring Data, Infestation Data, Host Plant Data, Management Data	Every day for some of the categories or whenever is necessary	01/2026-01/2029	Yes	Yes
Activity log data	Field observations, Data on cultivation and plant protection activities, weather data, sensor data, laboratory analysis results, samples, Frost Monitoring Start, Frost recording, Activation of anti-freeze measures, Monitoring Activities, Decision making, Environmental Data,	Every day for some of the categories or whenever is necessary	01/2022-01/2029	Yes	Yes
Other data	Geospatial data, Soil data, Crop management data, Historical Meteorological Data, Cultivation Practices Data, Fruit/Tree Data, Geographical data, Cultivation Practices Data	Once a year for some of the categories or whenever is necessary	01/2022-01/2029	Yes	Yes

2.1.15 Pilot #15: Emilia-Romagna, Italy/ Use case 3.1, 3.2

Pilot #15 is a vineyard, located in Tebano (RA), within the Emilia-Romagna region (northeast Italy). Covering 7 hectares, the vineyard is situated on flat terrain with a clayey loam soil. Cultivation follows an integrated management approach, combining sustainable practices to ensure a balanced ecosystem. The varieties grown are Sangiovese and Trebbiano, both grafted onto KOBER 5BB rootstocks. Planting was carried out in 2021, using the Guyot training system. The spacing between rows is 2.6 meters, with 1 meter between vines within the same row.

Figure 41. Weather station at Pilot #15

Figure 42. Soil sensor at Pilot #15

Pilot #15 is related to two use cases: 3.1 - Fruit trees disease forecast/detection; 3.2 - Anti-frost control. The data collect by the soil sensor is the soil moisture and soil temperature while the meteorological station records ambient temperature, relative humidity, wind intensity, wind direction, and rainfall.

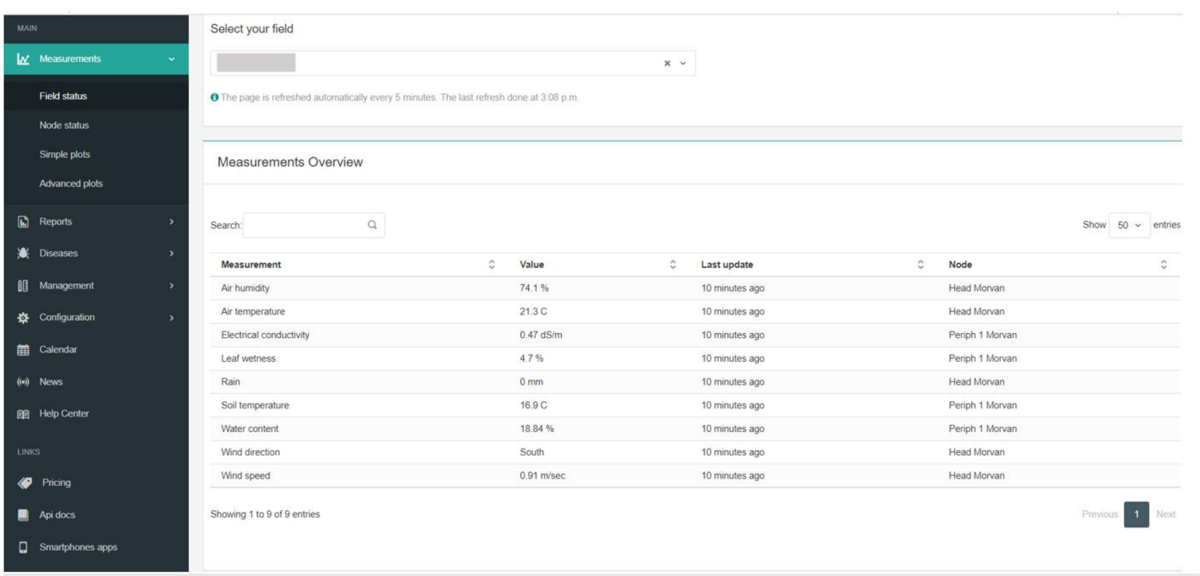


Figure 43. SynField measurement overview

2.1.16 Pilot #16: Chora, Messinia / Use case 3.1, 3.2, 3.4

Pilot 16 is located in Chora, Messinia in the Peloponnese Region of Greece and focuses on an olive grove involved in use cases UC 3.1, UC 3.2, and UC 3.4. In more detail:

- The objective of UC 3.1 is to support olive growers in managing diseases of olive trees, especially olive anthracnose, caused by species in the Colletotrichum complex. UC 3.1 aims to improve early detection and forecasting of disease outbreaks to minimize yield and quality losses.
- The objective of UC 3.2 is to assist olive growers in managing frost events, which can damage tree health and productivity, reduce yield, and impair olive oil quality, which are risks that are increasing with climate variability.
- The objective of UC 3.4 is to aid olive farmers in controlling the olive fruit fly (Bactrocera oleae), a major pest that can significantly reduce olive yield and quality if not effectively monitored and managed.

The NILEAS olive orchard is equipped with three weather stations that monitor rainfall, air temperature, humidity, wind speed and direction, and also measure soil moisture and temperature. These data streams are used both to feed weather forecasting models and to enhance on-farm data collection, including irrigation records. In addition, the orchard has 28 sensors monitoring soil moisture, soil temperature, air moisture, and air temperature. Furthermore, 8 additional air and soil sensors have been installed using SYN's SynField devices, which comprise 2 SynField X5 Head Nodes and 6 SynOdos peripheral units. In the next few days, 2 leaf wetness sensors will also be installed to support disease risk modelling.

Figure 44. Air and soil sensor installed in the Pilot #16

In the following figures, visualisations of various views of the SynField and Green project platforms are recorded.

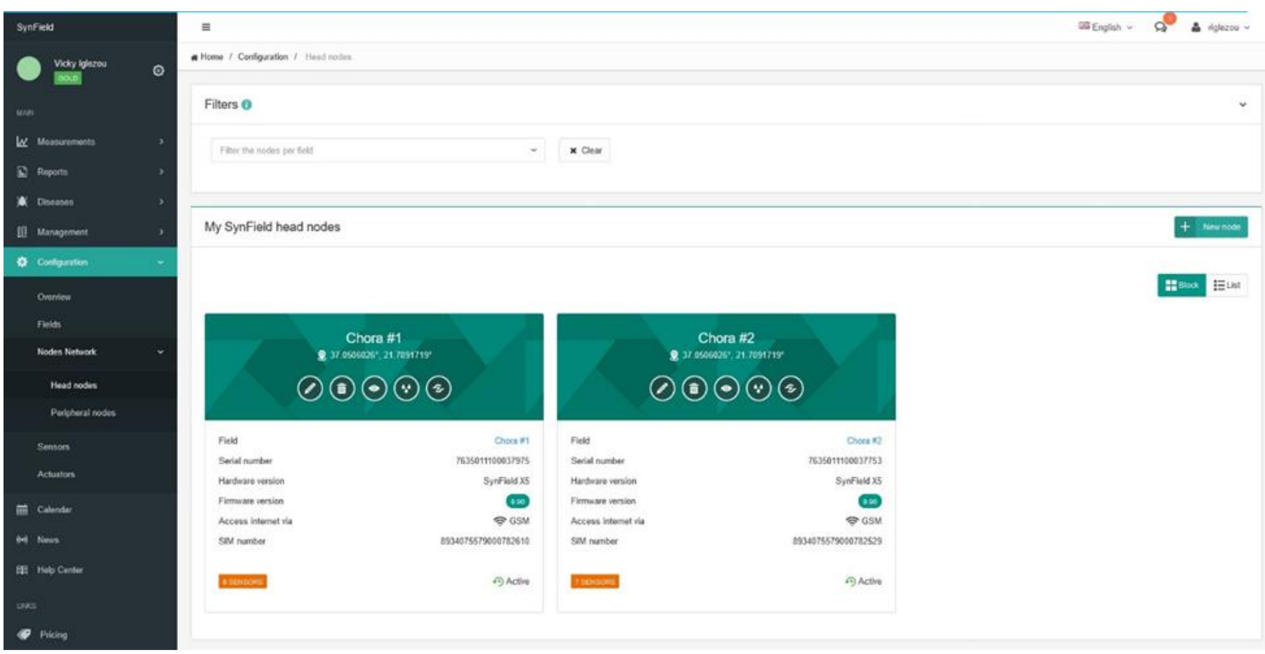


Figure 45. SynField head node preview

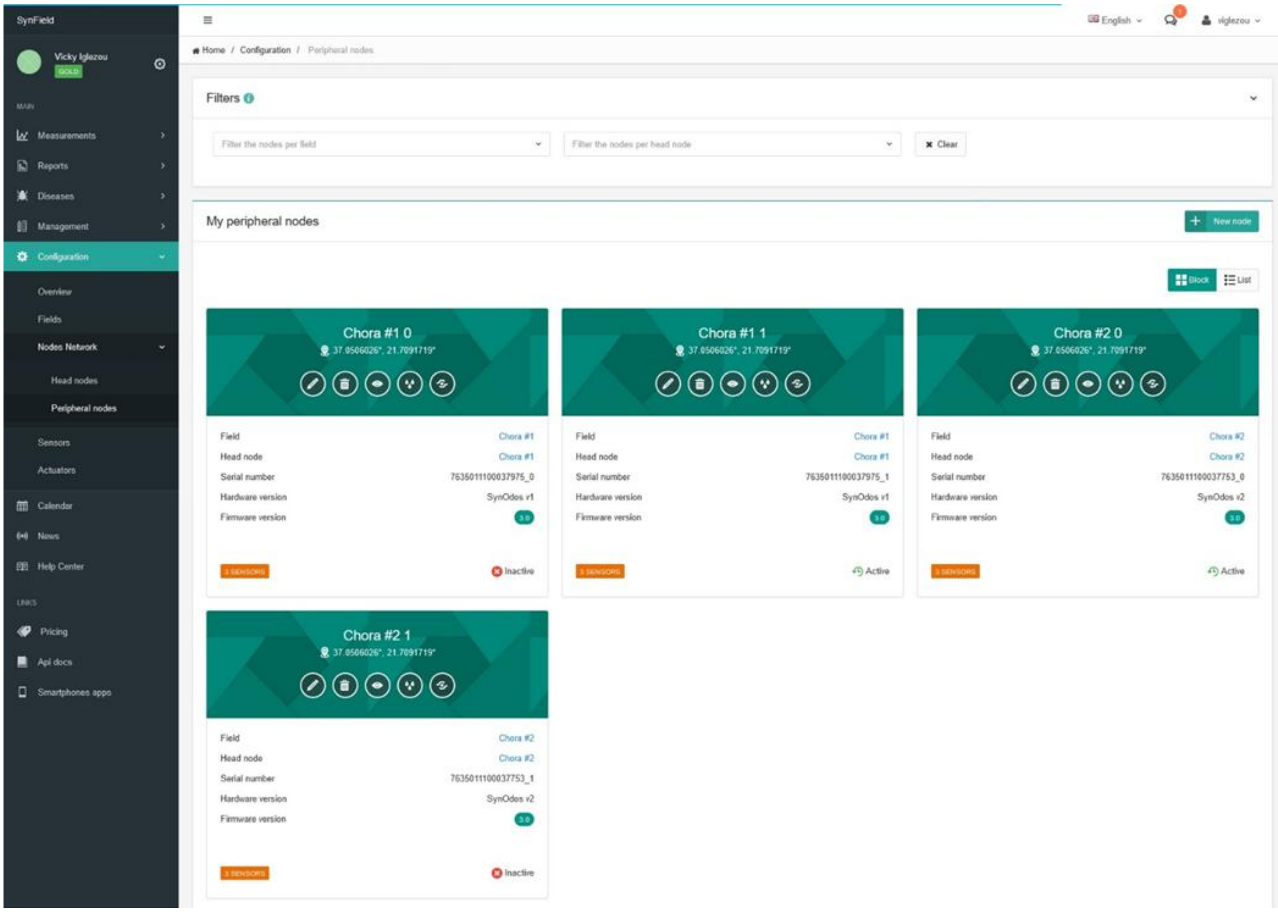


Figure 46. SynField peripheral node overview

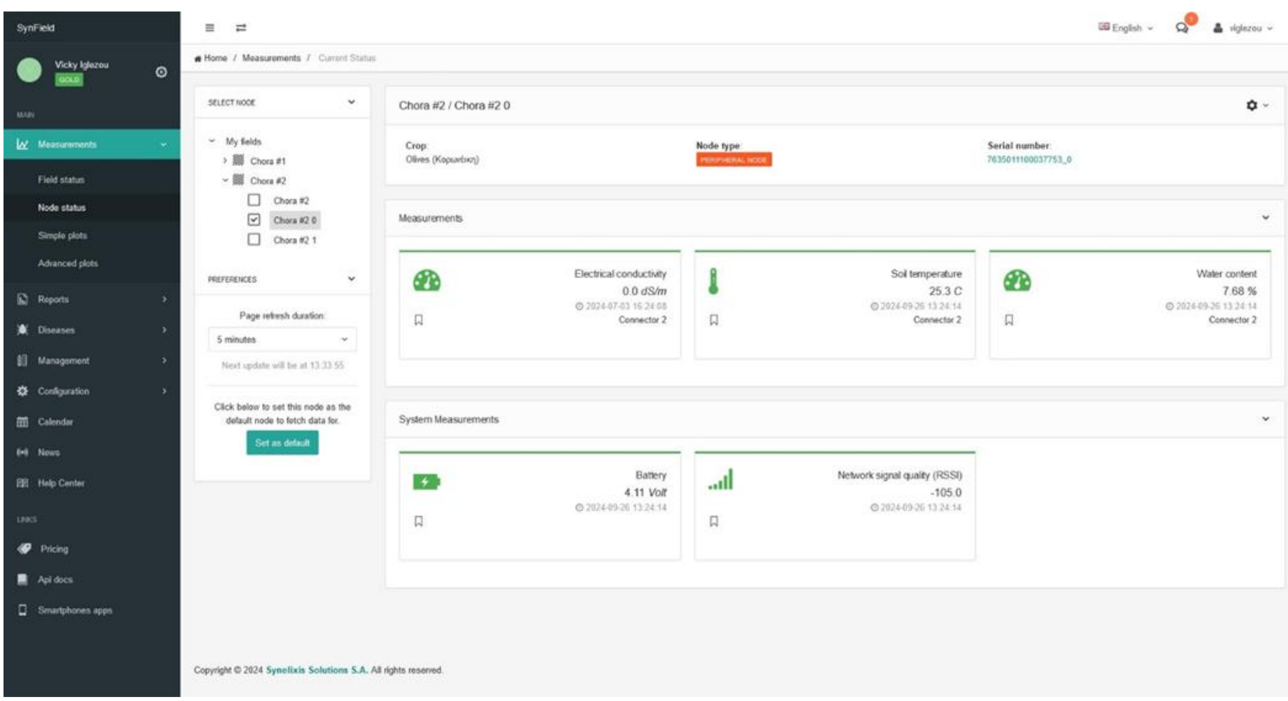


Figure 47. SynField peripheral node measurement overview

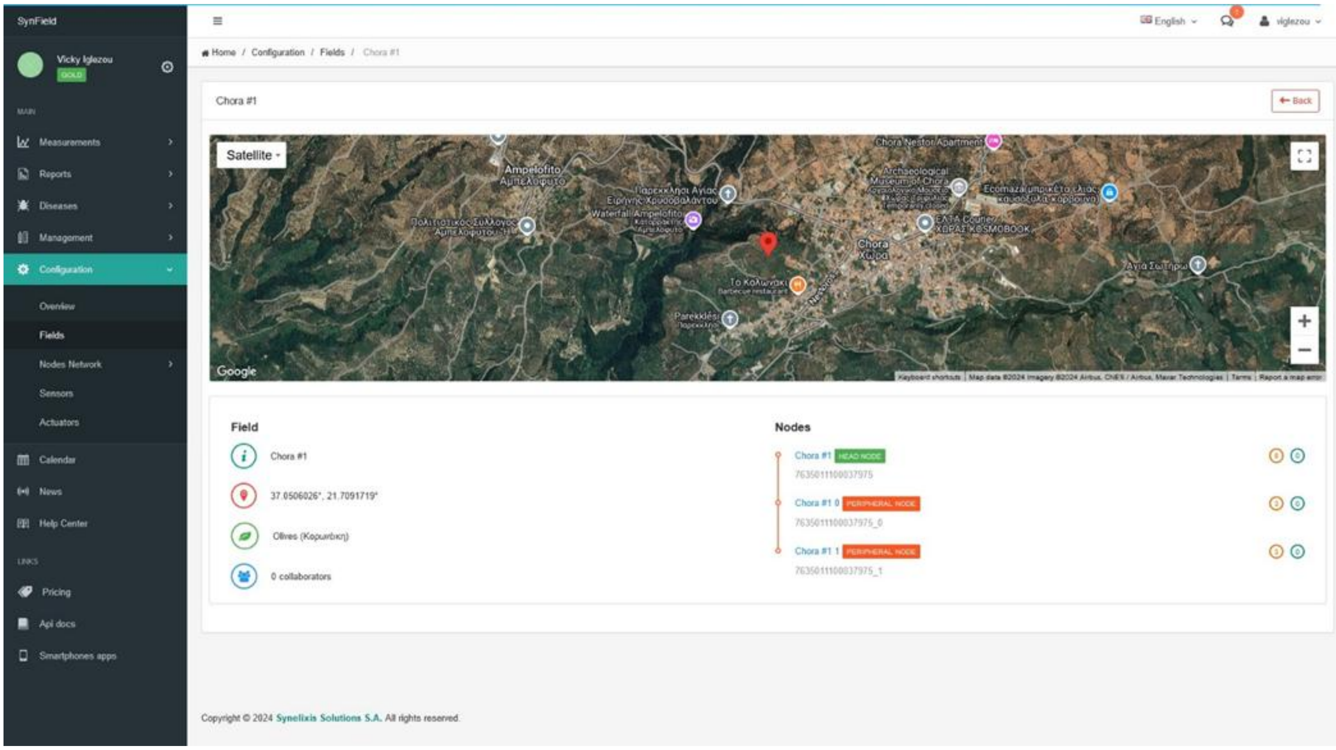


Figure 48. SynField field preview

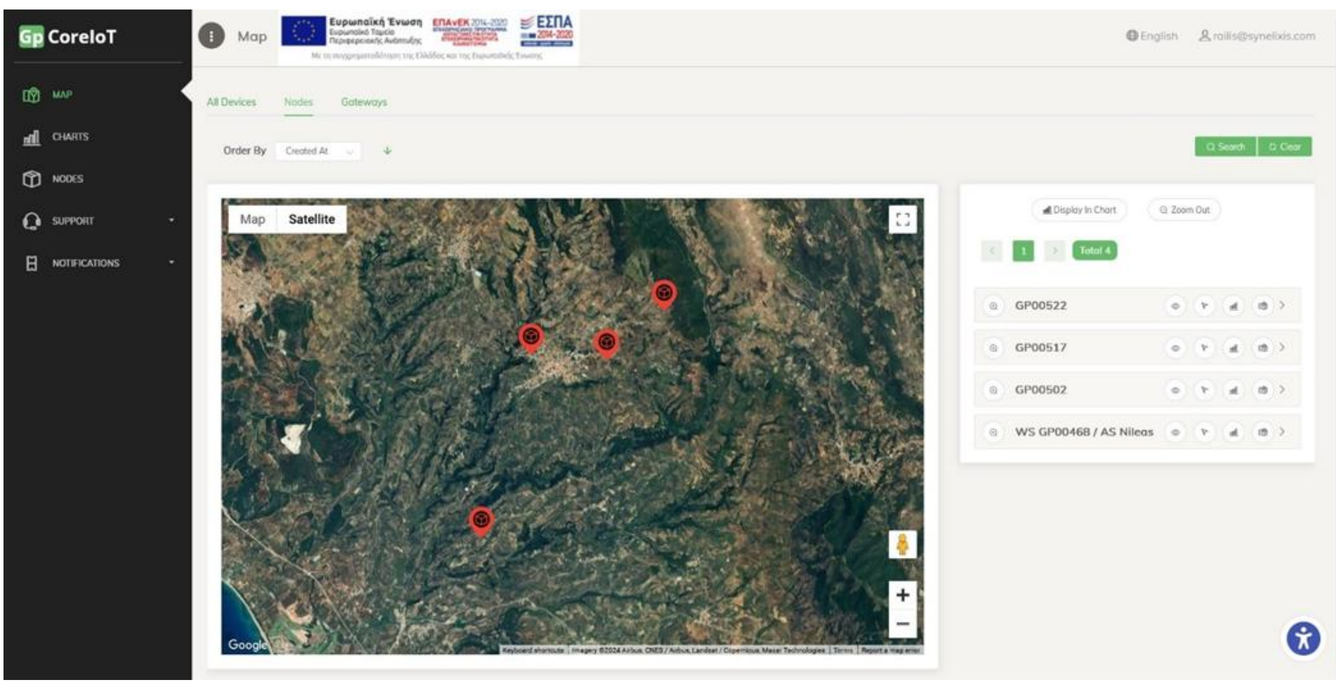


Figure 49. Green project parcel node placement

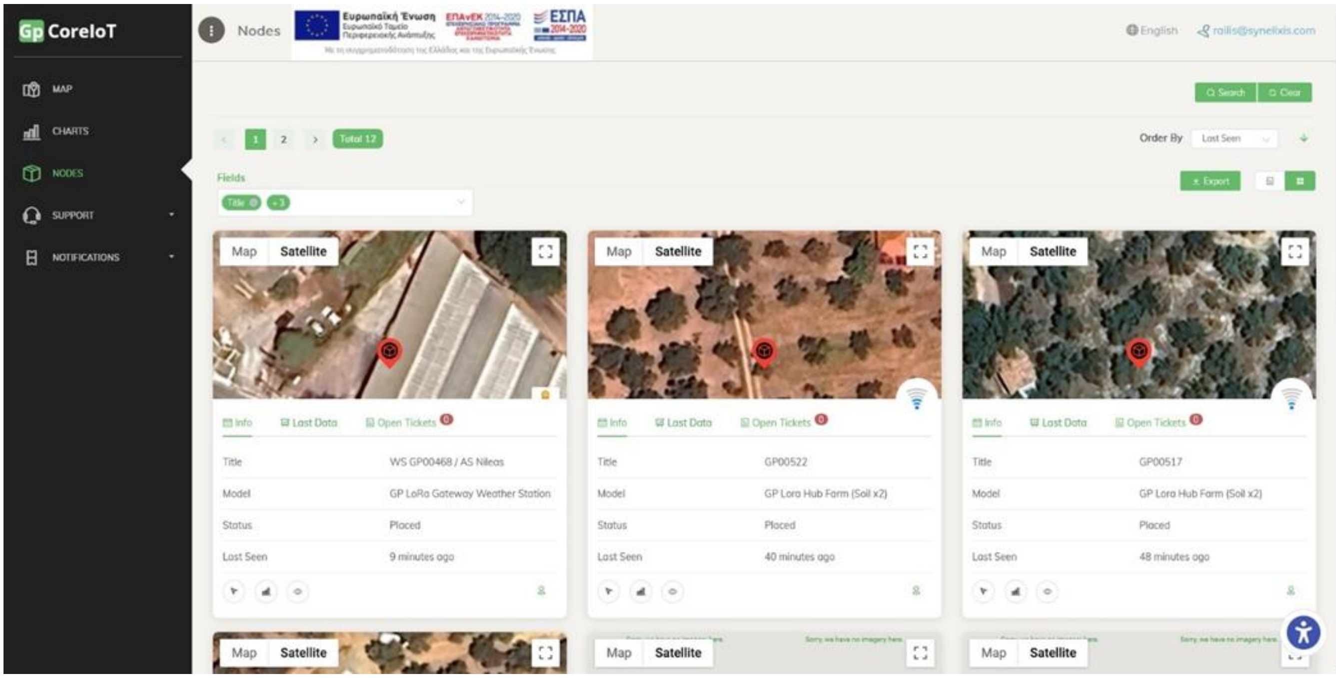


Figure 50. Green project node overview

2.1.17 Pilot #17: Rubicone, Emilia-Romagna/UC 3.1, 3.4

Pilot #17 is an olive grove which comprises of around 2000 olive trees, cultivated on approximately 3.5 ha. It falls within the territory of the DOP Colline di Romagna, particularly in the upper Rubicone area, 300 meters above sea level, in the municipality of Roncofreddo in the province of Forlì-Cesena, Emilia-Romagna region (N-E Italy). The olive trees are cultivated using a traditional system, with a globe training shape. The main cultivars present in the field are Leccino, Correggiolo and Ascolana. Responsible partner for this pilot is RI.NOVA

Figure 51. Weather station installed at Pilot #17

Figure 52. Olive fly trap at pilot #17

Pilot #17 is related to 2use cases: 3.1 - Fruit trees disease forecast/detection; 3.4 - Pest Control on Olive Fruit Fly.

