D2.1Assessment Framework and Governance Mechanisms

quantifarm.eu

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Abstract:	D2.1 presents the Assessment Framework and the Governance Mechanisms for Independent Evaluation. The report describes the methodology used to develop the QuantiFarm framework to assess the costs and benefit of DATs along the three pillars of sustainability (economic, environmental and social). In the first stage, 13 categories, 18 sub-categories and 80 indicators were identified. An initial governance structure was designed both to reflect the interests of farmers, consultants, DAT providers, third-party verifiers and policy-makers and to ensure that evaluation results are unbiased and uphold a high level of trust and confidence. Moreover, guidelines on how to calculate the indicators are provided.

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QuantiFarm Consortium			
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22	UAB ART21	ART21	LT
23	AGROSMART SIA	AgroSmart	LV
24	BENCO BALTIC DOO ZA SAVJETOVANJE IUSLUGE	BENCO	HR
25	FARM FRITES POLAND DWA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	FFP2	PL
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Table of Contents

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101059700

List of tables

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700

List of figures

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List of Abbreviations and Acronyms	
AI	Artificial Intelligence
C	Carbon
CAP	Common Agricultural Policy
DAT	Digital Agriculture Technology
DSS	Decision Support System
EU	European Union
FMIS	Farm Management Information Systems
FMS	Farm Management Systems
FSC	Forest Stewardship Council
GHG	GreenHouse Gases
GIS	Geographic Information System
IoT	Internet of Things
ISO	International Organisation for Standardisation
K	Potassium
LCA	Life Cycle Analysis
KPI	Key Performance Indicators
N	Nitrogen
NGO	Non-Governmental Organisation
P	Phosphorus
SDG	Sustainable Development Goals
SPM	Sustainability Performance Measurement
TBD	To Be Defined
TC	Test Case
TBL	Triple Bottom Line
UAV	Unmanned Aerial Vehicle
UN	United Nation
VRT	Variable Rate Technology
WP	Work Package

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Executive Summary

The QuantiFarm project responds to the need for independent quantitative and qualitative assessment tools considering the multiple and heterogeneous implications of DATs adoption in sustainability performance. Although the last two decades have seen a proliferation of indicator-based methods to assess various aspects of sustainability (Diazabakana et al., 2014; Bockstaller et al., 2009; Rosnoblet, 2006) in agri-food chains, no specific contribution was found in literature that covers the agri-food chains' heterogeneity, geographical conditions, harvesting seasonality, and the use or not of the technology; therefore, QuantiFarm's intention is to develop an assessment framework that considers such variables in order to provide an appropriate and practical tool that is relevant and useful for actors working under different conditions. Hence, QuantiFarm aims to develop a comprehensive and all-encompassing assessment framework that considers performance in the three dimensions of sustainability.

Within the project, WP2 aims at developing the Assessment Framework that will enable the quantitative and qualitative assessment of DATs in agriculture. In turn, the purpose of this first deliverable D2.1, *Assessment Framework and Governance Mechanisms*, is to present the initial versions of the Assessment Framework and of the governance mechanisms that will be adopted to assess the economic, social and environmental benefits and costs of DATs adopted in the TCs. QuantiFarm is developing such framework with 32 partners, building upon 30 TCs that are committed to the development of the project.

This initial version of the assessment framework and Governance Mechanisms consider the significance of sustainability performance assessment in agri-food supply chains, its drivers and barriers; and, how the different levels of governance that the assessment should follow (compliance, impartiality, reliability, transparency, credibility, meaningfulness). Specifically, the assessment framework development follow a dual approach: i) a top-down perspective that deductively constructs the main elements of the framework, and ii) bottom-up perspective for sustainability performance measurement (SPM) identification and selection. Hence the assessment frameworks is built on the three sustainability domains, i.e., environmental, economic and social, along 13 categories of performance assessment. These categories allowed to focus the performance measurement in the most relevant areas for the agricultural sector. In particular, 7 categories are identified in the environmental area, being the mostly addressed in agriculture; 4 in the economic domain and 2 in the social one (Figure 3: Category tree). Aiming at a higher level of disaggregation, 20 subcategories of performance measurement are identified, upon which the indicators (80 indicators - 48 environmental, 16 economic and 16 social) are proposed. The final proposal of indicators to be included in the assessment framework takes thoroughly into account the particularities of the test cases in terms of: crop/product, geographical location, harvesting season and DAT applied, if any.