Regarding the olive fruit fly monitoring, data collection is performed manually on a monthly schedule, based on observations of the traps. This regular, manual data gathering is essential for detecting early signs of olive fruit fly infestations, enabling timely interventions that align with organic pest control practices.

Azienda Agricola Podere la	SURVEY N	N° TRAP	SURVEY DATE	N° ADULTS IN THE TRAPS				SAMPLED OLIVES	BIOLOGICAL STATE								PUPAE	EXIT HOLES	% ACTIVE INFESTATION	% OLIVES ATTACHED
									EGGS		LARVAE I INSTAR		LARVAE II INSTAR		LARVAE III INSTAR					
				1	2	3	MEAN		ALIVE	DEAD	ALIVE	DEAD	ALIVE	DEAD	ALIVE	DEAD				
	1	3	27/06/2023	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
	2	3	04/07/2023	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
	3	3	11/07/2023	67	37	43	49	100	2	0	3	1	0	0	0	0	0	0	5	6
	4	3	18/07/2023	19	12	14	15	100	1	0	1	4	1	0	0	0	0	0	3	7
	5	3	25/07/2023	27	20	8	18	100	0	0	1	3	0	0	0	0	0	0	1	4
	6	3	01/08/2023	20	27	26	24	100	1	0	11	3	5	0	0	0	0	0	17	20
	7	3	08/08/2023	227	11	19	19	100	0	0	0	0	0	0	0	0	0	0	0	0
	8	3	16/08/2023	13	8	9	10	100	0	0	0	22	2	0	1	0	0	0	3	25
	9	3	22/08/2023	4	1	2	2	100	0	0	0	27	0	0	0	1	3	0	0	31
	10	3	29/08/2023	3	1	5	3	100	0	0	0	22	0	1	0	0	2	2	0	27
	11	3	05/09/2023	44	29	42	39	100	13	0	6	14	0	2	0	0	0	1	19	36
	12	3	12/09/2023	25	17	28	23	100	0	0	0	0	0	0	0	0	0	0	0	0
	13	3	19/09/2023	13	18	20	17	100	4	0	8	32	1	0	4	1	0	4	17	54
	14	3	26/09/2023	15	21	12	16	100	0	0	0	0	0	0	0	0	0	0	0	0
	15	3	03/10/2023	27	11	15	18	100	2	0	0	44	1	3	3	0	2	6	6	61
	16	3	10/10/2023	14	18	10	14	100	1	0	3	43	0	2	2	0	2	7	6	60

Figure 53. Example of olive flies monitoring form doing in pilot #17 for the year 2023

2.1.18 Pilot #18: Romania / Use case 1.1

Pilot#18 is located at BioRo. Following the completion of the initial configuration and deployment of the required digital technologies, the pilot entered the effective local implementation phase. The use case focused on reducing wasted irrigation water has been deployed under real farming conditions, enabling continuous monitoring and data-driven management of irrigation practices.

At local level, the use case is managed through the active involvement of farmers and technical operators, who rely on the deployed digital tools to support daily irrigation decisions. The system enables the collection, integration, and analysis of heterogeneous data sources relevant to irrigation efficiency and crop water requirements. The weather station was installed. The weather stations are completely autonomous – they have a solar panel and built-in battery and send data via GPRS/2G (SIM card) every 10 min. They send rain, soil moisture and temperature, wind speed and direction, air humidity and temperature, leaf wetness, solar radiation and other important agronomic data as evapotranspiration, dew point, precipitation sums, temperature sums (growing degree days), chill hours, etc. directly from the field to the users' smartphones or tablets.

Figure 54. Weather station at Pilot #18 Data collection

Multiple data flows support the implementation and validation of the use case. Soil sensors provide real-time information on soil moisture and temperature, while meteorological data, including weather forecasts and precipitation, are integrated to anticipate irrigation needs. In addition, operational data from irrigation systems (e.g. irrigation duration and water flow) are monitored to identify inefficiencies and potential water losses.

Historical datasets and analytical models are further used to generate irrigation recommendations tailored to local conditions. All data are aggregated and processed within a common digital platform, offering visual dashboards, alerts, and decision-support recommendations to end users. The validation of the use case is carried out by assessing reductions in unnecessary irrigation events, overall water consumption, and improved alignment between irrigation schedules and actual crop needs. These results confirm the effectiveness of the implemented solution in promoting more sustainable and efficient water use in agriculture.

Table 19. Summarized data table for Pilot#18

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	Meteobot weather station, soil sensor	Every 10 min.	02/2024 - ongoing	Yes	Yes
Activity log data	Field observations	On-request (each week)	02/2024 - ongoing	Yes	No

The following figures present an extract of time-series data collected from the deployed sensing infrastructure, illustrating the main environmental and soil parameters monitored at hourly resolution. The dataset includes atmospheric variables (air temperature, relative humidity, air pressure, dew point, and precipitation) as well as soil-related measurements (soil humidity and soil temperature). These data form the basis for continuous monitoring and analysis of local conditions, supporting data-driven decision-making and the validation of the implemented.

id	date	time	airTemperature	airHumidity	airPressure	dewPoint	precipitation	earthHumidity1	earthTemperature1
3233333332303334	01.01.2025	00:00	-2,5	93,6	1034,4	-3,3	0	96,1	4
3233333332303334	⚠1.01.2025	01:00	-2,5	93,6	1034,1	-3,4	0	96,1	4
3233333332303334	01.01.2025	02:00	-2,5	93,6	1033,7	-3,3	0	96,1	4
3233333332303334	01.01.2025	03:00	-2,6	93,6	1033,5	-3,5	0	96,1	4
3233333332303334	01.01.2025	04:00	-2,6	93,6	1033	-3,5	0	96,1	4
3233333332303334	01.01.2025	05:00	-2,7	93,5	1032,6	-3,6	0	96,1	3,4
3233333332303334	01.01.2025	06:00	-3	93,4	1032,4	-3,9	0	96,1	3,6
3233333332303334	01.01.2025	07:00	-3,1	93,4	1032,3	-4	0	96,1	3,1
3233333332303334	01.01.2025	08:00	-2,9	93,4	1032,3	-3,8	0	96,1	3
3233333332303334	01.01.2025	09:00	-3,1	93,4	1032,3	-4	0	96,1	3
3233333332303334	01.01.2025	10:00	-2,8	93,4	1032,4	-3,7	0	96,1	3
3233333332303334	01.01.2025	11:00	-2,6	93,5	1032,3	-3,5	0	96,1	3
3233333332303334	01.01.2025	12:00	-2,2	93,6	1031,9	-3,1	0	96,1	3
3233333332303334	01.01.2025	13:00	-2,1	93,6	1031,2	-3	0	96,1	3
3233333332303334	01.01.2025	14:00	-1,8	93,9	1030,5	-2,7	0	96,1	3
3233333332303334	01.01.2025	15:00	-1,8	93,9	1030	-2,7	0	96,1	3
3233333332303334	01.01.2025	16:00	-1,9	93,8	1029,6	-2,8	0	96,1	3
3233333332303334	01.01.2025	17:00	-1,9	93,9	1029,2	-2,8	0	96,1	3
3233333332303334	01.01.2025	18:00	-2,1	93,9	1028,8	-2,9	0	96,1	3,2
3233333332303334	01.01.2025	19:00	-2,3	93,7	1028,5	-3,2	0	95,7	3
3233333332303334	01.01.2025	20:00	-2,5	93,7	1028,2	-3,3	0	95,8	3
3233333332303334	01.01.2025	21:00	-2,5	93,6	1028	-3,4	0	95,7	3
3233333332303334	01.01.2025	22:00	-2,7	93,6	1027,7	-3,6	0	95,7	3
3233333332303334	01.01.2025	23:00	-2,9	93,5	1027,8	-3,8	0	95,7	3
3233333332303334	02.01.2025	00:00	-2,9	93,5	1027,9	-3,8	0	95,7	3
3233333332303334	02.01.2025	01:00	-3,2	93,3	1027,4	-4,2	0	95,7	3

Figure 55. Pilot#18: collected data from deployed sensing infrastructure

2.1.19 Pilot #19: Melle, Flanders, Belgium / Use case 4.1, 4.2, 4.3, 4.4

Pilot 19 is situated in Melle, Flanders (Belgium) near Ghent, and covers a Dairy barn at the ILVO Animal Science Unit research farm with ILVO as partner. The barn houses around lactating 145 Holstein-Friesian dairy cows with an average 305-day milk production of 10567 kg with 4.42 % fat and 3.56 % protein. In this dairy barn, various research trials are performed on topics such as feed components and feed efficiency, enteric emissions, colostrum quality, youngstock management etc. The gathered data are complete barn data typical for a state-of-the-art dairy farm in Northwestern Europe with individual cow recognition, including general cow information, milk production and milk quality, etc. The decision to utilize this farm is based on the fact that this specific research farm, next to normal dairy production data, also generates additional data related to monitoring greenhouse gas (GHG) and ammonia emissions, and depending on the type of experiment, individual feed intake data. Moreover, in this barn additional sensor systems that can be used for behaviour and health monitoring are present. The production data are supplied feed data, milk data (production, fat, protein, lactose, urea), animal weight, etc. Pilot #19 is related to four use cases: 4.1 - Reduce Greenhouse gas emissions; 4.2 - Reduce nitrogen deposition; 4.3 - Proactive cattle/pig health/welfare monitoring; 4.4 - Calving monitoring

In use case 4.1, methane emission reductions are aimed at by creating models able to predict the enteric methane emission from cows. Using such prediction models, methane reducing strategies can be tested and the effect of a strategy and its obtained reduction can be monitored at farm level. Therefore, general farm data including cow age, milk production, lactation stage, feed intake and feed nutritional values are used as input data, together with GreenFeed measurements to provide actual measured enteric methane emissions to be used as labelled data for model creation. In the future, the model will hence be used without the sensor measurements to provide a predicted emission value based on the relevant input data.

In use case 4.2, the aforementioned cow data are combined with the urea content of the milk as labelled data to create a prediction model for milk urea content as an indicator for nitrogen emissions. Similarly, the goal is to create a prediction model that can be used to predict urea excretion via the milk, hence serving as an indicator for nitrogen emissions to test potential nitrogen emission strategies at animal level.

In use case 4.3, the general cow data are combined with data of cow activity and rumination gathered by collar sensors to define a prediction model for mastitis development. Documented mastitis cases linking mastitis cases to certain cows, dates and severity levels are used as labelled data for model creation. The model will hence be used to predict mastitis cases at an earlier timepoint, thus providing the possibility to take action sooner and potentially prevent the severity from worsening.

In use case 4.4, the general cow information on the gestation including gestation stage, expected calving date, inseminations dates are used in combination with activity data to predict the timing of the onset of the calving. Documented calvings are used as labelled data for model creation. The created model will be used to predict the onset of the calving more accurately, allowing the farmer to better monitor the process and potentially detect issues at an earlier timepoint, thus allowing taking action sooner to prevent potentially life threatening health issues for the cow and calf.

An essential dataflow is generated when the cows are being milked. When cows participate in a trial, milking is performed twice a day in a 2-by-7 herringbone milking parlor (Figure 56). As such, milk yield records are being gathered. When not participating in experimental trials, cows are being milked in two voluntary milking systems (Delaval milk robots) **Error! Reference source not found.**. During trials, milk samples of four consecutive milkings are collected at least once per experiment period and analysed to obtain the fat and protein content, the urea content, and the biological milk quality (somatic cell count).

Figure 56. Cows are being milked in the 2-by-7 herringbone milking parlor.

GreenFeed systems are being used to gather data on the individual methane emission of dairy cows. Cows are allowed several visits per day to the monitoring system. Each time the cow visits the GreenFeed, it receives a small amount of concentrate. During eating, the exhaled air from the cow is extracted from the feed bin, and a sample of the airstream is led to the methane sensor. An airflow sensor measures the total volume of extracted air. After raw data collection, the GreenFeed supplier (C-Lock Inc., Rapid City, USA) provides a reviewed dataset with a methane emission value (g CH_4/day) per cow visit. Depending on the experimental needs, the GreenFeed system can be installed inside and outside the (Figure 58).

Figure 58. A GreenFeed emission monitoring system installed inside and outside the dairy barn.

Additional sensor systems to monitor cow behaviour are available. Some examples are Additionally, activity trackers are used for estrus detection and a custom-built behaviour monitoring system that can distinguish between ruminating, standing, or resting. This sensor is located close to the neck to accurately record neck movements that can be used to distinguish between behaviours. The body condition score of each cow is monitored regularly using the Delaval BCS camera (**Error! Reference source not found.**). Similarly, cows' body weight is recorded using automatic weighing scales that weigh the cow after milking.

Figure 57. Activity monitoring system based on accelerometers.

Moreover, the Synelixis SynAir sensor system was installed in a central location in the dairy barn. After making a support for the power unit (**Error! Reference source not found.**), it was installed on the ridge of the barn to be fully outside in direct sunlight to provide sufficient power for the system (Figure 59). The sensor unit was installed nearby in a central location of the barn (Figure 59). The sensor measures carbon dioxide (CO2), ammonia (NH3), air temperature, air barometric pressure, fine particulate matter, and air humidity. This sensor will provide information on ammonia levels inside the dairy barn as an additional data stream that can be useful during model development.

Figure 59. Installation of the power unit in the ridge of the barn and the sensor unit in a central barn location.

Table 20. Summarized data table for Pilot#19

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data via connectors (automatically)	-	-	-	-	-
Meteorological services data	-	-	-	-	-
IoT Data (manually)	General cow data feed intake, milk production and quality, feed nutritive value data, enteric methane data, collar activity data	Daily basis/trial basis	Continuously in active trial periods Several historic trials available 2020-2025	Closed	No
Activity log data	Cow health (mastitis) observations, calving observations	Daily basis/trial basis	Continuously historic data available 2020-2025	Closed	No
Other data	-	-	-	-	-

2.1.20 Pilot #20: Vecauce, Latvia / Use case 4.3, 4.4

Pilot 20 is situated in Vecauce (Latvia) and covers a Dairy barn at the LBTU teaching and research farm with ZSA as a project partner. Vecauce is a multidisciplinary farm that combines student training, research, crop farming, dairy farming, biogas production, fruit growing, forestry and has created one of the largest and most productive herds of dairy cattle in Latvia. The barn houses more than 1000 cows. In this dairy barn, various research trials are performed on topics such as feed components and feed efficiency, enteric emissions, colostrum quality, youngstock management etc. The gathered data includes individual cow recognition, including general cow information, milk production and milk quality, etc. The production data are supplied by the feed data, milk data (production, fat, protein, lactose, urea), animal weight, etc. Pilot #20 is related to two use cases: 4.3 - Proactive cattle/pig health/welfare monitoring; 4.4 - Calving monitoring

In use case 4.3, the obtained general cow data are combined with data of cow activity gathered by pedometers to define a prediction model for health issues. The model will hence be used to predict several cases for health issues at an earlier timepoint, thus providing the possibility to act sooner and potentially prevent the severity from worsening.

Figure 60. Pilot #20 Afimilk system

Figure 61. Example of a cow pedometer at Pilot #20

In use case 4.4, the obtained general cow information on the gestation including gestation stage, expected calving date, inseminations dates are used in combination with activity data from pedometers to predict the timing of the onset of the calving. Documented calving activities are used as labelled data for model creation. The created model will be used to predict the onset of the calving more accurately, allowing the farmer to better monitor the process and potentially detect issues at an earlier timepoint, thus allowing taking action sooner to prevent potentially life threatening health issues for the cow and calf.

For the above-mentioned use cases all the required data streams are already established.

Table 21. Summarized data table for Pilot#20

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
Meteorological services data	Latvian weather station data	60 min	01.25 - ongoing	Open	No
IoT Data (manually)	Cow pedometers	Daily	01.25 - ongoing	Closed	No
Activity log data	Cow health records	On events	01.25 - ongoing	Closed	No

Other data	Milk robot data	On each milking event	01.25 - ongoing	Closed	No

Excerpt of the data used for model development:

Day	Date	Activity
0	16.08.2024	387
1	17.08.2024	282
2	18.08.2024	235
3	19.08.2024	250
4	20.08.2024	188
5	21.08.2024	296
6	22.08.2024	178
7	23.08.2024	164
8	24.08.2024	160
9	25.08.2024	157
10	26.08.2024	160
11	27.08.2024	449
12	28.08.2024	496
13	29.08.2024	166
14	30.08.2024	157
15	31.08.2024	157
16	01.09.2024	155
17	02.09.2024	183
18	03.09.2024	225
19	04.09.2024	174
20	05.09.2024	179
21	06.09.2024	206
22	07.09.2024	194

Figure 62. Pilot#20: Cow pedometers data

The table reports daily activity values over the period from 16.08.2024 to 07.09.2024, showing clear temporal variability. Activity levels are relatively moderate during the first days (16–25 August), generally ranging between 157 and 296, with a gradual decline toward the end of this interval. A pronounced peak occurs on 27–28 August, where activity sharply increases to 449 and 496, representing the highest values in the observation period. After this peak, activity drops again and stabilizes at lower levels during early September, mostly fluctuating between 155 and 225. Overall, the data indicate a short-term surge in activity at the end of August, followed by a return to more stable and moderate daily values. It demonstrates the example of cow activity numbers in a short period.

2.1.21 Pilot#21: Katouna, Etoloakarnania, Greece/UC 4.3, 5.3

Pilot #21 is located in Katouna, Etoloakarnania, Greece, near Agrinio, covers and Organic Cattle Farm and is owned by TBA (To Biologiko Agroktima - TBA), which actually stands for Organic Cattle Farm in Greek. This pilot pertains to a cattle fattening system. All involved cattle belong to the Limousin breed, a French breed of beef cattle originating from the Limousin and Marche regions of France. Approximately 320 of TBA's animals are involved in Pilot #21. Two use cases are associated in the context of Pilot #21: a) UC 4.3 - Proactive cattle/pig health/welfare monitoring and b) UC 5.3 - Supply Chain transparency for Meat. However, due to administrative issues only UC 4.2 will be implemented in real pilot, while UC5.3 will be simulated using blockchain technology.

Figure 63. Pilot#21: Smart Collars installed in TBA

TBA has installed 281 smart collars from FarmLife which is collecting data related to rumination, heart bit (and multiple heart-bit in case of pregnancy), and comfort conditions. Data will be used for AI model training and federation to other pilots

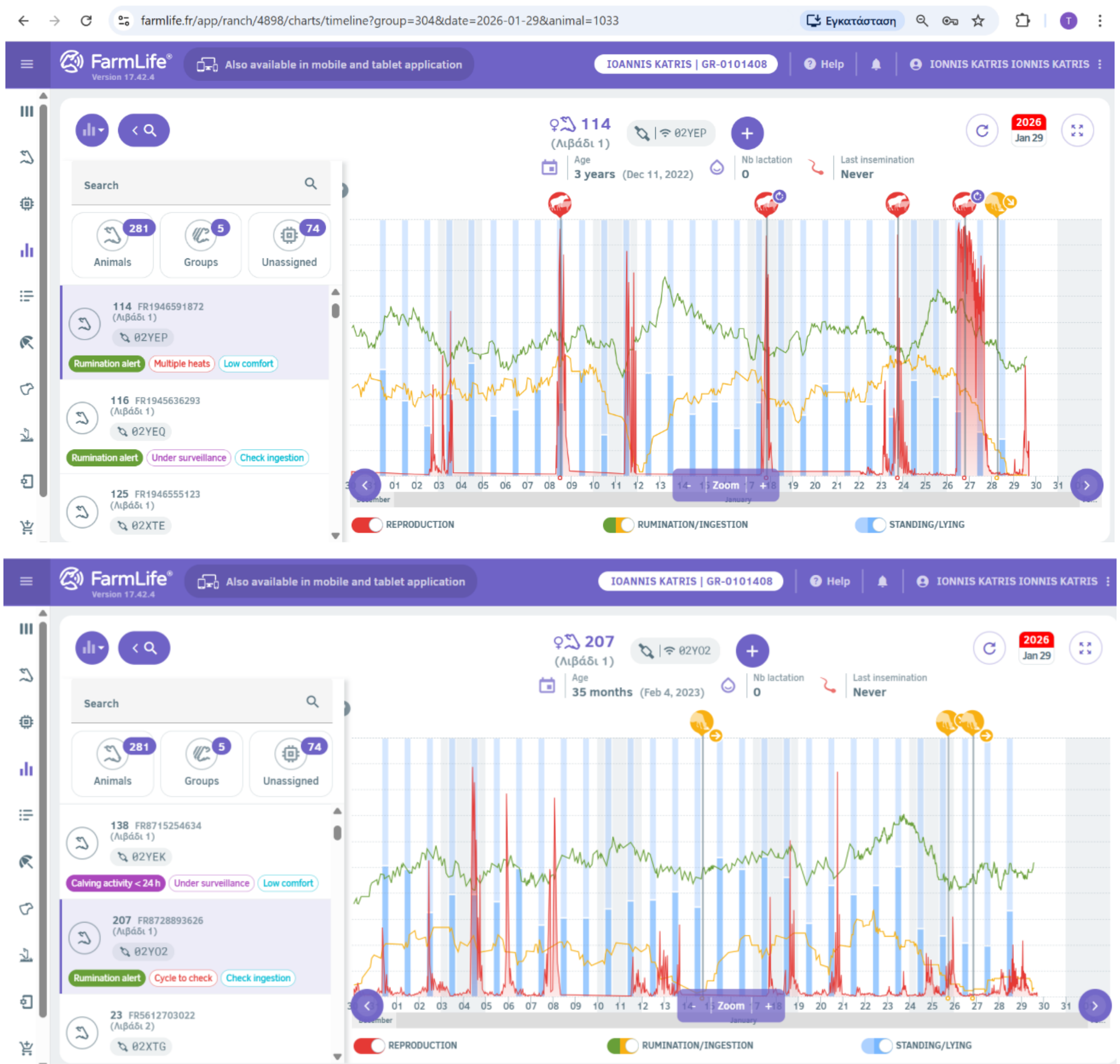


Figure 64. Pilot#21: Smart Collars installed in TBA

In the context of Pilot #21, a SynField X5 device along with a SynAir device have been installed. The measurements that are collected by the SynAir device include:

- Air temperature and relative humidity
- Barometric pressure
- Particulate Matter (PM)
- CO_2 emissions
- NH_3 emissions

The data collection in the context of Pilot #21 is conducted via SynField which receives the air quality measurements from SynAir and forwards them to the SynField cloud platform. Subsequently, these measurements are extracted and saved by the STORE component. The following figures depicts measurements collected in the context of Pilot #21.

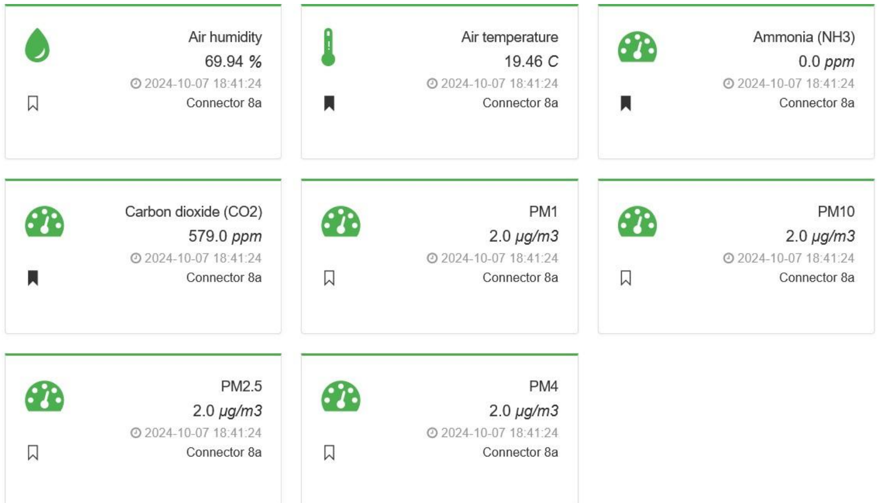


Figure 65. An overview of SynAir measurements collected for Pilot #21

2.1.22 Pilot #22: Melle, Flanders (Belgium) / Use case 4.1, 4.2, 4.3

Pilot 22 is situated in Melle, Flanders (Belgium) near Ghent and covers a Pig Campus with ILVO as partner. The pig campus comprises a pig barn fully equipped to perform research on pigs, including sows, piglets and fattening pigs. As such, a lot of data is generated at this experimental pig farm. The data are complete farm data of a closed pig rearing and fattening system including sows, piglets and fattening pigs. Like most newly built pig barns in this region, the ILVO barn is equipped with air scrubbers and low-emission floor types.

Figure 66. Compartment of the pig barn where the FTIR sensor measures the air concentrations of CO_2, N_2O, and CH_4

Data on emissions is also available. The production data are the commonly used pig farm indicators such as the number of piglets per litter per sow, the survival rate, temperature in the different barn compartments, and ventilation data. The abovementioned data are mostly gathered using commercially available farm equipment including feeders, ventilation systems, and farm software systems as well as air scrubbers. The barn has sensors for monitoring animal behaviours such as eating patterns, drinking patterns, water consumption, live weight, lameness detection, behaviour, and location in the compartments. Sensors monitor different types of nutrition with feeding stations, weather conditions (heat stress), management, stable environment, welfare and, behaviour, physiology and morphology of pigs. Pilot #22 is related to three use cases: 4.1. - Reduce Greenhouse gas emissions; 4.2 - Reduce nitrogen deposition; 4.3 - Proactive cattle/pig health/welfare monitoring;

In use case 4.1, methane emission reductions are aimed at by creating models able to predict the enteric methane emission from fattening pigs. Using such prediction models, methane reducing strategies can be tested and the effect of a strategy and its obtained reduction can be monitored at farm level. Therefore, general farm data including animal age, feed intake and feed nutritional values are used as input data, together with methane measurements to provide actual measured methane emissions at compartment level to be used as labelled data for model creation. In the future, the model will hence be used without the sensor measurements to provide a predicted emission value based on the relevant input data.

In use case 4.2, aforementioned pig and feed data are combined with air ammonia measurements as labelled data to create a prediction model for ammonia emissions. Similarly, the goal is to create a prediction model that can be used to predict ammonia emissions based on available farm data, and hence serve as an indicator for ammonia emissions to test the effect of potential emission reduction strategies.

In use case 4.3, a prediction model for faecal consistency score is used as an indicator for diarrhoea in piglets. Documented diarrhoea cases in the form of faecal consistency scores are used as labelled data and combined with pig data. The model will hence be used to predict diarrhoea cases at an earlier timepoint, thus providing the possibility to take action sooner and potentially prevent the issue from worsening and allowing animals to recover sooner.

Table 22. Summarized data table for Pilot#22

Data source	Data type	Data frequency (minutes or days)	Data time period	Data access	Publishable
IoT Data (manually)	General pig data Feed nutritive value data Methane data	Daily basis/trial basis	Continuously in trial periods historic trials available 2020-2025	Closed	No
Activity log data	Faecal consistency scores	trial basis	Continuously some historic trials available 2020-2025	Closed	No

2.1.23 Pilot #23: Katouna, Etoloakarnania, Greece/UC 5.1

Pilot #23 is located in Agrinio, Etoloakarnania, Greece and covers electricity generation from biogas. The pilot is closely located and directly associated with Pilot #4: *Forages* and Pilot #21: *Organic Cattle Farm*, and is owned by TBA. In the context of the pilot, manure originating from the Organic Cattle Farm (Pilot #21) is transferred via underground pipes to anaerobe digesters where biogas is produced. The produced biogas is utilised by a generator of 5MW which directly provides electricity to the smart grid. The solid and liquid remainders of the procedures are used as fertilizers and irrigation at Pilot #4 which in turn produces forages (clover and corn) to feed the animals in Pilot #21 with, thus closing the loop and forming a fully circular ecosystem (UC 5.1: Fully Circular ecosystem).
Due to restrictions, the implementation of the pilot will be postponed to the 2nd phase of the project (M37-M72).

2.1.24 Conclusion

Overall, the pilots presented in this chapter illustrate a high level of diversity in terms of agricultural domains, operational contexts, and technological maturity. While some pilots are already supported by well-structured data streams and developed AI models, others are progressing through stages of data collection and validation. Despite slight differences, common patterns emerge, the most notable being the increasing availability of heterogeneous data sources and a shared focus on efficiency, sustainability, and decision support. Taken together, these observations indicate a solid foundation for cross-pilot implementation, while also highlighting the need for harmonisation efforts and targeted support to address varying maturity and data-readiness levels across pilots.

2.2 Cross-pilot use case implementation

Activities and work completed within work package 3 will be as a basis for the work package 5, where activities will be started shortly. One of the important parts will be the cross-pilot use case implementation.

The cross-pilot implementation of use cases represents a core mechanism for ensuring coherence, scalability, and impact across the project's diverse pilot sites. Given the geographical, climatic, regulatory, and socio-economic differences between participating countries, a structured yet flexible approach is required to align local pilot activities with overarching project objectives.

Each pilot site implements a defined set of use cases that address specific agricultural challenges relevant to its local context. While these use cases may differ in scope, maturity, and technical requirements, they are developed within a common conceptual and methodological framework. This framework ensures that results are comparable across pilots and that best practices, lessons learned, and technical solutions can be transferred and reused where appropriate.

Cross-pilot coordination focuses on harmonising use case definitions, functional requirements, data flows, and evaluation criteria. Common templates, shared technical guidelines, and agreed performance indicators are used to support consistency while allowing pilots to adapt implementations to local conditions. Regular exchanges between pilot teams facilitate mutual learning and enable the identification of synergies, overlaps, and opportunities for consolidation.

The implementation process will follow an iterative approach, starting with requirement analysis and stakeholder engagement at pilot level, followed by technical development, deployment, validation, and refinement. Feedback from one pilot can inform improvements in others, reducing duplication of effort and accelerating overall project progress. This iterative cross-pilot feedback loop is essential for managing risks and ensuring that solutions remain user-driven and operationally relevant.

From a sustainability and exploitation perspective, cross-pilot use case implementation supports the development of scalable and interoperable solutions. By demonstrating applicability across multiple agricultural contexts and countries, the project strengthens the potential for wider adoption beyond the initial pilot sites. In this way, cross-pilot implementation not only enhances technical robustness but also maximises the long-term impact and European added value of the project.

Next chapter (Chapter 3) will provide the details about developed models and models, which are in pre-development stage.

3 AgriDataValue Platform Technical Validation

3.1 Continuous platform performance monitoring and validation

While the initial technical benchmarks were established in D3.3 (section 4.1) using stress-testing tools, in this version the ongoing monitoring of the AgriDataValue (ADV) Platform under real-life conditions is presented, aiming to ensure it can support multi-modal data originating from multiple sources.The ADV Platform, deployed as a Kubernetes (K8s) cluster, utilizes built-in orchestration and monitoring tools to maintain high availability and reliability for the pilot sites. The following metrics summarize the performance of the platform's core components—specifically the STORE component and IoT Connectors—during the implementation phase. The continuous monitoring of these K8s-based metrics confirms that the ADV Platform has reached a state of operational maturity sufficient for the pilot phase. The system demonstrated the stability required to handle heterogeneous data sources, providing a robust foundation for the iterative feedback loops described in the following sections

System uptime

To ensure "smooth operation", the K8s cluster was monitored for pod stability and service availability.

- **Average Platform Uptime:** the ADV platform maintained an uptime of 96.62%.
- **Pod Resilience:** The K8s deployment utilized probes to automatically recover from minor service interruptions. Throughout the testing phase, 216 automated restarts (due to updated component versions) were successfully handled by the orchestrator without impacting the end-users' experience.

Data Ingestion and Processing Performance

The STORE component is responsible for receiving and processing high-frequency data from diverse pilot sensors.

- **Ingestion Success Rate:** Monitoring of the IoT Sensor Data Capturing toolbox and associated connectors showed a data ingestion success rate of 93.75%.
- **Mean Time to Ingest (MTTI):** The average duration between a sensor firing at a pilot site (e.g., the Synelixis node stations) and the data becoming available in the ADV web application was:
  - SynField: 8.01 seconds
  - Ifarming API: 2.60 seconds
  - ADCON LiveData: 10.50 seconds
  - ThingSpeak: 5.09 seconds
  - Green Project API: 40.03 seconds
- **Throughput:** The platform successfully handles various loads of simultaneous data points per minute during activity periods of various intensities, as reported in D3.3.

Storage and Latency Metrics

As the volume of historical data grew to support ML training, the performance became a critical KPI for WP3.

- **API Response Latency:** The latency details, e.g., the core/api/v1/measurements endpoint, identified as the most load-intensive, was monitored for requests, and reported in D3.3.
- **Resource Utilization:**
  - CPU Usage: Average CPU utilization of the K8s nodes remained at 52.5%, allowing for significant "headroom" for the upcoming WP5 scale-up
  - Memory Footprint: Memory usage was optimized to 15.05GB through efficient containerization and database indexing

3.2 Use Case & ML model training and validation

The development of machine learning (ML) models within the AgriDataValue is structured to support deployment across multiple pilot sites while accounting for site-specific characteristics, constraints, and objectives. A common methodological framework is applied to ensure consistency, scalability, and comparability of results, while allowing for controlled customization where required by local conditions.

Model development begins with data acquisition and assessment at each pilot site. This includes the identification of relevant data sources, evaluation of data quality and completeness, and alignment with data governance and privacy requirements. Where feasible, data harmonization strategies are applied to enable the reuse of shared features, schemas, and preprocessing pipelines across pilots. Feature engineering and model selection are performed using a combination of domain knowledge and data-driven techniques. Baseline models are first established to provide reference performance metrics. Subsequently, more advanced models are developed and tuned to address site-specific data distributions, operational environments, and performance targets. Transfer learning, federated learning, or model adaptation techniques may be employed to leverage knowledge across pilot sites while minimizing data movement and preserving local autonomy. In the subsections below, the ML models described in D2.3 are summarized per pilot.

To ensure a structured transition to the large-scale deployment in WP5, a final "Pilot Readiness Checklist" has been established. This checklist consists of a standardized checklist to be completed for each pilot and serves as the final technical audit for each pilot's implementation and performance monitoring. Completion of these items confirms that the pilot has transitioned from a controlled "Proof of Concept" (TRL 4-5) to an operational "Proof of Use" (TRL 7).

3.2.1 Pilot 5 / Use Case 1.3: Weed Detection in Potatoes

3.2.1.1 ML Model

Similar to the celeriac use case, this model aims to detect weeds in potato fields.

Because the Pilot 10 model was trained as a general weed-vs-crop detector rather than being crop-specific, the same model is directly applied to this potato use case.

3.2.1.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 23. Readiness level for Pilot#5

Category	Requirement	WP3 Status
Technical	**Cross-Pilot Transfer:** Successful direct application of the general weed-vs-crop detector	[✓] Ready
	API Latency: Retrieval times for multispectral drone maps optimized.	[✓] Ready
Operational	**Hardware Integrity**: 4 drone flights completed with standardized sensor calibration.	[✓] Ready
Governance	**Anonymization:** De-identification of parcel geometries for public data release.	[✓] Ready

3.2.2 Pilot 6 / Use Case 1.3: Greenhouse Humidity Control

3.2.2.1 ML Model

A binary classification model that determines whether greenhouse windows should be opened or closed to manage humidity and reduce pesticide usage. Input data included indoor/outdoor temperature, wind speed, radiation, and humidity. Tested various classifiers including Logistic Regression, KNN, and Random Forest. Random Forest achieved the highest performance with an F1 score of 0.933**.**

3.2.2.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 24. Readiness level for Pilot#8

Category	Requirement	WP3 Status
Technical	**Real-time Signal:** Random Forest binary signals (Open/Close) integrated into Dashboard.	[✓] Ready
	API Stability: 10–15 min sensor polling intervals verified in IOTD.	[✓] Ready
Operational	**Hardware Reliability:** SynField environmental nodes restored after bilateral troubleshooting.	[✓] Ready
Governance	**Usability Feedback:** Map-centric UI adopted based on pilot partner feedback.	[✓] Ready

3.2.3 Pilot 6 / Use Case 2.4: Greenhouse Window Opening Percentage

3.2.3.1 ML Model

A regression model that predicts the specific percentage of window opening required to maintain optimal indoor greenhouse temperature.

Version 1 was developed using historical data; Gradient Boosting was the top performer (R^2 of 0.96).

Version 2 was updated using real-time data collected via SynField IoT platforms during the ADV project.

Gradient Boosting remained the clear choice, achieving an R^2 of 0.7919 for side-two windows.

3.2.3.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 25. Readiness level for Pilot#6

Category	Requirement	WP3 Status
Technical	**Dynamic AI Scaling:** Successfully handled erratic SynField timestamps via closest-match merging.	[✓] Ready
	Regression Quality: Achieved **0.79 R^2** using Gradient Boosting on PROJECT data.	[✓] Ready
Operational	**Feature Engineering:** Lag-1 moving average implemented to prevent data leakage.	[✓] Ready
Governance	**Interoperability:** Alignment with **AIM** for greenhouse actuator entities	[✓] Ready

3.2.4 Pilot 8 / Use Case 2.2: Leek Biomass and Nitrogen Uptake

3.2.4.1 ML Model

A regression model designed to predict biomass and nitrogen content to optimize fertilization and reduce environmental leaching. A Sequential Neural Network (Keras) was trained on soil properties, nitrogen levels, and spectral measurements (NDVI, FAPAR). The model achieved an R^2 of 0.98 for nitrogen uptake and 0.92 for biomass.

3.2.4.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 26. Readiness level for Pilot#8

Category	Requirement	WP3 Status
Technical	**Analytics Depth:** Multi-layer Keras Sequential model integrated for multi-target regression.	[✓] Ready
	Data Correlation: Satellite NDVI/FAPAR successfully merged with soil nitrogen scans.	[✓] Ready
Operational	**Prediction Quality:** High accuracy verified (**0.98 R^2** for nitrogen uptake).	[✓] Ready
Governance	**Data Sovereignty:** Sharing policies defined for external lab results via IDS.	[✓] Ready

3.2.5 Pilot 10 / Use Case 1.3: Weed Detection in Celeriac

3.2.5.1 ML Model

This model detects weeds in celeriac fields to enable "spot-spraying," reducing pesticide costs and toxic environmental effects. Formulated as an object detection task using a YOLOv8 detector. Due to the high resolution of original UAV images, they were sliced into 14,742 smaller patches (640x480) for processing. Weed instances were augmented from 4,219 to 11,154 to balance the dataset against crop instances.

Achieved an mAP50 of 0.887 for weeds. The model is capable of real-time application, with an inference time of only 1.7ms per image.

3.2.5.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 27. Readiness level for Pilot#10

Category	Requirement	WP3 Status
Technical	**Platform Stability**: K8s cluster verified for high-resolution UAV image slicing.	[✓] Ready
	Data Ingestion: Sliced patch ingestion (14,742 patches) to STORE component verified.	[✓] Ready
	Inference Speed: Real-time capability confirmed at **1.7ms** per image	[✓] Ready
Operational	**Model Accuracy:** Achieved **0.887 mAP50** for small-object weed detection.	[✓] Ready
Governance	**Digital Independence:** Farmers trained on manual data entry for labeling verification.	[✓] Ready

3.2.6 Pilot 11 / Use Case 1.3: Apple Size Prediction

3.2.6.1 ML Model

Approaches apple size optimization as both a regression task (exact size) and a classification task (four size categories) to allow for proactive thinning management.

SVM achieved the best classification accuracy at 0.875, while Random Forest led regression performance.

3.2.6.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 28. Readiness level for Pilot#11

Category	Requirement	WP3 Status
Technical	**Feature Breadth:** Integration of trunk circumference, blossom value, and 3-year weather trends.	[✓] Ready
	Classification Quality: SVM reached **0.875 accuracy** for commercial size categories.	[✓] Ready
Operational	**Decision window:** current-year data up to blossom ensures a management window for thinning.	[✓] Ready
Governance	**Anonymization:** Removal of private parcel numbers for shared research datasets.	[✓] Ready

3.2.7 Pilot 12 / Use Case 1.3 & 3.1: Fruit Farm Phenology and Pest Risk

3.2.7.1 ML Model

Implemented for stone and pome fruit farms in Aragon, Spain, to predict phenological stages and disease risks.

Uses Dense Neural Networks (3–5 layers) tuned via Optuna on historical data from the RedFara surveillance network (2016–2025).

Achieved an R^2 of 0.974 for the phenology model.

3.2.7.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 29. Readiness level for Pilot#12

Category	Requirement	WP3 Status
Technical	**Large-scale Processing:** Processing of 2016–2025 historical data via Optuna tuning.	[✓] Ready
	API Latency: Verified for high-load RedFara surveillance queries	[✓] Ready
Operational	**Model Resilience:** Dropout layers (0.05–0.5) successfully prevented overfitting on regional data.	[✓] Ready
Governance	**Ethics Compliance:** Public data release via **Zenodo** meets project FAIR principles.	[✓] Ready

3.2.8 Pilot 15 / Use Case 3.1: Vineyard Pathogen Prediction

3.2.8.1 ML Model

These models predict the likelihood of four major grape pathogens: Downy Mildew, Powdery Mildew, Botrytis, and Erysiphe.

Version 1 Utilized K-Nearest Neighbors (KNN) as the primary classifier after testing against Logistic Regression, SVM, and Random Forest. It achieved precision scores above 0.93 for all pathogens.

Version 2 Integrated TabPFN (a transformer-based tabular predictor) and gradient-boosting models (XGBoost, CatBoost).

TabPFN significantly outperformed classical methods, reaching an accuracy of 0.9669 for Downy Mildew.

3.2.8.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 30. Readiness level for Pilot#15

Category	Requirement	WP3 Status
Technical	**Inference Orchestration:** Deployed via **TabPFN** transformer for tabular micro-climates.	[✓] Ready
	XAI Alignment: Summary cards available for Downy and Powdery Mildew risks.	[✓] Ready
Operational	**Data Consistency:** SMOTE oversampling used to balance rare infection events.	[✓] Ready
Governance	**Traceability:** Prediction outputs anchored to **CHAINTRACK** for auditable treatment logs.	[✓] Ready

3.2.9 Pilot 17 / Use Case 3.4: Olive Fruit Fly Monitoring

3.2.9.1 ML Model

Dual models for Treatment Requirement (predicting if intervention is needed) and Risk Assessment (identifying high-risk infestation conditions). Utilizes Logistic Regression based on weekly trap counts and agroclimatic indicators. Both models demonstrated high accuracy (0.96 for Treatment and 0.95 for Risk).

3.2.9.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 31. Readiness level for Pilot#17

Category	Requirement	WP3 Status
Technical	**Dual-Model Support:** Simultaneous Risk Assessment and Treatment Requirement flows verified.	[✓] Ready
	Federated Flow: Integration with **Flower** framework for privacy-preserving regional training	[✓] Ready
Operational	**Prediction Quality:** Achieved **0.96 accuracy** for daily treatment intervention advice	[✓] Ready
Governance	**Language Support:** Interface translated into 6 languages for Mediterranean growers.	[✓] Ready

3.2.10 Pilot 18 / Use Case 1.1: Smart Irrigation for Corn

3.2.10.1 ML Model

Predicts net irrigation water requirements (NIWR) based on the FAO-56 algorithm using environmental and OpenMeteo API data.

XGBoost was the top-performing model with an R^2 of 0.9832**.**

3.2.10.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 32. Readiness level for Pilot#18

Category	Requirement	WP3 Status
Technical	**Forecast Integration:** Merged OpenMeteo API for real-time 24-hour irrigation forecasting.	[✓] Ready
	Model Accuracy: Achieved the highest project regression performance (**0.98 R^2**) via XGBoost	[✓] Ready
Operational	**Feature Extraction:** Hourly measurements successfully transformed to daily statistics in STORE.	[✓] Ready
Governance	**Standardization:** Adheres to **FAO-56** guidelines for crop water requirements.	[✓] Ready

3.2.11Pilot 1 / Use Case 1.1: Corn Irrigation

3.2.11.1 ML Model

Because the crop (corn) and operational requirements are identical to Pilot 18, the Smart Irrigation model from Pilot 18 is directly applied here as federated model/transfer learning without modification.

3.2.11.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 33. Readiness level for Pilot#1

Category	Requirement	WP3 Status
Technical	**Cross-Pilot Reuse:** Verified deployment of Pilot 18 XGBoost model without modification.	[✓] Ready
	Platform Stability: K8s verified for multi-node IoT sensor streams in Poland.	[✓] Ready
Operational	**Historical Sync:** 2023–2024 fertilization plans successfully digitized for model context.	[✓] Ready
Governance	**User Training:** Pilot owner participated in technical demonstrations for WP5 readiness.	[✓] Ready

3.2.12 Pilot 19 / Use Case 4.1: Daily Methane Emission Prediction

3.2.12.1 ML Model

Developed to estimate daily methane emissions in dairy cows using data from GreenFeed systems combined with feed intake and production records. The model utilized a supervised regression approach, with CatBoost and XGBoost as top performers. The introduction of temporal methane features (3-day and 7-day rolling averages) significantly improved generalization. The CatBoost model achieved a testing of 0.713 and an RMSE of 0.034

3.2.12.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 34. Readiness level for Pilot#19 UC4.1

Category	Requirement	WP3 Status
Technical	**Platform Stability:** K8s cluster stability verified for GreenFeed data ingestion..	[✓] Ready
	Data Ingestion: Successful automated integration of enteric methane time-series	[✓] Ready
	API Latency: Avg. response for emission queries meets the <300ms benchmark.	[✓] Ready
Operational	**Hardware Integrity:** GreenFeed systems calibrated and reporting with <1% dropout.	[✓] Ready
	Standardization: Adheres to AIM for animal-level methane statistics	[✓] Ready
Governance	**Ethics & Anonymization:** De-identification protocols for animal production data in place	[✓] Ready
	User Training: Pilot owners trained on interpreting emission reduction insights.	[✓] Ready

3.2.13 Pilot 19 / Use Case 4.2: Milk Urea (Ureum) Concentration Prediction

3.2.13.1 ML Model

Focuses on predicting milk urea concentration as an indicator of protein metabolism efficiency and nitrogen utilization. It employs tree-based regression models trained on weekly records of feed intake, milk composition, and animal characteristics. Both CatBoost (Tuned) and TabPFN demonstrated the best overall performance, each reaching an of 0.66 on the test dataset.

3.2.13.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 35. Readiness level for Pilot#19 UC4.2

Category	Requirement	WP3 Status
Technical	**Inference Integration:** Successfully deployed via Dynamic AI (DynAI) orchestration.	[✓] Ready
	XAI Alignment: Summary cards available for protein metabolism insights.	[✓] Ready
Operational	**Preprocessing:** Automated z-score normalization pipeline verified in STORE.	[✓] Ready

	Data Consistency: Weekly aggregated production records synchronized	[✓] Ready
Governance	**Privacy:** Access control enforced via Keycloak for sensitive farm production data..	[✓] Ready
	Feedback Loop: Likert-scale feedback mechanism integrated for dietary optimization	[✓] Ready

3.2.14Pilot 20 / Use Case 4.3: Cow Welfare Anomaly Detection

3.2.14.1 ML Model

Uses an Isolation Forest (unsupervised learning) to flag deviations in cow activity time-series data that may indicate health issues or calving events.

Adding exponentially weighted moving averages (EWMA) to activity data improved the Calving Event Detection Rate to 0.750.

3.2.14.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 36. Readiness level for Pilot#20 UC4.3

Category	Requirement	WP3 Status
Technical	**Inference Orchestration:** Isolation Forest (unsupervised) integrated into real-time activity log.	[✓] Ready
	API Latency: Verified for high-frequency "movements per minute" data retrieval	[✓] Ready
Operational	**Context Building:** EWMA features implemented to reduce noise in behavioral time-series.	[✓] Ready
Governance	**Traceability:** Health anomaly alerts notarized on-chain via **CHAINTRACK**.	[✓] Ready

3.2.15Pilot 20 / Use Case 4.4: Early Detection of Calving Events

3.2.15.1 ML Model

Formulated as an anomaly detection task rather than conventional classification, assuming that behavior patterns exhibit unique deviations 1–4 days before calving. It uses a K-Nearest Neighbors (KNN) distance approach applied to collar-mounted sensor activity data.

To maximize its utility as an early warning tool, the model was tuned to prioritize recall. It achieved a strong recall of 0.875 for the "calving soon" class, ensuring the majority of events are identified ahead of time.

3.2.15.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 37. Readiness level for Pilot#20 UC4.3

Category	Requirement	WP3 Status
Technical	**Model Resilience:** Handling of high-frequency accelerometer data from cow collars.	[✓] Ready

	Alert Triggering: Integrated into the AI Flows interface for real-time notification.	[✓] Ready
Operational	**Preprocessing:** 3-day rolling moving average implemented to reduce signal noise.	[✓] Ready
	Recall Priority: Model tuned to 0.875 recall to minimize unattended calvings.	[✓] Ready
Governance	**Digital Independence:** Farmers trained to manage collar assets and interpret alerts.	[✓] Ready
	Traceability: Calving event records anchored to the CHAINTRACK blockchain.	[✓] Ready

3.2.16Pilot 21 / Use Case 5.3: Supply Chain Model for meat traceability

3.2.16.1 Use case model

This use case describes a scenario for tracking meat traceability using the Blockchain technology available in the AgriDataValue platform, resulting in a dedicated supply chain framework. The aim is to record the complete end-to-end journey of a single asset as it transforms from animal to meat, ensuring that every step involving the key actors is captured and immutably stored in the internal blockchain. This approach guarantees that the market operator receiving the final product can verify the entire chain of custody for quality control purposes. The main goal is to demonstrate the technologies implemented in the AgriDataValue platform. The solution can make transactions between actors in the production and distribution chain more secure, reliable, and transparent. It is possible to record, certify, and map the meat that is processed and transferred between actors who are often distant and *connected* through the supply chain. More details about this model are available on D2.3 deliverable.

3.2.16.2 Readiness status

Below, the readiness level checklist for this pilot:

Table 38. Readiness level for Pilot#21

Category	Requirement	WP3 Status
Technical	**Interoperability:** Multi-instance replication verified for cross-platform supply chain logs	[✓] Ready
	Blockchain Security: Ethereum/Hyperledger Besu nodes integrated for immutable records.	[✓] Ready
Operational	**Event Handling:** Automated logic for Barn-to-Market handover events confirmed	[✓] Ready
Governance	**Regulatory Alignment:** Metadata specification meets EU standards for meat identity verification.	[✓] Ready

3.3 Feedback-Loop Collection and User-Driven Innovation

The AgriDataValue (ADV) project adopted an iterative "improvement spiral" approach to ensure that the platform and use case implementations remain closely aligned with end-user needs. Throughout the latest implementation phase, a structured feedback mechanism was established, moving from preliminary UX testing to a comprehensive series of bilateral consultations with all pilot partners.

In accordance with the "improvement spiral" approach defined in the project's objectives, Task 3.4 moved beyond theoretical evaluation to implement a continuous feedback mechanism. This cycle ensured that the AgriDataValue

(ADV) Platform was not developed in isolation but was progressively refined through direct interaction with pilot owners and technical chairs.

Preliminary UX Validation Phase

Before the wide-scale consortium rollout, a targeted pilot-partner group consisting of three indicative pilot partners—TECNOVA, RINO, SIMAVI, and NILEAS—was granted early access to the ADV Platform through the Web Application.

- **Objective:** To assess the intuitiveness of the initial User Interface (UI) and the clarity of data visualizations with an initial user testing session on the AgriDataValue Platform.
- **Methodology:** Partners login to the Web Application and explored the various pages and functionalities of the AgriDataValue Platform as provided and visualised to the user through the Web Application. Partners conducted a "Think Aloud" assessment while performing standard tasks and provide feedback on the following:
    - If they have encountered any problems, crashes, bugs, things that did not work as they would have expected. For example, they started filling in a form and the page froze, or they could not click on a button, etc
    - If they had trouble navigating through the Web App's pages. For example, it was not straightforward/easy how to go to a specific page with a specific functionality
    - If they had trouble understanding what is the functionality provided in one of the pages. For example, some functionality was not self-explanatory and they would need some manual
    - If they think that some functionality that has been described in one of the Pilot Use Cases is missing
- **Key Outcome:** Feedback from this phase led to redesigning, as well as several changes on the Web Application and bug fixes, e.g., transitioning from a list-based view to the map-centric interface currently utilized to improve spatial awareness for farmers, and fixing the navigation between pages.

The Bilateral Consultation sessions (September 2025 – December 2025)

Following the initial UX fixes, a comprehensive series of bilateral teleconferences was conducted with every pilot partner. These sessions functioned as a formal "Requirement Fine-Tuning" stage, with the following objectives:

- finalise the description and goals use cases as defined in the context of WP1, and described in D1.2,
- finalise the related user-stories as defined in the context of WP1/3,
- verify the datasets being collected during the initial preparation phase in the context of WP3,
- verify the deployment of the sensor infrastructure to be used during the execution of the pilots.

Some of the outcomes of that series of telcos are listed below:

Table 39. Bilateral telcos for use cases fine-tuning

Feedback Category	Specific Impact on ADV Platform
Use Case Scope	• Removed P6_UC1.3 from the large scale roll out • Changed details of P11 • Updated details of P5, P7, P8, P9 • Validated description of P19, P20, P22, identifying cross-pilot opportunities • Updated P14 details and approach • Updated details of P18

	• Updated target of P12 • Updated scope of P21
ML Model Training	• Confirmed/Clarified input and output features • Updated datasets to match expected results • Updated pre-processing needs for dataset preparation • Identified gaps in historical data labeling, leading to the development of a manual data entry module through the web application.
Hardware Troubleshooting	• Resolved sensor drop-outs (P6, P14, P16, P19, P22). In some occasions restored devices were sent.
Feature Modification	• Further refined and highlighted the Activity Log page as the main point for daily pilot operations logging • Added Translations in 6 languages • Added Disease Assessment page • Applied changes in forms, e.g., notes/indications about metric units • Redesigned the Phenology drop down menu • Redesigned the Main page and merged the Map page • Replaced table views in pages with chart views • Redesigned the AI Flow page

Technical Training and Demonstration sessions

The final stage of the WP3 feedback loop involved a series of recorded **Technical Demonstration Telcos**. These sessions functioned as the first formal training for pilot partners in preparation for the operational phase.

- **Real-time Feature Validation:** Partners observed live demonstrations of the platform's capabilities.
- **Training Resources:** The recordings were uploaded on the project's central file repository, ensuring that technical support remains accessible during the scale-up.

3.4 Strategic Recommendations for Pilot Scale-up

The iterative process of **Task 3.4** has identified several critical pathways for the successful transition from WP3 implementation to WP5 scale-up. Most of them have already been considered by the WP5 leader, who was also participating in these telcos.

Operational Continuity and Technical Reliability

- **Standardized Infrastructure:** Based on the reliability metrics from section 4.1, future scale-up sites should utilize the manual data upload where cellular connectivity is intermittent.
- **Data ingestion monitoring:** The platform should be monitored for all pilot sites in case data ingestion stops.

User Empowerment and Digital Independence

- **Training Continuity:** The digital independence courses initiated in latest period should be mandatory for all new agricultural stakeholders joining the ADV ecosystem to ensure they can manage their own pilot assets, activity logging, maps and data layers.

- **Feedback Regularity:** The bilateral telco model should be preserved in WP5, with "Sync Sessions" scheduled periodically to ensure that any local changes are reflected in the AI model's performance.

Data Interoperability for Cross-Pilot Transfer

- **Harmonized Schemas:** To achieve true cross-pilot use case implementation, all scale-up sites must adhere to the ADV Data Model established during the training data extraction phase in WP3. This is achieved via the ADV Adapters which convert local data models into the ADV Data Model.
- **API Maturity:** In case of new APIs from IoT platforms, it is a high priority to develop new ADV Adapters to ensure historical context is available for all new pilot

4 Evaluation Framework Background

In the following chapters, an evaluation framework is presented that can be used to evaluate and validate the AgriDataValue use cases. First, an evaluation is made of the state-of-the-art tools after which the theoretical concepts are described in detail, along with a proposed approach to apply them in practice. As such, the presented framework provides a manual with theoretical concepts, but will not be applied as such, as not all parts can be executed or are relevant in respective ADV use cases. Depending on the use case, use case owners can use the best fitting approaches to evaluate the use case, the used methodology and the solutions developed within AgriDataValue. After application of the solutions on practical situations within the pilots, the developed solutions and results can be validated and provide input for the pilot's adaptation and scale-up.

In this section an analysis is made of the state of the art of tools and existing frameworks for evaluating IT systems which support activities such as the applications being developed within the AGRIDATAVALUE project. As a base for the definition of the framework we used the work of Lacueva et. Al 6.1 [1] which proposed a framework for evaluating the impact that Digital Interventions (the deployment of applications) have on shopfloor workers and the factories they are working in. As this reference framework focuses on the evaluation of Industry 4.0, we adapted this framework to the requirements of AGRIDATAVALUE. However, we considered similar tools for evaluating the quality of the solutions which, in the end, is a way to find new requirements and improvement opportunities.

First, sub-sections 4.1, 4.2 and 4.3 present a background of the different frameworks used to evaluate the acceptance and success, and the quality of the systems. Then, in sub-section 4.4 the adaptation of the framework we propose for evaluating the Pilot´s applications are presented.

4.1 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) is rooted in the Theory of Reasoned Action [2], which predicts behavioural intentions based on beliefs about the outcomes of a behaviour [2] [3]. TAM focuses on two key determinants of technology adoption: perceived usefulness (PU) and perceived ease of use (PEOU) [4]. PU refers to the degree to which a person believes a technology will enhance job performance, while PEOU relates to the perceived effort required to use the technology. TAM has been widely used in IT research and can be applied to a broader range of technology adoption contexts [5] [6]. The traditional TAM model is introduced in Figure 67.

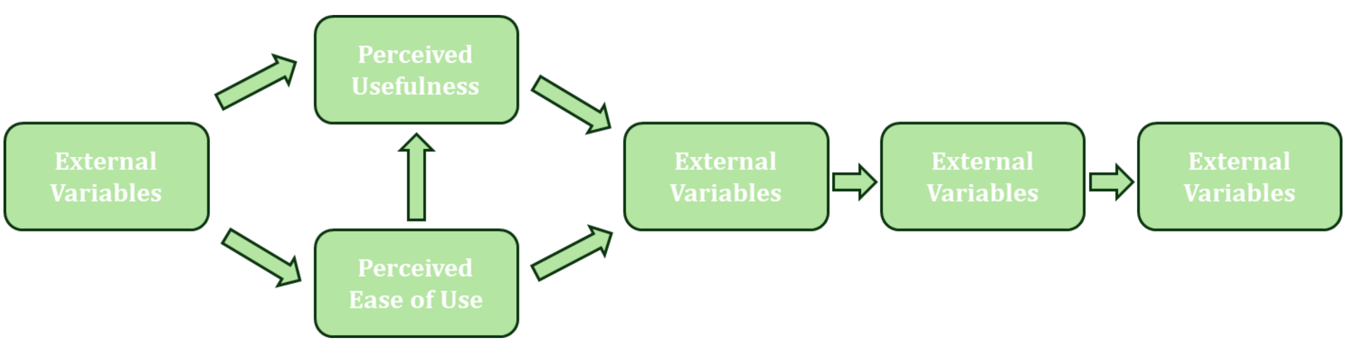


Figure 67. The original Technology Acceptance Model (Davis et al., 1989).

4.1.1.1 The Unified Theory of Acceptance and Use of Technology (UTAUT)

The Technology Acceptance Model (TAM) posits that individual reactions to information technologies (IT) influence both intentions to use and actual use of technology. While intentions are a primary driver of actual use, experiences with the system can also shape subsequent reactions. To gauge these reactions and predict future adoption, semi-standardized user surveys are often conducted after initial testing phases. The basic concept underlying the theory of the acceptance of information technology is depicted in Figure 68.

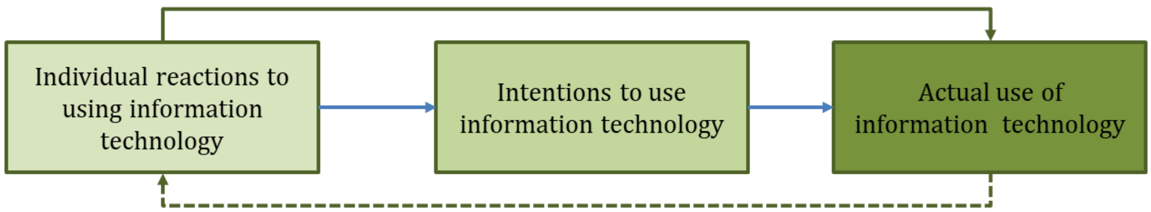


Figure 68. Concept underlying acceptance theory (Venkatesh et al., 2003).

The Unified Theory of Acceptance and Use of Technology (UTAUT) integrates key elements from previous models, such as TAM, to provide a comprehensive framework for understanding technology acceptance. UTAUT identifies four core constructs that directly influence user behaviour: performance expectancy, effort expectancy, social influence, and facilitating conditions. These variables are widely used in information systems research to explain technology adoption and usage. The UTAUT model is depicted in Figure 69.

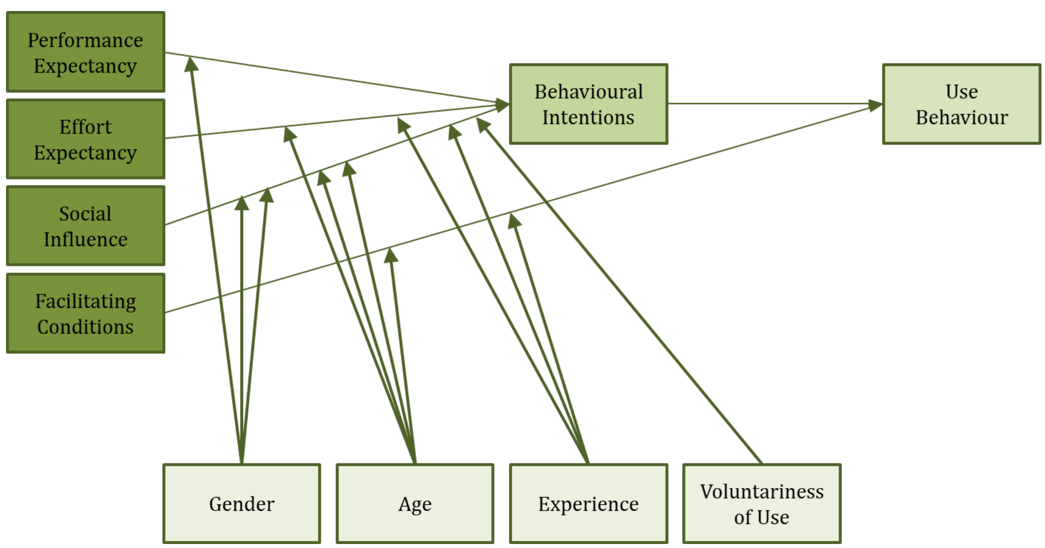


Figure 69. The Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003).

According to the UTAUT [7] the direct determinants of technology acceptance are:

(1) **Performance expectancy** (perceived usefulness): the degree to which an individual believes that using the system in real life will help to attain gains in job performance. It is the strongest predictor of acceptance
(2) **Effort expectancy** (perceived ease of use): the expected degree of ease associated with the use of the system
(3) **Social influence**: the degree to which an individual perceives that important others believe he or she should use the system

(4) **Facilitating conditions:** the degree of support in terms of organizational or technical infrastructure perceived by an individual

It is posited that the impact of these four constructs is mediated by gender, age, experience and voluntariness of use.

4.1.1.2 The IS success model

DeLone and McLean (D&M) have introduced the original Information Systems (IS) Success Model in 1992. However, the role of IS has changed and progressed after that and they have published an updated version of the model in 2003 [8]. In Figure 70, the updated D&M IS Success Model is presented. In the model, there are three major dimensions of quality, i.e. information quality, systems quality and service quality. Each of the dimensions should be measured separately as they have an influence on the use and user satisfaction. For example, information quality can be assessed based on how well it's organized, how effectively it's presented, how clearly it's written and is the information useful and up-to-date. System quality refers e.g. to the system's easiness to use, user friendliness, stability, security and speed. High quality service should be e.g. prompt, responsive, fair, knowledgeable and available [9].

As a result, e.g. a high-quality system will be assumed to have more use, more user satisfaction, and positive net benefits. In another case, more use of a low-quality system will be assumed to have more dissatisfaction and negative net benefits [8].

The D&M Information System (IS) Success Model provides a framework for evaluating the success of information systems. The updated 2003 model, see Figure 70, emphasizes three key dimensions of quality: information quality, system quality, and service quality [8]. Each dimension contributes to user satisfaction and system usage. For example, high-quality information is well-organized, clear, and up-to-date, while high-quality systems are easy to use, stable, and secure. Effective service is prompt, responsive, and knowledgeable. The D&M model suggests that systems with higher quality are more likely to be used, lead to greater user satisfaction, and yield positive outcomes. Conversely, low-quality systems may result in dissatisfaction and negative [9].

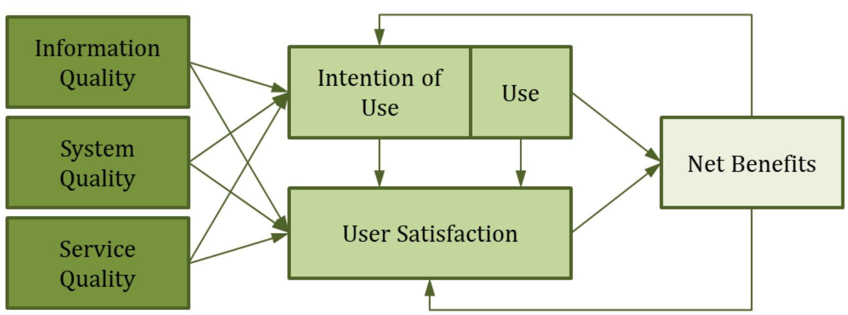


Figure 70. Updated D&M IS Success Model (DeLone and McLean, 2003).

4.2 The diffusion of innovations

One challenge in introducing new AGRIDATAVALUE solutions into farms is securing their adoption. Rogers' theory of innovation diffusion provides a framework for understanding this process. Diffusion involves the spread of an innovation through a social system, which in this case is the farming environment. While Rogers primarily focused on technological innovations, the theory's principles can be applied to various contexts, including sociology, marketing, and information systems [10]. The rate of adoption, or how quickly an innovation is adopted by a social system, is influenced by five key attributes of innovations (statistically, from 49 to 87 % of the variance in the rate of adoption is explained by these attributes): (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability [10]. .Key attributes of innovations affecting its acceptance. Table 40 shows the influence of these attributes with the acceptance of IT systems.

Although the theory of innovation diffusion is widely adapted in several disciplines, there is also some general criticism related to the theory [11] [12] [13]:

- Seeing diffusion as a linear, unidirectional communication activity, while in most cases diffusion is and interactive process of adaptation and adoption,
- Viewing diffusion as a one-to-many communication system, although point-to-point transfer is also important,
- Preoccupying diffusion research as action-centred and issue-centred communication activity, although it is also a social process with interpersonal networks,
- Using adoption as the dependent variable (the decision to use the innovation), while other studies have used attitudinal change as the dependent variable,
- Suffering from a so-called pro-innovation bias, assuming that an innovation should be adopted by all members of society as rapidly as possible.

The pre-diffusion phase, the period before the familiar S-curve of innovation adoption, is often understudied. This phase can be lengthy, requiring product development, production, distribution, and the establishment of necessary infrastructure. Identifying and engaging with early adopters, particularly technologically advanced individuals, is crucial during this phase. These early adopters can act as change agents, influencing the subsequent stages of diffusion.

Table 40.Key attributes of innovations affecting its acceptance.

Relative advantage refers to the perceived superiority of an innovation compared to existing alternatives. A higher perceived relative advantage is associated with a faster rate of adoption. This advantage can be measured in terms of economic factors like cost savings or financial return, but non-economic factors such as convenience, satisfaction, and social prestige also play a crucial role. The specific attributes of an innovation that are most important to potential adopters depend on the nature of the innovation itself and the characteristics of the target audience.
Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters.
Trialability is the degree to which an innovation may be experimented with on a limited basis.
Observability is the degree to which the results of an innovation are visible to others. It is closely related to the connections of the social system: some ideas are easily observed and communicated to other people, whereas other innovations are more difficult to observe, to try or to describe to others.

Complexity refers to the perceived difficulty of understanding and using an innovation. A higher perceived complexity is associated with a slower rate of adoption. While complexity may not always be a significant barrier, it can be a major obstacle for certain innovations, especially those that are significantly different from existing technologies or practices (Tidd and Bessant, 2013; Rogers, 1983).

The limits and inadequacies of diffusion theory may be overcome by considerations of complementing it with other theories and approaches or integrating them. Similar types of terms and concepts exist in TAM, UTAUT, IS Success and innovation diffusion theories.

4.2.1 HMI Assessment

User-centred design emphasizes the importance of evaluating the product throughout its development. Mock-ups and early prototypes can be used to validate interaction design and user experience, including perceived ease of use and usefulness, at an early stage. While models like TAM and UTAUT consider user acceptance, it's essential to independently evaluate Human-Machine Interaction (HMI) to assess the specific impact of an application on users and their tasks. Mock-ups and prototypes serve as valuable communication tools, enabling rapid iteration based on user feedback and enhancing user involvement and motivation. By separating these evaluation methods from theoretical models, we can apply them at different stages of the development process. The results of these evaluations can be used for various purposes, such as gathering requirements, refining design, assessing user acceptance, and more. HMI evaluation can evaluate three main issues: 1) physical interaction (which restrictions should be considered?, how the user feels?, etc.); 2) content (is the presented information useful?, is the content consistent?, etc.); 3) the user attitude and understanding.

Several frameworks exist to evaluate Human-Machine Interfaces (HMI). These can be categorized into two types:

1. **Usability Frameworks:** These focus on the user's evaluation of the interface's efficiency, satisfaction, learnability, memorability, and error rates. Evaluation techniques include expert reviews, task-based assessments on clickable mock-ups, benchmarking against similar applications, and questionnaires like the System Usability Scale (SUS) [14] and the User Experience Questionnaire (UMUX) [15]. These frameworks are introduced in Chapter 4.2.2.
2. **User Experience Frameworks:** These concentrate on the user's sensory and emotional response to the interface. They often rely on questionnaires like the Hedonic and Utilitarian Dimensions of User Experience (HED/UT) to assess these aspects [16]. They are introduced in Chapter 4.2.3.

The proposed methods are based on external measurements, which are obtained on (more or less) regular "shots" which are (to some extent) subjective (because they are not usually performed while executing the daily task, but on an "evaluation event"). As we already mentioned, more objective measurements would be provided by logging information while the applications is being used [17]. This real time measurements would include not only determining how the user is using the interface but also readings from sensors (accelerometer, gyroscope, physiological, etc.) defining the user (farmer) digital Imprint (UDI). While these measurements can be used, for example, to determine the stress level of the cognitive load of a user [18], before considering their use it must be contemplated that the process is a time-consuming process (and it can affect the system performance) and there are many legal issues to be considered.

The proposed methods rely on external measurements, which are often subjective as they are typically conducted during specific evaluation events rather than in the context of daily tasks. More objective measurements can be obtained through real-time logging of user interactions and sensor data, such as accelerometer, gyroscope, and physiological readings used [17]. These data can be used to create a Digital User Imprint (DUI) and Analyse metrics like stress levels and cognitive load [18]. However, implementing such real-time monitoring requires careful consideration of factors like performance impact and legal implications.

4.2.2 Usability

Nielsen, et al. defined usability as comprising five attributes: efficiency, satisfaction, learnability, memorability, and error rate, while also recognizing the influence of utility on overall system usability [19]. More recently, ISO 9241-11 defined usability as the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments, highlighting the importance of user, goal, and context [20]. During product development, measuring usability helps to gain a deeper understanding of user needs and improve the product for a better user experience. Establishing usability criteria early in the design phase and using summative measures to evaluate goal achievement throughout development is crucial.

Summative measures, obtained from user performance, satisfaction, hedonic questionnaires, or expert evaluations, are used to establish baselines, compare products, and assess the fulfillment of usability requirements. These measures require a sufficiently large and representative sample of users performing tasks in a realistic context. Statistical analysis is essential to ensure the validity and reliability of the results. Formative measures, on the other hand, focus on identifying usability problems, understanding user needs, and refining requirements. Qualitative data is the primary source of information in formative evaluation. However, quantitative measures like the number of identified problems can be useful, especially when statistically Analysed. While summative measures are more expensive due to the need for larger sample sizes and statistical analysis, formative measures are less resource-intensive and can be conducted with a smaller group of experienced evaluators [21]. Table 41 provides a summary of the main methods used in both summative and formative evaluations.

Table 41. Summative/formative methods.

Purpose	Description	When in Design Cycle	Typical Sample Size (per group)	Considerations
Early Formative Evaluations				
Exploratory	High level test of users performing tasks	Conceptual design	5-8	Simulate early concepts, for example with very low fidelity paper prototypes.
Diagnostic	Give representative users real tasks to perform	Iterative throughout the design cycle	5-8	Early designs or computer simulations. Used to identify usability problems.
Comparison	Identify strengths and weaknesses of an existing design	Early in design	5-8	Can be combined with benchmarking.
Summative Usability Testing				
Benchmarking/ Competitive	Real users and real tasks are tested with existing design	Prior to design	8-30	To provide a basis for setting usability criteria. Can be combined with comparison with other eSystems.

Final	Real users and real tasks are tested with final design	End of design cycle	8-30	To validate the design by having usability objectives as acceptance criteria and should include any training and documentation.

Usability evaluation methods can be categorized into three types [22]:

1. **Usability Inspection:** Expert-led evaluations [23], such as reviews, inspections, and walkthroughs, that Analyse the design of the interface without involving users. These methods are cost-effective but may not identify all usability issues [24]. The different expert's evaluation methods are shown in Table 42.

2. **Usability Testing:** User-centered evaluations where users interact with the system or prototypes. Methods include coaching, performance measurement, question-asking protocols, retrospective testing, thinking aloud, co-discovery learning, teaching methods, and remote testing. These methods provide insights into how users interact with the interface.
3. **Usability Inquiry:** User-focused methods that involve gathering information from users through interviews, focus groups, field observations, and surveys. These methods help to understand user needs and requirements. Table 43 shows a brief comparison between Inspection and Test.

Table 42. Types of Expert's Evaluation Methods (Petrie, 2009).

Guidelines	**Task Scenarios**	
	No	**Yes**
None	Expert Review	Usability Walkthrough
		Pluralistic Walkthrough
		Cognitive Walkthrough
General Guidelines	Heuristic Inspection	Heuristic Walkthrough
Detailed Guidelines	Guideline Inspection	Guidelines Walkthrough

Table 43. Comparison of Inspection and Test Usability Methods (adapted from Holzinger, 2005)

	Inspection Methods			**Test Methods**		
	Heuristic Evaluation	**Cognitive Walkthrough**	**Action Analysis**	**Think Aloud**	**Field Observation**	**QNR**
Applicable Phase	All	All	All	Design	Final Testing	All
Required Time	Low	Medium	Low	High	Medium	Low
Needed Users	None	None	None	3+	20+	30+
Required Evaluators	3+	3+	1-2	1	1+	1
Required Equipment	Medium	High	High	Mediu m	High	Low
Intrusive	No	No	No	Yes	Yes	No

A special group of methods for evaluating usability are the SUS, UMUX, and UMUX-LITE. These questionnaires are typically administered after users have interacted with the system but before any debriefing or discussion. Respondents are asked to provide immediate responses to each item, rather than reflecting on them for an extended period:

- The System Usability Scale (SUS) is a simple, ten-item Likert scale that provides a global assessment of a system's usability [14]. It covers various aspects such as support needs, training requirements, and complexity. Respondents rate each item on a 5-point scale, and the overall SUS score is calculated from the average of these ratings.
- Borsci, et al. [25] suggests that when the SUS is administered to users after a short period of product use, it is more appropriate to consider it a unidimensional scale. In this context, partitioning the scale into "Usable" and "Learnable" components is recommended. Additionally, it's important to note that newer users may have lower satisfaction scores compared to more experienced users. When the SUS is administered to more experienced users, it exhibits bidimensional properties, allowing for the calculation of an overall SUS score as well as separate "Learnable" and "Usable" scores. In this case, overall satisfaction levels are typically higher among more experienced users.
- The Usability Metric for User Experience (UMUX) [26] is a ten-item questionnaire designed to produce scores similar to SUS. It includes a general question about ease of use and three specific questions related to efficiency, effectiveness, and satisfaction, all rated on a 7-point Likert scale.
- UMUX–LITE [27] is a short version of UMUX which applies a two items questionnaire which proceed from UMUX and it also has a 7-point Likert scale.

Borsci, et al. [25] compared UMUX, UMUX-LITE, and SUS and found that UMUX-LITE, when adjusted, provides results closer to SUS than UMUX. While both UMUX and UMUX-LITE are reliable and valid proxies for SUS, the authors recommend using them in conjunction with SUS rather than as replacements. They advise against using UMUX alone for analyzing user satisfaction due to its potential for overly optimistic results. UMUX-LITE can be useful as a quick preliminary tool in early design phases, while a combination of SUS and UMUX-LITE (or UMUX) is recommended for advanced design and summative evaluation phases.

4.2.3 User Experience

User Quality of Experience (QoE) is a subjective concept that is difficult to measure. User Experience (UX) is a key component of QoE, focusing on a user's sensory and emotional response to interacting with a product or system. Understanding how users interact with a User Interface (UI) can provide valuable insights into their UX and overall QoE [17].

User Experience (UX) is defined as a person’s perceptions and responses resulting from the use or anticipated use of a product, system, or service [28] [29]. When interacting with an IT system, UX considers three key elements: the process (what the user does), the outcomes (what the user achieves), and the effect (what the user feels). It's important to recognize that UX extends beyond usability, encompassing various aspects [30]:

- UX takes a more holistic view than usability, aiming to balance task-oriented aspects with non-task-oriented aspects like beauty, challenge, and self-expression.
- UX is more concerned with users' subjective reactions to systems, their perceptions of the systems themselves, and their interaction with them, compared to usability, which emphasizes objective measures.

- UX focuses on the positive aspects of system use, aiming to maximize them, whether those positive aspects are joy, happiness, or engagement, while usability often focuses on removing barriers or problems.

There are several methods for UX evaluation and measurement. Questionnaires, interviews, and surveys are commonly used in HCI studies. A comprehensive list of methods classified by various criteria is presented by Vermeeren et al. [31]. Some representative methods include AttrakDiff, Differential Emotions Scale (DES), Experience Sample Method (ESM), Hedonic Utility Questionnaire (HED/UT), Long Term Diary study, PANAS, and Premo or Timed ESM.

4.3 Technological Approaches

Chapter 4.3 discusses the importance of measuring the acceptance and impact of an IS implementation on users of AGRIDATAVALUE developments. Traditional methods like surveys, interviews, and observations require user participation, which can be time-consuming and potentially unpleasant. While these methods are well-established, they are not always practical, especially in the early stages of development. To address these limitations, alternative approaches like analysing usage logs and data structure are proposed. These methods can complement traditional techniques, providing additional insights into user behaviour and system effectiveness.

Agriculture 4.0 is a term for technologies like IoT, AI, Blockchain, and Machine Learning used in farming [32]. While these technologies are integrated, users often see them as a single system. This makes it hard to evaluate the impact of each individual technology and identify areas for improvement in terms of acceptance, usability, and performance. A proposal for farmers could include these types of ICT solutions:

- Knowledge Management Systems (KMS) can help manage two types of knowledge: explicit and tacit. Explicit knowledge is easily documented and shared, while tacit knowledge is personal and harder to transfer. Enterprise resource planning (ERP) and Manufacturing Execution System (MES) systems provide explicit knowledge, but they are not KMS themselves. KMS can leverage social networks like chat, video conferencing, and wikis to capture and share tacit knowledge. These solutions can be effective in farming, as they have been in other sectors.
- Data Management refers to the components involved in data management, from collecting data from IoT devices or systems like ERP to processing and providing information or knowledge to farmers.
- Semantic Workflow Engine, which is the frontend between the user interfaces and the back-office of the project.

  HMIs are the user interface of AGRIDATAVALUE solutions. While user perception depends on the quality of underlying systems, the quality of the HMI itself is a major factor in determining overall solution quality and success.

AGRIDATAVALUE solutions can provide data that can be classified into three categories: Information Quality, Service Quality (not applicable in this context), and System Quality. This technological approach will be valuable for the framework as it will allow for a comprehensive evaluation of the system's effectiveness:

- Complement and benchmark data from traditional methods with new data sources, feeding the same evaluation dimensions.

- Launch a new and innovative evaluation approach, not just by collecting data, but by establishing a comprehensive process based on a solid foundation.
- Establish the basis for an automated data collection methodology for evaluation.

4.3.1 Measurements from ICT systems

In this chapter we detail some of the possible measurements (in terms of information sources and/or data) that the expected ICT solutions for AGRIDATAVALUE can help us to get the information required in the Evaluation Framework.

4.3.1.1 Knowledge Management System Metrics

Knowledge Management (KM) provides procedures and technology to help knowledge flow to the right people at the right time, improving efficiency and effectiveness. KMS aim to foster the reuse of intellectual capital, enable better decision-making, and create conditions for innovation. Several metrics have been developed to measure KMS performance, particularly when using IS support. Knoco (2014) and Haghi (2004) offer practical perspectives, while Wong (2013) provides an academic review. Knowledge metrics can be classified into three categories:

- Knowledge Resources are intangible assets of an organization, such as human capital, knowledge, and intellectual property. These are particularly relevant to the AGRIDATAVALUE project.
- Human Capital refers, within our scope, to farmers as the holders of most of the tacit knowledge, ideas, skills and abilities that add value to the company. Knowledge and information capital refers to the quantity and quality of knowledge that a company owns. Usually, this knowledge is stored in a company's data repository system (i.e. database) in various forms such as text, images, audios and videos.
- KM processes include knowledge acquisition, internalization, creation, application, utilization, codification, storage, transfer, and sharing.
- Factors affecting KM include culture, management, leadership, organizational infrastructure, and technology.

From AGRIDATAVALUE perspective, the most relevant metrics in this scope are the ones related to the KM Processes, since our solutions are supposed to support them. Table 44, adapted from [33] , presents relevant metrics for the purpose of our project:

Table 44. Metrics for measuring the performance of KM processes. Adapted from (Wong, 2013).

Category	Metric
Acquisition and Retrieval	Repeat usage of the repository items Employees search information for tasks from various knowledge sources administered by the organization Number of site accesses Number of downloads How often users are accessing the knowledge resources Internal training and the exchanges frequency Number of meetings for idea generation attended per employee per month Working hours per employee spent for inputting knowledge into KMS per month Number of new knowledge, ideas, and solutions created per employee per month Number of documents and articles accessed or downloaded per employee per month Number of documents and articles uploaded or updated per employee per month Development time for new products How many 'times' each employee brings up a proposal Number of meetings for idea generation attended per employee per month Number of new knowledge, ideas, and solutions created per employee per month Number of new products, inventions, and services generated per year
Creation and Generation	How often users are using the knowledge resources and practices The use of new knowledge and the ability to transform Number of new products, inventions, and services generated per year Number of problems solved, and ideas implemented per employee per month
Application and Utilization	Amount of codification of available knowledge assets Amount of the organizational memory (OM) codified and included in the computerized portion of the OM. How often users are contributing to the knowledge resources Working hours per employee spent for inputting knowledge into KMS per month Number of documents and articles accessed or downloaded per employee per month Number of documents and articles uploaded or updated per employee per month
Codification and Storing	Amount of codification of available knowledge assets Amount of the organizational memory (OM) codified and included in the computerized portion of the OM. How often users are contributing to the knowledge resources Working hours per employee spent for inputting knowledge into KMS per month Number of documents and articles accessed or downloaded per employee per month Number of documents and articles uploaded or updated per employee per month
Transferring and Sharing	Number of team rooms and participants in each Level of interactions, discussions and collaborations among employees on important identified subjects Communication capability Employees share information and knowledge necessary for the tasks Employees improve task efficiency by sharing information and knowledge Employees promote sharing of information and knowledge with other teams Number of hours the employees participate in workshops/seminars/networks or other activities, per month Number of knowledge shared per measurement interval Number of users participating in knowledge sharing activities Level of information communication among the staff Level of inter-departmental information communication Level of information communication with customers Number of knowledge sharing sessions attended per employee per month Number of active communities of practice, research groups, and special interest groups Number of communications per employee per month
"Transversal" Metrics	Number of knowledge users Number of frequent KMS users Number of knowledge assets generated per year

4.3.1.2 Data Management.

Data Management encompasses building blocks that gather data from machines or IoT devices or systems like ERP and process it to provide information or knowledge to farmers. These building blocks include traditional database systems and new big data technologies.

Evaluating data quality is crucial. It involves both subjective perceptions and objective measurements. Subjective perceptions can be assessed through questionnaires, while objective measurements can be based on data quality dimensions like accuracy, objectivity, believability, accessibility, relevancy, timeliness, completeness, interpretability, and consistency [34]. Batini, et al. recognized that there are many discrepancies in the definition of these dimensions because of the contextual nature of DQ [35]. Reviewing the more significant studies of the existing literature, the author identified the basic set of data that compose the 'quality' dimension:

- Accuracy is a measure of how close a value (v) is to a correct value (v'). It can be divided into two types: syntactic and semantic. Syntactic accuracy measures how close v is to v' in terms of syntax (e.g., correct spelling). Semantic accuracy measures how close v is to the correct definition domain (e.g., whether a value is a valid name).
- Completeness refers to the sufficiency of data for a given task. In relational databases, it's often linked to null values, which represent missing data. Understanding the reason for missing data is crucial for characterizing completeness.
- Consistency ensures that data adheres to semantic rules. In relational databases, integrity constraints enforce these rules. Integrity constraints can be intra-relation (within a single table) or inter-relation (across multiple tables).
- Time-related dimensions consider the temporal aspect of data, including currency, volatility, and timeliness. These dimensions are defined as follows:
    - Currency measures how up to date a piece of data is. It's typically assessed based on the last update time. For data with fixed update frequencies, currency is straightforward. For data with variable frequencies, an average frequency can be used, but with potential error.
    - Volatility describes the rate at which data changes over time. It's an inherent characteristic of data types, so specific metrics aren't needed.
    - Timeliness measures the appropriateness of data age for a specific task. It considers both the currency of the data and its availability before a planned usage time.

Table 45 describes some metrics that can be applied to the DQ dimensions.

Table 45. Data Quality Metrics. Adapted from [35].

Dimension	Metrics Definitions
Accuracy	Syntactic Accuracy= Number of correct values/number of total values
	Number of delivered accurate tuples
	Number of duplicated values

Completeness	Number of not null values/Total Number of values
	Number of tuples delivered/Expected Number
Currency	Time data are stored in the system – time in which data are updated in the real world
	Time last update
	Request time – last update
	Age + (Delivery Time – Input date)
Timeliness	Max (0; 1-Currency/Volatility)
	Percentage of process executions able to be performed within the required time frame
Consistency	Number of consistent values/Total number of values.
	Number of tuples violating constraints/ number of coding differences
	Number of things in real world/Number of records describing different things

4.3.2 HMI Measurements

Chapter 4.3.2 introduced traditional methods for evaluating HMIs, often designed for WIMP interfaces and more suited to lab settings than real-world scenarios. These methods can also be applied to mobile applications, which have specific characteristics.:

- Mobile context: Users are not tied to a single location and interact with people, objects, and environments around them.
- Connectivity: Network connections can be slow and unreliable, affecting the performance of applications.
- Small Screen Size: It limits the information that can be displayed.
- Different Display Resolution, which may lead to different UX.
- Limited Processing Capability and Power.
- Data entry methods.

While traditional usability evaluation methods can be applied to mobile applications, they are often expensive, time-consuming, and do not fully account for mobility factors [36]. Data logging offers a promising alternative, providing detailed usage statistics and identifying navigational errors or inefficiencies [36]. By analyzing low-level metrics like session times, screen calls, and button clicks, valuable insights into user behaviour can be gained, even for existing applications.

5 Evaluation Framework

In this chapter, the theoretical concepts of chapter 4 are used to formulate an evaluation framework that can be used in practice within the ADV project. The evaluation framework presented here is derived from the work presented by Lacueva et. Al [1] to evaluate Industry 4.0 solutions, and is divided into two main components: Impact Analysis (IA) and Quality Validation (QV).

Impact analysis will be conducted for each use case and pilot. It will assess whether, and to what extent, the digital interventions—including changes in practices and information systems, as well as the introduction of technological solutions—achieve the expected results in farming and livestock operations.

Table 46. Examples of measurements of the impact for each use cases cluster.

Use Case Cluster	Assessment (examples).
Cluster 1: Optimize the quality and quantity of the crop production and increase the environmental sustainability.	% of reduction of wasted irrigation water, fertilizers, pesticides, energy.
Cluster 2: Precision irrigation/fertilization, harvest /diseases prediction for vegetables/arable crop increased production.	% of production increase.
Cluster 3: Protect the health and quality of fruit trees and vineyards crop. Increase quality and quantity, avoid diseases with less pesticides, foresee and mitigate frost.	% reduction of pest treatments Number of protected frosts
Cluster 4: Use edge cloud and real-time IoT sensor data (e.g. neck collar, feeders, emission sensors) together with GPS location data to monitor the cattle/pig health, activity, feeding and calving, proactively control milk and meat quality, reduce the greenhouse gas emissions and nitrogen deposition.	% reduction of nitrogen deposition
Cluster 5: Validate cross domain use cases (fruit, vineyards, livestock, milk, oil, biogas, manure, energy) and address both supply and demand sides of the supply chain, including interoperability and traceability of platforms, electricity production and waste management.	Corelate and upgrade IoT sensor and business data from > 20 supply chain stakeholders

Quality Validation (QV): Determines if the evaluated artefact meets user expectations in terms of system, information, and interaction quality. The depth of evaluation depends on the maturity of the artefact:

- Mock-ups/demonstrators: Proof of concept
- Functional prototypes/pilots: Proof of value
- Deployed solutions: Proof of use

The evaluation of the QV process provides a comprehensive assessment of the quality of the project's deliverables.

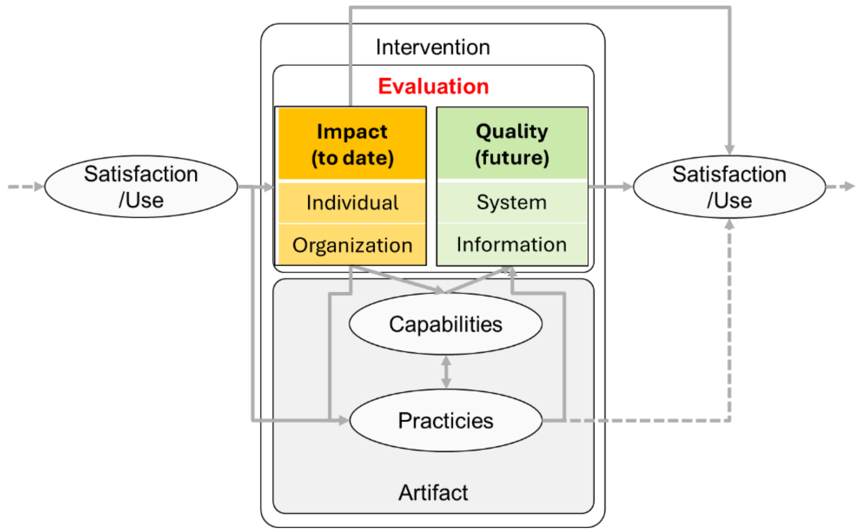


Figure 71. Formulation of the evaluation framework. Adapted From (Gable et al., 2008).

The evaluation process for farmer-centered IS artifacts in the Pilots is reflexed in Figure 71Figure 68. QV evaluates the quality of the information system, information, and technologies involved in the artifact. Determines the potential for future user satisfaction and usage. The evaluations will be conducted throughout the project lifecycle (they must be longitudinal). The focus and approach of each evaluation are determined based on the project stage and artifact maturity.

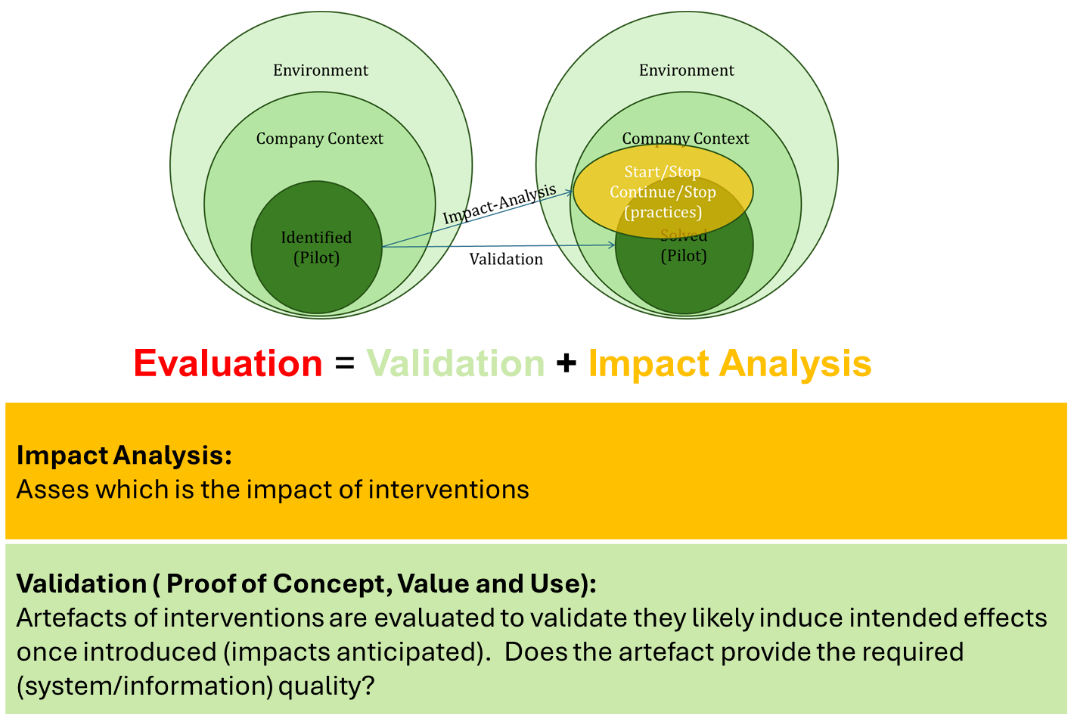


Figure 72. Overview of the evaluation

The evaluation of the AGRIDATAVALUE project will assess the impact of interventions system acceptance, and success. This will be done through longitudinal studies.

Impact Analysis (IA):

- Uses a variety of methods, including surveys, interviews, and log data.
- Establishes a baseline measurement to track changes over time.
- Analyses the impact of interventions on the defined dimensions.

Quality Validation (QV):

- Evaluates the quality of artifacts at different stages (mock-ups, prototypes, pilots).
- Employs methods such as interviews, observations, and surveys.
- Focuses on system and information quality, including usability, usefulness, accuracy, and relevance.
- Provides insights for iterative improvement of the artifacts.

The rest of the document will provide detailed guidelines for conducting both IA and QV, along with the expected results. Before initiating an evaluation process, several ethical and legal considerations must be addressed.

- **Ethical Considerations:**
  - Anonymity: Ensuring participant anonymity is crucial to encourage honest responses.
  - Informed Consent: Clearly explain the purpose of the evaluation and obtain informed consent from participants.
  - People (farm workers, farmers, etc.) Reticence: Address potential user reluctance by emphasizing that the evaluation is not about individual performance but rather the impact of the intervention.
- **Legal Considerations:**
  - Legal Frameworks: Adhere to relevant legal frameworks, especially regarding data privacy and user rights.
  - Data Collection Restrictions: Be aware of limitations on data collection methods, such as surveys, in certain locations.
  - People (Farm workers, Farmer, etc.) Consent: Obtain formal consent from users before conducting evaluations.
- **Tool Selection:**
  - Language Barriers: Consider language barriers and choose appropriate tools (questionnaires or interviews).
  - Resource Constraints: Evaluate available resources to determine feasible methods.
  - Artifact Maturity: Tailor the evaluation approach to the maturity level of the artifact.
  - Expected Impact: Align the evaluation with the anticipated impact of the IS solution.
- **Participant Selection:**
  - Representativeness: Select a representative sample of different users (stakeholders) and use scenarios (on field, in office, etc.).
- **Control Group:** Consider including a control group of users not using the solution to isolate the impact of the intervention.

By carefully considering these factors, the evaluation process can be conducted ethically and effectively, yielding valuable insights into the impact of the AGRIDATAVALUE applications.

5.1 Impact Assessment & Quality Validation Assessment

QV interventions are sessions where ICT artifacts are presented to users for validation. The intervention's approach depends on the artifact's maturity level. This chapter will discuss the purpose, methods, and conduct of these interventions.

5.1.1 Mock-up Validation

The initial intervention at the Pilot sites can involve evaluating use cases using mock-ups. This evaluation aims to prove feasibility by gathering user feedback on concepts, future functionalities, and interaction paradigms. This will ensure the solutions align with the user requirements.

The evaluation session will be conducted in a quiet office using **the think-aloud method**. Users will verbalize their thoughts on the interface while the facilitator encourages discussion through questioning. This qualitative approach, combined with standardized questionnaires, will provide insights into user perceptions of the mock-ups and the underlying concept.

By conducting this early-stage evaluation, the project team can gather valuable feedback to refine the concept, interface, and drive the next development iteration.

Mock-ups evaluation planning and setup

To conduct the mock-up evaluation session, careful planning of human and material resources is essential. The responsible facilitator for each use case must prepare all necessary materials and coordinate the session with IP representatives. This includes booking the evaluation facility, scheduling a day, and selecting and convening users for different time slots.

While a single facilitator can conduct the paper mock-up evaluation session, it is recommended to have two researchers present: one to facilitate the session and another to observe. This approach ensures a more comfortable environment, enhances the validity of the study, and allows for a broader understanding of participant perspectives. In the room of the study, there may be:

- Stacks of paper with printed paper mock-ups scenarios to evaluate.
- Markers and pens in reach of the participant.
- Blank paper
- IC and questionnaires.
- Optionally: A laptop/tablet in case we use clickable mock-ups.
- Optionally: Audio/video recorders placed behind the participant if we want to record the session.

Session procedure protocol

The mock-up evaluation session should ideally be conducted individually. The proposed evaluation method involves presenting participants with different scenarios, each corresponding to a specific use case task. Participants will be asked to evaluate the process of performing these tasks using the provided mock-ups. This process will be conducted in two rounds for each scenario, with the specific purposes outlined below.

A. Round A or Thinking Aloud: in the first round of the evaluation, participants are presented with a use case scenario and encouraged to navigate the mock-up independently, thinking aloud as they go. They are asked to imagine the mock-up is a real prototype and to physically interact with it, even if it's just paper. If they make a wrong choice, they are allowed to try again, and the facilitator asks why they made that choice. If they get stuck, they are asked how they would proceed. The facilitator avoids guiding participants' observations and instead focuses on their spontaneous reactions.
B. Round B or post-experience: The second round of the evaluation aims to delve deeper into the participant's thoughts on the application and its features. Participants are guided through the scenarios again, **but this time the facilitator draws their attention to specific details**, such as the purpose of buttons, features, and the overall aesthetics. Participants are encouraged to provide feedback and suggest improvements. To conclude the session, a guided interview is conducted to gather overall feedback. Additionally, an UMUX-LITE questionnaire can be administered to collect quantitative data on the participant's initial impressions of the mock-ups.

5.1.2 Prototype Validation

Before end-user evaluation, an expert review by project leaders is recommended to ensure prototype quality. This review will focus on Nielsen and Molich's (1990) interaction design heuristics, such as visibility of system status, real-world match, user control, consistency, and error prevention. Based on expert feedback and necessary improvements, the first farmer evaluation will use a user observation method, detailed below.

User Validation

User observation is a contextual technique that helps understand user problem-solving methods and environmental influences on device interaction. To capture these factors, observations will be conducted in real work environments to evaluate external conditions like noise, light, and clothing on prototype usage and task performance. However, in challenging environments, controlled laboratory settings may be necessary.

The interventions will involve prototypes at various stages of development, from initial prototypes to final deployments. These prototypes will be vertical slices, focusing on specific functionalities to allow for early validation of quality and usability. These vertical prototypes are particularly useful for validating design approaches and exploring alternative architectures in high-risk projects. By focusing on specific functionalities and implementing key components, teams can assess technical feasibility and user experience before committing to full-scale development.

Preparation for User Observations

Before delving into the technique, several considerations are crucial:

- **Research Objectives:** Clearly define the specific insights to be gained from the observational study. In this case, the focus is on understanding how participants interact with AGRIDATAVALUE prototypes in their workplaces. Scenario-based approaches with different assignments will be used to facilitate this.
- **Participant Recruitment:** The pilot facilitator will select a relevant number of users for each activity scenario, aligning with the job descriptions to ensure meaningful results.
- **Observer Recruitment and Training:** Trained observers will be recruited to conduct the procedure protocol, explain the process to participants, and adhere to AGRIDATAVALUE ethical guidelines regarding data collection and usage.

User observation procedure protocol and setup

Individual user observations will be conducted on a real scenario (or on lab if not possible). Participants will use prototypes in real work environments to perform tasks based on their daily routines. These tasks are organized into scenarios that align with the activity scenarios. The initial prototype will include a subset of features to address specific requirements and serve as a foundation for the final implementation. The goal is to enable farmers to use AGRIDATAVALUE solutions in the final pilot to complete their tasks.

A researcher or facilitator will accompany each participant during the observation, encouraging them to think aloud about their problem-solving process. The observer will document the participant's interactions with the application, task completion strategies, difficulties encountered and the impact of external factors.

The facilitator must maintain neutrality and use a recording device to capture the participant's verbalizations. It's essential to remind the participant that the focus is on evaluating the AGRIDATAVALUE solution, not their personal skills or efficiency.

The important points to examine during the observation are:

- The analysis should compare the actual behaviours of participants with the expected behaviours based on the design and intended use of the application.
- The analysis should consider how operators integrate the AGRIDATAVALUE application into their routines and the specific strategies they employ to utilize it effectively.
- It's crucial to examine activities holistically, considering how the solution is used within the context of the device and the overall workflow. This includes observing factors like device handling, interaction with other machinery, and potential interruptions caused by the device, connectivity, etc.
- The moderator should collect qualitative insights and identify specific behaviours that can be repeated and observed in future interactions. These observations should be documented for further analysis.

Once the user observation process is complete, a short interview is conducted to gather feedback from the farmers. They are asked about their overall satisfaction, system and information quality, and their intention to use the prototype.

After the prototypes are deployed for intensive use, follow-up interviews are conducted periodically to continue gathering feedback. Users are encouraged to provide ongoing feedback as they use the prototype independently.

Pilots' validations

Pilot validations serve as a proof of concept for the AGRIDATAVALUE solutions. In this phase, the mature solutions are in use within the farm, and data sources like logs can provide additional, less intrusive measurement methods.

A pilot deployment involves rolling out the solution to a group of farmers. For validation, farmers involved in the pilot will be convened to discuss their experiences.

During the pilot stage, the solutions are running in the farm's production environment, that is probably in fields. This requires careful consideration of operational factors. The validation aims to understand how the solution integrates into farmers' practices, its benefits, and any unexpected issues. A facilitator will be assigned to support users during the pilot, addressing errors, problems, and providing technical assistance as needed.

5.2 Interpreting Evaluation Results

This section focuses on interpreting the results of evaluations, which are crucial for determining future actions, whether it's after an initial evaluation or a full assessment of an intervention. An intervention, in this context, refers to the deployment of a Smart-farming solution aimed at influencing farmers' practices. Evaluating an intervention involves two key processes: validation of the deployed artifact and Impact Analysis (IA). The significance of each process depends on factors such as the artifact's maturity, the project stage, and the timing of the evaluation (before or after deployment). The subsequent chapters delve into the interpretation of results. The initial chapter outlines the purposes of IA and validation, providing a foundation for understanding the interpretations discussed in the following chapters.

5.2.1 Impact Analysis and Validation Purposes

IA and validation serve distinct purposes. IA assesses whether the changes in practices enabled by deployed artifacts lead to the desired improvements in farming practices. Validation, on the other hand, determines if the artifacts meet user requirements in terms of information, functionality, and system performance.

The relative importance of IA and validation varies depending on factors such as the artifact's maturity, the project stage, and the timing of the evaluation. Mock-ups and prototypes represent two primary maturity levels. The following paragraphs deep into the evaluation purposes and data analysis considerations for both types of artifacts, with specific guidance provided in Chapter 5.2.2.

Evaluation of Mock-ups

Mock-ups are early-stage tools used to facilitate communication between users (farmers) and development teams. They lack functional interaction interfaces, serving primarily to validate the development team's understanding of the problem. Due to their limited functionality, only quality validation (QV) can be applied to assess the intervention.

Prototypes, on the other hand, provide a more advanced level of interaction with the system. They offer valuable insights into information and user interaction improvements, as well as the understanding of processes to be supported by backend functionalities. The closer the prototype resembles the final HMI design and the target device, the more accurate the evaluation results will be.

Key differences between mock-ups and prototypes:

- **Functionality**: Mock-ups lack backend functionality, while prototypes have limited functionality.
- **Evaluation**: Mock-ups are primarily evaluated through QV, while prototypes can be evaluated through both QV and IA.
- **Deployment**: Mock-ups are not deployed, while prototypes can be deployed for testing and user feedback.

In summary, while both mock-ups and prototypes play crucial roles in the evaluation process, their focus and impact differ. Mock-ups are essential for early-stage validation and understanding, while prototypes provide a more realistic assessment of user experience and system functionality.

Evaluation of Prototypes

Prototypes are more advanced than mock-ups, as they implement functionalities that directly impact farmer practices. Consequently, their deployment can influence problem-solving, innovation, satisfaction, and productivity. The evaluation aims to assess the extent of these impacts.

The degree of impact depends on the prototype's maturity, quality, and implemented functionalities. Once deployed, prototypes generate both application and log data, enabling the use of both qualitative and quantitative evaluation methods.

Key considerations for evaluating prototypes:

- **Pre- and Post-Intervention Evaluation:** Both IA and QV should be conducted before and after deployment.
- **Validation:** Focuses on assessing the artifact's quality, functionality, and user experience.
- **Impact Analysis:** Determines the extent of changes in farmer practices and performance.
- **Data Analysis:** Analyse both qualitative and quantitative data to gain insights into the intervention's effectiveness.
- **Decision-Making:** Use evaluation results to inform decisions about future iterations, improvements, and new functionalities.

By carefully considering these factors, the evaluation of prototypes can provide valuable insights into the impact of AGRIDATAVALUE (Smart-farming) interventions and guide future development efforts.

5.2.2 Interpreting Evaluation Results

While validation focuses on the artifact's quality, IA assesses its impact on farmers.

Mock-ups:

- Early-stage tools for communication and concept validation.
- Lack functionality, so primarily evaluated through validation.
- Provide insights into front-end and back-end requirements.
- IA results can gauge the impact of the development process itself.
- Both validation and IA results inform the decision to proceed with development.

Prototypes:

- Implement functionalities that influence farmer practices.
- Evaluated through both validation and IA.
- Validation assesses the artifact's quality and user experience.
- IA measures the impact on farmer behaviour and performance.
- Combined results inform decisions about further development, deployment, and potential impact.

Pilots:

- Mature prototypes deployed on a larger scale.
- Evaluation focuses on both validation and IA, with a stronger emphasis on IA.
- Assess the real-world impact and scalability of the solution.
- Provide valuable insights for full-scale deployment.

The following paragraphs provide detailed guidance on interpreting evaluation results for mock-ups, prototypes, and pilots.

Mock-ups Evaluation Results Interpretation

Mock-ups are early-stage prototypes that primarily focus on understanding user interaction requirements and the processes to be supported. They lack backend functionalities and are not intended for real-world deployment. As a result, evaluations of mock-ups are primarily focused on **validation**.

Key points for interpreting evaluation results of mock-ups:

- **Validation:**
  - Focuses on user interface, interaction design, and system usability.
  - Identifies specific interaction requirements and potential challenges.
  - Provides insights into the necessary backend functionalities.
  - Helps refine the requirements for the virtual process and information exchange.
- **Impact Analysis (IA):**
  - While mock-ups don't directly impact farmer practices, IA can assess user expectations and perceived value.
  - Provides a baseline for measuring potential impact in future stages.
  - Helps identify potential issues and areas for improvement.

The results of mock-up evaluations can inform decision-making regarding project viability, prioritization, and the scope of future prototypes. By understanding user needs and identifying potential challenges early on, the development team can make informed decisions to ensure the success of the project.

Prototypes Evaluation Results Interpretation

Once a project is selected, the number and scope of interventions are planned, including the functionalities to be implemented and their expected impact. This information guides the evaluation planning process, determining what aspects to evaluate within each intervention.

Prototypes, with their implemented functionalities, have the potential to influence farmer practices. However, the extent of this impact depends on the prototype's maturity and quality.

The following sections delve into interpreting evaluation results, focusing on decision-making before and after deployment.

- **Before deployment (t_i):**
  - IA: Provides a baseline measurement to track future changes.
  - Validation: Assesses the artifact's quality and identifies potential issues.
- **After deployment (t_{i+1}):**
  - IA: Measures the actual impact on farmer practices and compares it to the expected impact.

- Validation: Identifies areas for improvement and informs future development.

Before deployment (**t_i**), validation provides more valuable insights than IA. The validation process identifies improvement opportunities and non-conformities in user requirements. These non-conformities can significantly impact the artifact's quality and may necessitate postponing the deployment until they are addressed. The IA at t_{i+1}, when the artifact has been in use for a while, is crucial for determining the variance in measurements and assessing the overall success of the intervention.

Intervention Prototype Evaluation

After the initial deployment of an artifact, a second evaluation will be conducted. This evaluation will leverage both quantitative and qualitative data for validation and impact assessment (IA).

- **Validation:**
  - Identify Improvement Areas: Validation data will help identify areas for improvement and new functionalities to enhance user support.
  - Prioritize Requirements: Prioritize and add new requirements to the list for future interventions.
- **Impact Assessment**:
  - Measure Impact: IA will assess whether the intervention achieved the expected effects by measuring objective indicators.
  - Control Group Comparison: If available, a control group can help isolate the impact of the intervention from external factors.
- **Addressing Non-Conformities**:
  - Prioritize Fixes: If non-conformities (errors, performance issues) are detected, addressing them and redeploying the artifact is the top priority.
  - Leverage Log Data: Log data can help identify the root causes of problems and pinpoint specific components.
  - Re-evaluate After Fixes: After resolving issues, a new evaluation is necessary to assess the impact of the corrections.
- **Analysing Unexpected Results**:
  - Trace Back to Root Causes: For unexpected results, a detailed analysis of the data, including both IA and validation data, will be conducted to identify the root causes.
  - Examine Building Blocks: If specific building blocks (BBs) are not contributing as expected, their evaluation results will be analysed to determine the reasons.
  - Consider Re-implementation: If BBs are not implemented correctly or quality issues persist, re-implementation or corrective actions will be required.
- **Iterative Improvement and Pilot Deployment:**
  - Continuous Improvement: If the artifact is performing well but has room for improvement, a new intervention may be considered to enhance its capabilities.
  - Pilot Deployment: If significant improvements are not feasible or cost-effective, the prototype may be transitioned into a pilot deployment to gain further insights and experience.

Pilots Evaluation

While prototypes and pilots may seem similar, they serve distinct purposes in the development and evaluation of technological solutions. Prototypes are early-stage versions of a product or system, designed to test concepts and gather feedback. They are often used to validate design choices, explore user interactions, and identify potential issues. Prototypes are typically developed and tested in controlled environments, such as laboratories or design studios. On the other hand, pilots involve deploying a solution in a real-world setting to assess its performance and impact. They are used to evaluate the scalability, reliability, and usability of a solution under real-world conditions. Pilots often involve a larger user base and require more extensive infrastructure and support.

- Key Differences in Evaluation
  - Focus: Prototype evaluations prioritize user experience, interaction design, and functional validation. Pilot evaluations, in contrast, focus on performance, reliability, and scalability.
  - Data Collection: Prototype evaluations often rely on qualitative data, such as user feedback and observations. Pilot evaluations typically involve both qualitative and quantitative data, including performance metrics and user surveys.
  - Timing: Prototype evaluations are conducted early in the development process, while pilot evaluations occur later, closer to product launch.
- Technology Readiness Levels (TRL) and Pilot Duration: the TRL scale is a measure of technology maturity. To achieve TRL levels 5 and 6, a solution must be validated and demonstrated in relevant environments. Prototypes can help validate these levels in controlled settings. However, to reach TRL 7, which requires demonstration in an operational environment, a pilot deployment is necessary. During this period, intermediate evaluations can be conducted to monitor progress, identify issues, and make necessary adjustments.

6 Evaluation Preparation

In the previous chapter, theoretical concepts of evaluation were given. In chapter 6, an overview of preparation guidelines is made to facilitate application of the theoretical framework and its concepts in practice. This chapter hence provides a guide with the key considerations for evaluating interventions, particularly in the context of stakeholder (farmers, agronomist, etc.) involvement and data collection. As it is explained in previous paragraphs, the evaluation process should be iterative and should be integrated throughout the development lifecycle. The focus of the evaluation process shifts from validating user requirements in early stages to measuring the actual impact of the intervention on farmer practices as the artifact matures. Where possible, it is highly recommended to include the use of control groups (i.e., farmers not using the AGRIDATAVALUE provided solutions) for obtaining meaningful results. The findings from each evaluation (iteration) inform subsequent development decisions and help to refine the intervention.

The evaluation approach is multifaceted, combining long-term impact assessment with ongoing quality validation. As introduced in previous sections, the evaluation approach, combines Impact Analysis and Quality Validation (QV):

- Impact Analysis is the summative part of the evaluations:
    - It focuses on measuring the long-term impact of the project on each of the use cases/pilots scenarios.
    - It should be conducted throughout the project lifecycle to provide a longitudinal perspective.
    - Each use case/pilot will define the indicator to be considered to assess the impact of the introduction of the AGRIDATAVALUE solution.
- Quality Validation (QV):
    - Focuses on evaluating the quality of ICT artifacts (system, information, interaction) from the user's perspective.
    - Tailored to the maturity level of the artifact (mock-up, prototype, pilot).
    - Early stages focus on feasibility and user requirements.
    - Later stages focus on usability, value, and impact on work practices.
    - Considers indicators such as perceived usefulness, intention to use, data relevance, and information accuracy.

As said, both Impact Analysis and QV are conducted throughout the project. They are independent activities but can provide valuable insights into each other. The main issues to consider before starting an evaluation are:

- Ethical and Legal Concerns:
    - Data privacy: Ensuring worker anonymity is crucial, which requires careful communication and addressing potential concerns from both workers and unions.
    - Legal compliance: Obtaining informed consent from workers is essential, and legal restrictions may limit data collection methods in certain locations.
- Addressing User Reticence:

  - Clear communication: Explaining that evaluations aim to assess the intervention's impact, not individual performance, is vital to build trust and encourage participation.
  - Framing as an opportunity: Emphasize that user feedback is valuable for improving the intervention and influencing its development.
- Choosing Evaluation Tools:
  - Factors influencing tool selection: Consider legal restrictions, language barriers, available resources, the maturity of the solution, and the expected impact.
  - Available tools: Questionnaires are suitable where legally permissible, while semi-structured interviews are an alternative in more restrictive environments.
- Selecting Participants:
  - Representative samples: When evaluating mock-ups and prototypes, select places and users that are representative of the target population.
  - Control groups: If feasible, include a control group of users not using intervention to isolate the impact of the solution.

In essence, these considerations emphasize the importance of ethical, legal, and practical factors in designing and conducting effective evaluations. Building trust with users, ensuring data privacy, and carefully selecting evaluation methods are crucial for obtaining meaningful and reliable results.

The three main stages of the evaluation process, which are shown in Figure 73, are:

1. **Preparation:**
   - Define the scope of the evaluation, including the interventions, expected changes in practices, and the impact on users and organizations.
   - Consider ethical and legal issues, such as data privacy and informed consent.
   - Select initial evaluation tools based on the evaluation objectives.
2. **Planning & Execution:**
   - Align the evaluation timeline with the development and deployment phases of the intervention.
   - Determine the appropriate evaluation environment based on the maturity of the artifact (e.g., lab setting for mock-ups).
   - Schedule pre- and post-intervention evaluations with appropriate time windows.
   - Collect baseline data before the intervention to track changes.
3. **Analysis & Conclusions:**
   - Analyse the data collected in each evaluation phase.
   - Interpret results considering the maturity of the artifact and previous evaluation findings.
   - Determine the next steps based on the evaluation outcomes (e.g., further development, alternative solutions).
   - The relative importance of validation (user feedback) and impact analysis (measuring actual changes) shifts as the artifact matures.

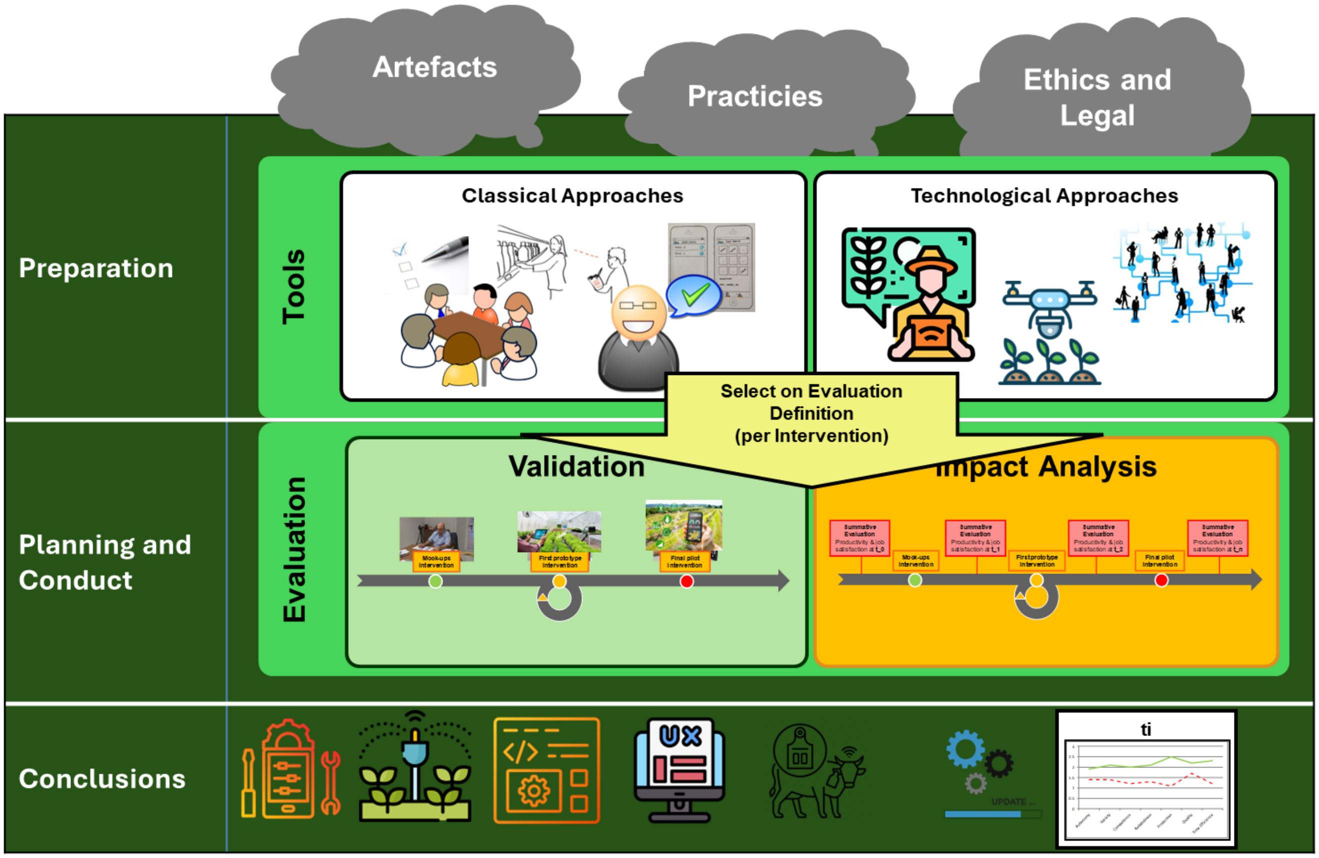


Figure 73. Evaluation setting up overview.

6.1 Quality Validation Preparation and Assessment

QV interventions are sessions aimed at presenting the ICT artefacts to the user for their validation. Each intervention will depend on the maturity level of the artifact. In this section, we will present how to conduct the intervention as well as its purpose and the methods proposed.

6.1.1 Mock-up validation

This section describes the initial evaluation activity involving the use of mock-ups.

- **Focus:** The primary goal is to **prove the feasibility** of the proposed concepts and gather initial user feedback.
- **Method:**
  - **Think-aloud protocol:** user interact with the mock-ups while verbalizing their thoughts and problem-solving processes.
  - **Facilitator-led:** The facilitator encourages user participation through questions and prompts.
- **Data Collection:**
  - **Qualitative:** User perceptions, feedback on the interface and the underlying concepts.
  - **Quantitative:** Data collected through standardized questionnaires.

- **Objectives:**
  - **Validate** user requirements and ensure the solutions meet worker needs as defined in WP1.
  - **Gather insights** to inform and improve the design and development of prototypes.
  - **Iterate:** Drive the development process by incorporating user feedback into subsequent iterations.
- **Artifacts evaluation set-up:**
  - **Mock-ups evaluation session set-up:**
    - **Resource Planning:** Requires careful planning of human and material resources; Facilitators need to coordinate with IPs, book facilities, schedule sessions, and convene participants.
    - **Human Resources:** Ideally, two researchers should be involved: one as facilitator and the other as observer.
    - **Material Resources:** Printed paper mock-ups; Writing materials (markers, pens, blank paper); Informed Consent forms (IC) and questionnaires.
      - Optional: Laptop/tablet for clickable mock-ups, audio/video recording equipment.
    - **Session Procedure Protocol:** To evaluate the mock-ups, individual sessions are conducted for each worker. Each session presents scenarios simulating real-world tasks. This two-round approach allows for a thorough assessment of the worker's interaction with the application.
      - <u>Round A or *Think Aloud*</u>**:** In the first round, participants are presented with a use case scenario and encouraged to interact with the mock-up as if it were a real system. They are asked to "*think aloud*" while navigating, explaining their reasoning for each choice. The facilitator avoids direct guidance, allowing participants to explore the mock-up freely and address any challenges they encounter.
      - <u>Round B or post-experience:</u> The second round focuses on gathering detailed feedback on the participant's perceptions of the application. This includes exploring their opinions on specific features, aesthetics, and potential improvements. The UMUX-LITE questionnaire can be used to assess their initial reactions. The session concludes with a guided interview to gather overall feedback from the participants.
- **Key takeaways:**
  - Early user involvement through mock-up evaluations is crucial for ensuring the success of the project.
  - The think-aloud method provides valuable qualitative insights into user experiences and perspectives.
  - This initial feedback loop helps to refine the design and development process based on real user needs.
  - Adequate material resources are necessary to facilitate a smooth and effective evaluation process.

6.1.2 Prototype Validation

User observation is a crucial method for evaluating prototypes in their real-world context. By observing users in their actual workplaces, we can understand their problem-solving strategies and how environmental factors (noise, lighting, etc.) influence their interaction with the system. While on-site observations are preferred, laboratory settings may be necessary in challenging environments.

The focus will be on evaluating 'vertical prototypes,' which provide a complete slice of functionality for a limited portion of the system. This approach allows for early validation of design and technical feasibility, reducing risks in subsequent development phases.

Before we will explain this technique, it is important to consider a few things first:

- We need to decide what we expect to learn from our observational study. To do so, we propose scenario-based approaches with different assignments.
- We need to recruit the participants for our research.
- Trained observers are required to conduct the user observation protocol, explain the process to participants, and ensure ethical guidelines are followed throughout data collection.

User observation procedure protocol and setup

Annex B provides a detailed guideline for the initial prototype's Quality Validation (QV), including a session agenda. The facilitator begins by welcoming participants, introducing the AGRIDATAVALUE project, and outlining the goals and objectives of the QV session, along with the assigned tasks for workers: I.e., "*As part of the AGRIDATAVALUE project, a European initiative focused on Smart Farming and Agri-environmental Big Data, we are conducting this study to evaluate the effectiveness of our proposed solutions in enhancing problem-solving, innovation skills, and cognitive job satisfaction among workers. This study aims to better understand how you approach your daily tasks when using our solution...*".

User observations will be conducted individually on the farmer work location, mirroring real-world work scenarios. Farmers will be tasked with completing assignments using the prototype within their typical work environment. These assignments, based on the activity scenarios, will utilize the ICT solutions to address specific farming challenges.

The initial prototype will include a core set of features, serving as the foundation for the final implementation. The goal is for farmers to eventually perform their regular tasks using the fully developed AGRIDATAVALUE solutions.

A researcher will accompany each participant, observing their interactions with the prototype while they "*think aloud*". The researcher will document the participant's problem-solving process, identify any difficulties encountered, and note any external factors that may influence their performance. The researcher must maintain neutrality and assure the participant that the focus is on evaluating the application, not their individual skills or efficiency.

The important points to examine during the observation are:

- What are the participants actually doing? As opposed to what we expected they might do.
- What routines do the farmers have with the AGRIDATAVALUE tool? How are they integrating it into their activities?
- Ensure that we are examining activities in their whole; look at how the solution is used in context with the device and the flow of his job activities: how does the participant hold the device; how does he interact with the rest of machinery; does he have to stop to look at the tablet...

- Observer must get qualitative insights and if he appreciates an example of behaviour that could be repeated; he should make a note of it and look for it in future observations.

Following the user observation, a brief interview is conducted to gather the worker's feedback on their experience. This includes assessing their general satisfaction, gathering their opinions on system and information quality, and exploring their intention to use the prototype.

After the prototypes are deployed for intensive use, follow-up interviews will be conducted periodically. Workers are encouraged to provide ongoing feedback throughout the deployment phase as they utilize the prototype independently.

Pilot validation

Pilot validations serve as a real-world proof of concept for the AGRIDATAVALUE solutions within their operational environment. With the solutions deployed, data sources like log files can supplement traditional validation methods.

Pilot deployments involve introducing the solutions to a group of farmers. Validation focuses on understanding how the solutions integrate into farmers' daily routines, their usage patterns, perceived benefits, and any unexpected challenges. A dedicated facilitator will provide technical support and act as a point of contact for users to report errors, problems, or suggest improvements.

6.2 Interpreting Results

The primary objective of interpreting evaluation results is to inform subsequent actions, whether it's after an initial evaluation or a comprehensive assessment of an intervention. An intervention, as defined in previous chapters, involves deploying Smart-farming solutions to facilitate specific changes within farming practices. Consequently, evaluating an intervention necessitates two distinct assessment processes: 1) validation of the deployed artifact and 2) Impact Analysis. The relative importance of validation and IA varies depending on the maturity of the artifact, the project phase, and whether the evaluation occurs before or after deployment.

As already explained, Impact Analysis assesses whether the deployed artifacts contribute to improve the KPI of each of the use cases/pilots. Validation focuses on evaluating the quality of the artifacts to ensure they meet farmer requirements for information, functionality, and system performance. The relative importance of Impact Analysis and validation varies depending on the maturity of the artifact (mock-ups vs. prototypes), the project phase, and the timing of the evaluation (before or after deployment). The following paragraphs detail the evaluation and interpretation of results for both mock-ups and prototypes.

6.2.1 Evaluation of Mock-ups

Mock-ups, utilized early in development, facilitate communication between users and developers by presenting non-functional representations of the intended system. They allow for the validation of developers' understanding of the problem. Since mock-ups lack backend functionality, only Customer Acceptance can be conducted. Farmer interaction with mock-ups provides valuable insights into information requirements, user interface improvements, and the understanding of backend functionalities. The closer the mock-up resembles the final design and the more realistic the validation environment, the more meaningful the results.

Mock-ups are easily modified, enabling rapid iterations in the design process. However, since they lack backend functionality, they cannot have direct impact. Therefore, IA assessments primarily focus on identifying and addressing potential evaluation biases and establishing a baseline for subsequent evaluations.

Given their limited functionality, validation results are generally more critical than IA results when evaluating mock-ups and early prototypes.

6.2.2 Evaluation of Prototypes

Prototypes, by introducing new functionalities, directly impact farming practices. Evaluating these impacts is crucial. The degree of impact depends on the prototype's maturity and implemented functionalities. Data collected during deployment (application usage data, log files) enables both Customer Acceptance and Technical Acceptance for evaluation.

Before deployment, validation assesses the prototype's quality, ensuring it meets worker requirements and provides the necessary functionalities. This information guides development decisions and determines if the prototype is ready for deployment. After deployment, validation focuses on identifying areas for improvement, such as new functionalities, enhanced user interactions, and support for additional tasks.

Impact Analysis, conducted before and after deployment, measures the change in each objective. Comparing these results with expectations determines the intervention's success.

While Impact Analysis gains prominence with prototypes, validation remains crucial. It provides feedback to developers, helps identify root causes for unexpected IA results, and informs decisions regarding future development based on the potential for impact improvement, artifact quality, and the cost of necessary changes.

6.2.3 Interpretation of the Results of Prototype Evaluation

Before starting the execution of each pilot (or its first deployment), the number and scope of interventions are defined, including the functionalities of each artifact release and their anticipated impact. This information guides the evaluation project (of the corresponding pilot) planning, specifically determining which aspects will be evaluated within each intervention (i.e., if different optimizations will be produced in different implementation iterations which will be evaluated in each iteration).

Prototypes, by implementing functionalities, are expected to influence farming practices, and thus in the achievement of the expected impact. The extent of these changes (the degree of impact) is influenced by the prototype's maturity, which is determined by its implemented features and the quality of their implementation.

The subsequent paragraphs outline how to interpret evaluation results. Before deploying the solution, Impact Assessments (IA) and validation results are used to make informed decisions. After deployment, the impact of the deployed artifact is assessed by analyzing changes in measurements compared to the baseline established before deployment (t_i).

IA is particularly crucial when evaluating prototypes, as its measurements directly determine the success of interventions and the overall project. While post-deployment evaluation results become important at t_{i+1} to assess the impact of the deployed artifact, the pre-deployment IA at t_i provides a crucial baseline for measuring improvements.

6.2.3.1 t_i Prototype Evaluation

At t_i (before deployment), validation will provide more valuable insights than an Impact Analysis. The validation process at t_i will result in a list of improvement opportunities (including revised and new requirements) and identified non-conformities with user requirements. Since non-conformities directly impact the quality of the artifacts, they must be carefully evaluated to determine if the intervention (artifact deployment) can proceed or needs to be postponed until the identified issues are resolved.

6.2.3.2 Interpretation of the Intervention Prototype Evaluation Results

After deploying the artifact, a second evaluation is conducted afterwards. This evaluation can utilize both Classical Approaches (CA) and Technological Approaches (TG) data for validation and Impact Assessment (IA). Validation data provides insights for identifying new improvements and/or functionalities to better support workers. These requirements are evaluated, prioritized, and added to the list for future interventions. On the other hand, the IA assessment, the variation of the objective indicators, will show if the intervention causes the expected effect or not. When it is possible to use a CG, the indicators obtained from it can be used to determine the influence of possible external effects to the project objectives achievement.

If the expected effect is achieved but the artifact quality is poor (e.g., errors, low performance), the priority is to resolve non-conformities and redeploy the artifact as soon as possible. Log data (TA data) can provide valuable insights into the source of problems (e.g., problematic Business Blocks - BBs). When the expected effect is not achieved for one or more objectives, both IA and validation measurements are Analysed to determine the root causes. If validation identifies non-conformities for a given BB, they are addressed, and the artifact is redeployed for re-evaluation.

When validation does not reveal non-conformities, a more detailed analysis of the IDs (Impact Dimensions) is conducted to identify potential causes of unexpected impact results. The validation data could be used for trying to determine the causes of the problem. In some cases, it is caused by the not implementation of the required functionalities. This can be determined by reviewing the requirements list. In this case, new interventions should be considered. In other cases, the artifacts may suffer from quality issues (e.g., poor performance, bugs). Once the causes are determined, solutions are implemented, and the artifact is re-evaluated.

When the expected effect is achieved and artifact quality is good (with only minor requirements changes and new functionalities reported), consider the cumulative objective achievements and the prioritized list of valued requirements. If significant objective improvements are possible at reasonable costs, consider further interventions. If limited improvement opportunities exist or the costs of improvements outweigh the expected benefits, consider transitioning the prototype to a pilot phase.

6.2.4 Pilots' Evaluation

The distinction between a prototype and a pilot is subtle. While functionally equivalent, pilots, with their larger user base, necessitate a more robust infrastructure compared to prototypes. Pilot evaluations are built upon prototype evaluation results. Prototype IA results demonstrate the value of the deployed artifact through impact measurements, providing a foundation for more objectively determining the expected impact of the pilot deployment. Pilot validation shifts its focus from refining interaction and functionalities to addressing performance and error issues.

Like other artifacts, we recommend conducting two evaluation phases for pilots. Before the intervention (t_i), Impact Analysis is conducted to establish a baseline for pilot measurements. Validation will focus on ensuring the artifact functions correctly. In the case of problems detection, identifying and resolving infrastructure problems must be prioritized (e.g., network access) over refining interaction and functionalities. After Intervention (t_{i+1}), t a post-intervention evaluation will be performed. Based on the results of the pre-intervention evaluation (particularly validation), a decision should be made regarding whether to proceed with the intervention or delay it until identified problems are resolved.

At t_{i+1}, IA gains paramount importance. Pilot success is directly measured by the degree of project objective achievement. While validation becomes less critical, ongoing monitoring is essential (TA). This is because the quality of the artifact significantly influences its acceptance. Like t_i, the reporting of new requirements or major problems at this stage is not expected. The duration of the [t_i, t_{i+1}] interval, the period between pre- and post-intervention evaluations, depends on the specific pilot objectives and the desired level of evidence. As pilots run on real-world operational conditions, evaluation results and supporting evidence can be used to assess the solution's achievement of a specific Technology Readiness Level (TRL).

7 Conclusions

At this stage AgriDataValue project has successfully established a solid methodological and technical foundation for the targeted application domains. The completion of the pilot data acquisition phase represents a critical milestone, providing real-world, representative data that enabled early validation of the proposed pipeline and informed subsequent development choices. The pilot results demonstrated the feasibility of the approach and highlighted key data characteristics that were directly incorporated into model design and evaluation. During the next project phase pilot data collection will continue to fine-tune and validate the developed models.

In parallel, a wide variety of models have been implemented and assessed, covering multiple modeling paradigms and levels of complexity. This diversity allowed for systematic comparison across approaches, improved understanding of performance trade-offs, and increased robustness of the overall solution. The availability of multiple validated models also ensures flexibility for future optimization, scaling, or adaptation to evolving requirements.

Overall, the project deliverable go beyond a proof of concept: it provides a scalable framework, validated on pilot data, and supported by a comprehensive set of models ready for further refinement and deployment. This positions the project well for the next phase, whether focused on expanded data acquisition, model optimization, and operational integration.

This deliverable also presents a framework for evaluating AGRIDATAVALUE solutions deployed to support the improvement needs of each pilot involved in the project. The framework definition includes the methodology to be followed to evaluate each version of the tools deployed in a longitudinal cycle and a set of tools that can be used to perform these evaluations. The evaluation itself aims to determine if the objectives set for each pilot are being met, the quality of the deployed tools, and, if applicable, determine if any issues are due to their quality and identify opportunities for improvement.

8 References

[1] F. Lacueva, S. Mayo, P. Heinrich, P. Moertl and L. Hannola, "Evaluation Framework. Project Report - FACTS4WORKERS: Worker-Centric Workplaces in Smart Factories.," 2016.

[2] R. B. M. F. I. A. Douglass, "Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research," *Philosophy & Rhetoric,* vol. 10, no. 2, p. 130–132, 1977.

[3] E. P. A. I. Madden TJ, "A comparison of the theory of planned behaviour and the theory of reasoned action," *Personality & Social Psychology Bulletin,* vol. 18, no. 1, p. 3, 1992.

[4] B. R. W. P. Davis FD, "User Acceptance of Computer Technology: A Comparison of Two Theoretical Models.," *Management Science,* vol. 35, no. 8, p. 982–100, 1989.

[5] I. J. C. P. Legris P, "Why do people use information technology? A critical review of the technology acceptance model," *Information and Management,* vol. 40, no. 3, pp. 191-204, 2003.

[6] O. O. E. B. Awa HO, "Integrating TAM, TPB and TOE frameworks and expanding their characteristic constructs for e-commerce adoption by SMEs," *Journal of Science and Technology Policy Management,* vol. 6, no. 1, pp. 76-94, 2015.

[7] B. S. B. H. Venkatesh V, "Bridging the Qualitative-Quantitative divide: Guidelines for conducting mixed methods research in information systems," *MIS Quarterly,* vol. 1, no. 21-54, p. 37, 2013.

[8] W. H. a. E. R. M. DeLone, "The DeLone and McLean Model of Information Systems Success: A Ten-Year Update," *Journal of Management Information Systems,* vol. 19, no. 4, pp. 9-30, 2003.

[9] L.-P. A. Holsapple CW, "Defining, Assessing and Promoting E-Learning Success: An Information Systems Perspective," *Decision Sciences Journal of Innovative Education,* vol. 4, no. 1, pp. 67-85, 2006.

[10] R. EM, Diffusion of Innovation., 3rd ed., Free Press, 1953.

[11] B. J. Tidd J, Managing Innovation – Integrating Technological, Market and Organizational Change, 5th ed., [3rd] reprint ed., Wiley, Ed., 2016.

[12] M. E. M. V. Peres R, "Innovation diffusion and new product growth models: A critical review and research directions," *International Journal of Research in Marketing,* vol. 27, no. 2, pp. 91-106, 2010.

[13] S. F. MacVaugh J, "Limits to the diffusion of innovation: A literature review and integrative model.," *Innovation Management,* vol. 13, no. 2, pp. 197-221, 2010.

[14] J. Brooke, "SUS-A quick and dirty usability scale. , 1996, vol. 189, no 194, p. 4-7.," *Usability evaluation in industry,* vol. 189, no. 194, pp. 4-7, 1996.

[15] "The usability metric for user experience," *Interacting with Computers,* vol. 22, no. 5, p. 323–327, 2010.

[16] S. E. G. B. Voss KE, "Measuring the hedonic and utilitarian dimensions of consumer attitude," *Journal of Marketing Research,* vol. 40, no. 3, pp. 310-320, 2003.

[17] H. J. B. Hashemi M, "An Interaction-centred User Monitoring Framework," in *PhyCS 2015 - 2nd International Conference on Physiological Computing Systems, Proceedings*, 2015.

[18] C. A. B. S. J. L. M. R. T. G. E. U. Setz, "Discriminating stress from cognitive load using a wearable EDA device," *IEEE Transactions on Information Technology in Biomedicine, Information Technology in Biomedicine,* vol. 14, no. 2, p. 410–417, 2010.

[19] J. Nielsen, Usability Engineering, Boston: Academic Press, 1993.

[20] ISO 9241-11 Ergonomic Requirements for Office Work with Visual Display Terminals (VDT)s-Part II Guidance on Usability.

[21] M. M. Cheng LC, A Reference to Usability Inspection Methods, Singapore: Springer, 2016.

[22] A. Rana and M. Mridu, "Analytical Comparison of Usability Measurement Methods. , vol. 39, no 15, p. .," *International Journal of Computer Applications,* vol. 139, no. 15, pp. 11-18, 2012.

[23] J. Nielsen, "Usability inspection methods.," in *Conference companion on Human factors in computing systems.*.

[24] N. D. Hollingsed T, "Usability inspection methods after 15 years of research and practice," in *SIGDOC'07: Proceedings of the 25th ACM International Conference on Design of Communication*, 2007.

[25] F. S. B. S. B. F. G. M. Borsci S, "Assessing user satisfaction in the era of user experience: comparison of the SUS, UMUX, and UMUX-LITE as a function of product experience," *International Journal of Human-Computer Interaction,* vol. 31, no. 8, pp. 484-495-495, 2015.

[26] K. Finstad, "The usability metric for user experience," *Interacting with Computers,* vol. 22, no. 5, p. Interacting with Computers, 2010.

[27] U. B. M. D. Lewis JR, "UMUX-LITE - When there's no time for the SUS.," in *Conference on Human Factors in Computing Systems - Proceedings*, 2013.

[28] "ISO 9241-210: 2010–Ergonomics of human-system interaction–Part 210: Human-centred design for interactive systems.," ISO.org, 2010.

[29] "ISO FDIS 9241-210 (2009) Human-centred design process for interactive systems.," ISO., 2009.

[30] H. Petrie and N. Bevan, "The evaluation of accessibility, usability and user experience.," *The universal access handbook,* pp. 10-20, Petrie, H.; Bevan, N.

[31] L. E.-C. R. V. V.-V.-M. K. O. M. H. J. Vermeeren APOS, "User experience evaluation methods: current state and development needs," in *NordiCHI 2010: Extending Boundaries - Proceedings of the 6th Nordic Conference on Human-Computer Interaction*, 2010.

[32] F. S. L. C. d. S. F. M. M. J. G. A. B. a. F. G. A. da Silveira, "Farmers' perception of the barriers that hinder the implementation of agriculture 4.0," *AGRICULTURAL SYSTEMS,* vol. 208, 2023.

[33] K. Y. T. L. P. L. C. S. &. W. W. P. Wong, "Knowledge Management performance measurement: measures, approaches, trends and future directions," *Information Development,* vol. 31, no. 3, pp. 239-257, 2015.

[34] F. P. P. H. S. A. L. S. J. M. A. I. H. M. A. Sidi, "Data quality: A survey of data quality dimensions.," in *Information Retrieval & Knowledge Management (CAMP)*, 2012.

[35] C. C. C. F. C. M. A. Batini, "Methodologies for data quality assessment and improvement," *ACM Computing Surveys,* vol. 41, no. 3, 2009.

[36] H. C. Lettner F, "Automated and unsupervised user interaction logging as basis for usability evaluation of mobile applications," in *international Conference Proceeding Series*, 2012.

[37] European Commission, "EC H2020 Programme, Guidelines on FAIR Data Management in Horizon 2020, Version 3.0.," [Online]. Available: https://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf.

[38] International Standards Organisation, "ISO 26324:2012(en) Information and documentation — Digital object identifier system," [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:26324:ed-1:v1:en.

9 Data Acquisition Tools – Survey Models

9.1 Prototype Evaluation Questionnaire

(PLEASE READ CAREFULLY)

The goal of this survey is to capture your current perception about the new AGRIDATAVALUE technology.

Some tips to fill out the questionnaire:

The individual aspects are specified by a descriptive text. You can give your answer by crossing one of the five boxes beneath the description.

Example 1

I know a lot about soccer and its rules:
I strongly disagree ☐ ☐ ☐ ☐ ☒ I strongly agree

In this example the person strongly agrees i.e. she knows a lot about soccer.

Please fill out the questionnaire completely and carefully without omitting any answers!

The analysis of the results will be carried out in anonymized form only!

General information

I am currently working as		
I have been working here since		years.
I am	....	years old.
I am	☐ female	☐ male

How willing you are to incorporate new ways-of-doing in your daily work?

Absolutely reluctant	☐	☐	☐	☐	☐	*Absolutely willing*

Technology acceptance

Perceived usefulness

	I strongly disagree	I disagree	Neither agree nor disagree	I agree	I strongly agree
Overall, the system is useful for daily operations	❑	❑	❑	❑	❑
The system decreases my workload (if negative, implies added effort due to the system)	❑	❑	❑	❑	❑
The system improves the chance to do something that make use of my abilities	❑	❑	❑	❑	❑
The system improves the chance to develop new and better ways to do the job	❑	❑	❑	❑	❑
[AGRIDATAVALUE xxx Applicaton] is useful for my daily work (replace [] by use case relevant activity - e.g. Checking part availability through the system is useful for my daily work)	❑	❑	❑	❑	❑

Perceived ease of use

	I strongly disagree	I disagree	Neither agree nor disagree	I agree	I strongly agree
Overall, the system is easy to use	❑	❑	❑	❑	❑

The system displays an appropriate amount of information	❑	❑	❑	❑	❑
Customizing the displayed information is easy	❑	❑	❑	❑	❑
The information displayed is easy to read in all conditions	❑	❑	❑	❑	❑
Messages for interaction with the user are clear and easily comprehensible	❑	❑	❑	❑	❑
The system triggers an acceptable number of notifications	❑	❑	❑	❑	❑
The system swiftly recovers after loss of signal or breakdown	❑	❑	❑	❑	❑
It's easy to find the information that I need	❑	❑	❑	❑	❑
Getting used to the system was easy (training effort was low)	❑	❑	❑	❑	❑
[DOING XXX] is easier by using the system (replace [] by use case and/or pilot	❑	❑	❑	❑	❑

relevant activity - e.g. Checking part availability is easier by using the system)					

Social influence

	I strongly disagree	I disagree	Neither agree nor disagree	I agree	I strongly agree
My mate farmers feel that the system is useful	❑	❑	❑	❑	❑
Most of my colleagues will be happy to use the system	❑	❑	❑	❑	❑
I can solve problems that arise in my daily tasks on my own	❑	❑	❑	❑	❑

Compatibility (with processes and routines or with other tools)

	I strongly disagree	I disagree	Neither agree nor disagree	I agree	I strongly agree
I deal with a manageable amount of information and inputs	❑	❑	❑	❑	❑
I see added value replacing current XX system (e.g. manual machine book) with this new system	❑	❑	❑	❑	❑
The system fits our working practices and processes	❑	❑	❑	❑	❑

Prototype Validation

System quality

Please judge the AgridataValuye system and indicate to what extent you agree with the following statements.					
	I strongly disagree.	I disagree	Neutral	I agree	I strongly agree
Overall, the system is	❑	❑	❑	❑	❑

useful for daily operations.					
The shift handover is easier with the system than without.	❑	❑	❑	❑	❑
This system's capabilities meet my requirements.	❑	❑	❑	❑	❑
The system reduces my workload.	❑	❑	❑	❑	❑
The system gives a good overview of the workflow.	❑	❑	❑	❑	❑
Overall, the system is easy to use.	❑	❑	❑	❑	❑
The system is easy to learn.	❑	❑	❑	❑	❑
The response times are adequate.	❑	❑	❑	❑	❑
The system integrates well into my work processes.	❑	❑	❑	❑	❑

Information quality

Please judge the information as displayed in the AGRIDATAVALUE system and indicate to what extent you agree with the following statements.					
	I strongly disagree	I disagree	Neutral	I agree	I strongly agree
Information in the system is useful for my work.	❑	❑	❑	❑	❑

Information is correct.	❑	❑	❑	❑	❑
Information is complete.	❑	❑	❑	❑	❑
Information is precise.	❑	❑	❑	❑	❑
Information is up to date.	❑	❑	❑	❑	❑
It is easy to find the information I need.	❑	❑	❑	❑	❑
Information is easy to understand.	❑	❑	❑	❑	❑

Use and User satisfaction

Please state your satisfaction with the *AGRIDATAVALUE* ***system and indicate to what extent you agree with the following statements.***					
	I strongly disagree	I disagree	Neutral	I agree	I strongly agree
This system's capabilities meet my requirements.	❑	❑	❑	❑	❑
I enjoy using the system.	❑	❑	❑	❑	❑
Overall, I am satisfied with the system's quality.	❑	❑	❑	❑	❑
Overall, I am satisfied with the information's quality.	❑	❑	❑	❑	❑
I will use the system regularly.	❑	❑	❑	❑	❑
I will use the system with pleasure.	❑	❑	❑	❑	❑

9.2 UMUX

The UMUX is a brief, 4-item questionnaire that measures perceived usability. It's a reliable alternative to the longer System Usability Scale and can be easily used in various research settings, including user testing and in-the-wild studies. The UMUX questions alternate between positive and negative phrasing.

Please, answer the following questions	Entirely disagree	Mostly disagree	Somewhat disagree	Undecided / Neutral	Somewhat agree	Mostly agree	Entirely agree
[This system's] capabilities meet my requirements.	❑	❑	❑	❑	❑	❑	❑
Using [this system] is a frustrating experience.	❑	❑	❑	❑	❑	❑	❑
[This system] is easy to use.	❑	❑	❑	❑	❑	❑	❑
I have to spend too much time correcting things with [this system].	❑	❑	❑	❑	❑	❑	❑

Where the content of the brackets ([This system's]) can be changed to the actual name of the system, or a more suitable word for the application.

The UMUX can be administered verbally or in written format (including digital questionnaires). Each question is rated on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree).

9.2.1 Calculating the UMUX score

- **The rules:**
  - Positively worded questions are 1 and 3
  - Negatively worded questions are 2 and 4
  - **Scoring each question:**
    1. For positively worded questions, take the number of the reply and subtract 1 (e.g. if the answer to the question 1 is *Slight Agreement—5,* then the question is scored: 5 – 1 = 4)
    2. For negatively worded questions, take the number of the reply and subtract it from 7 (e.g. if the answer to the question 2 is *Slight Agreement—5*, then the question is scored: 7 – 5 = 2)

- **Find the participant score:** We have the score of each question, to calculate the UMUX score for each participant:

    1. Add all the questions' score
    2. Multiply by 4.1667 (or 100 / 24)
    3. You will get a score between 0 and 100, this is the UMUX score

    To sum up, the formula for calculating the participant's UMUX score is:

    UMUX = ((Item_1 − 1) + (Item_3 − 1) + (7 − Item_2) + (7 − Item_4)) * (100/24)

- **The overall score of the UMUX (the system's score):** Often one would use the UMUX to "put a number" to the usability of the whole system / application in question. In that case, the System's score (or overall UMUX score) is the average of all the participant's scores.
- **Presenting the UMUX results:** Except for presenting the mean UMUX score of the system, usually the Standard Deviation and participants volume (sample size) are presented as well.
- Minor number of Participants to get significant results: 42 participants.

9.3 UMUX-Lite

The UMUX-Lite is a simplified version of the UMUX, focusing on two key factors: perceived usefulness and perceived ease of use. This aligns with the Technology Acceptance Model, which suggests that user acceptance is influenced by these two factors.

Please, answer the following questions	Entirely disagree	Mostly disagree	Somewhat disagree	Undecided / Neutral	Somewhat agree	Mostly agree	Entirely agree
This prototype capabilities meet my requirements.	❑	❑	❑	❑	❑	❑	❑
This prototype is easy to use.	❑	❑	❑	❑	❑	❑	❑

The UMUX-Lite questionnaire assesses user acceptance by using two positively worded questions from the UMUX: perceived usefulness and perceived ease of use. Each question is rated on a 7-point Likert scale. By calculating a score based on these ratings, the UMUX-Lite provides a quantitative measure of user experience.

9.3.1 Calculating UMUX-Lite Score

The UMUX-Lite score is a quantitative measure of system usability based on user feedback. To calculate the score for each user:

1. **Sum the scores:** Add the user's ratings for "Usefulness" and "Ease of Use."
2. **Adjust the score:** Subtract 2 from the total.
3. **Normalize the score:** Multiply the result by 8.33 to scale it from 0 to 100.

To calculate the system-wide UMUX-Lite score, average the individual user scores. This provides an overall measure of usability across all users.

9.4 AGRIDATAVALUE Open Questions Questionnaire/Interview

Next, we provide a set of open questions to be performed after the user evaluates the AGRIDATAVALUE application.

1. Questions about F4W quality, e.g.
    a. General (user satisfaction)
        i. How is your overall impression of the prototype? (Soft- and hardware)
        ii. How does it meet your requirements?
        iii. What do you like? (3 positive aspects)
        iv. What do you dislike? (3 negative aspects)
        v. What would you change? Do you have suggestions for improvement?
    b. System quality
        i. In what way is the system useful for your work? Does it make the process of <change by the objective(s) of the system>?
        ii. How do you perceive its ease of use / learning?
        iii. How does it integrate into your work processes?
    c. Information quality
        i. How do you judge the information in the system?
        ii. Are they relevant / useful / correct?

2. Questions about (intention to) use:
    a. In what way may using the prototype change your farming practices?
    b. Under what conditions will / would you use the prototype regularly?
    c. Under what conditions will / would you use the prototype with pleasure?