Regarding the Governance Mechanisms, the definition of the main principles of the governance structure (transparency, impartiality, credibility, relevance), and the role of verifiers is presented; along with the main roles and stakeholders, the baseline conditions, competences and qualifications that TCs will need to define and record for applying the assessment framework. Moreover, the elements required for evaluation and verification are described, along with the procedures for non-conformities management and complaints management

In the next phases of the QuantiFarm project, the assessment framework will be revised and updated considering additional inputs from TCs and partners (that periodically will be incorporated to the framework) and leading to the definition of a composite multidimensional index, that will include a monetary quantitative measure and a set of descriptive and qualitative indicators.

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1. Preface

1.1. Project Summary

The QuantiFarm project aims at supporting the further development of Digital Agriculture Technologies (DATs, from now on) as a key element for improving sustainability performance (economic, environmental and social) and competitiveness of the agricultural sector. To this end, QuantiFarm introduces a comprehensive assessment framework for independent qualitative and quantitative assessments of the multiple costs and benefits of digital agriculture technologies. QuantiFarm intends to ensure replicability and uptake of digital technologies by deploying innovative tools, services, recommendations and making them relevant and of practical use to farmers, advisors, and policy makers across Europe. QuantiFarm involves in the project activities around 30 Test Cases (TCs) which span over 20 countries in 10 Biogeographical regions across Europe, capturing multiple geo-political and financial settings. More than 100 farms of different types, sizes, ownership and operating conditions, committed to participate in the project, both directly but also through cooperatives and large umbrella organisations. The TCs actively engage farmers, advisors, DIHs, researchers/scientists, DATs providers, certification experts and policy makers as well. In line with QuantiFarm's objectives, the QuantiFarm Digital Innovation Academy will be established as the main capacity building mechanism for advisors and other AKIS actors on the various types of digital technologies available, their costs, benefits and impact on sustainability and will offer training sessions for advisors. Moreover, QuantiFarm comprises 32 partners, representing all relevant stakeholders, including 8 scientific organizations and 12 farmer representatives and consultants.

1.2. Document Scope

The purpose of this deliverable is to present the initial versions of the Assessment Framework and of the governance mechanisms that will be adopted to assess the impact of DATs adopted in the TCs.
Considering the complexity of assessing the impacts of DATs in terms of costs and benefits and of contribution towards sustainability, the overall work on the assessment framework can be divided in two phases: i. identification of key variables impacted by DAT to be monitored along the years and development of the initial version of the framework; and ii. refinement of the framework and overall evaluation of DATs by means of a monetary index and a set of more descriptive indicators. This deliverable focuses in particular on the first part of the work, which set the bases for the monitoring activities of the TCs, while detailed information on how the assessment of DATs will be performed will be presented in the second version of this document.

Building upon a literature review of the most widely used assessment frameworks and of the impacts of DATs, this document describes the QuantiFarm assessment framework and illustrates in detail how the framework has been adapted to reflect the specificity of each TCs. The description of the framework components is then complemented by a description of the governance structure and mechanisms to ensure that the outcomes are accurate, consistent, reliable and verifiable.
This initial version of assessment framework and the governance mechanisms will be advanced and refined during the project and documented in two upgraded versions that will be released in M18 and M42, respectively, including the second part of the work, that will focus particularly on the composite indicator.

1.3. Document Structure

The document is comprised of the following chapters:

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Chapter 1 provides a summary of the project, the document scope and its structure

Chapter 2 introduces the assessment framework and the governance mechanisms focusing on their relevance within and beyond the project. The chapter also presents a brief description of the TCs where the framework will be applied and provides an overview of the methodology.

Chapter 3 presents a literature review of the most widely used frameworks to assess sustainability impacts, describes the overall assessment framework delving into the specific application to the individual TCs and illustrates the governance mechanisms.

Chapter 4 presents the conclusions and describes the next steps.

Appendix 1 provides guidelines for the calculation of the indicators.

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2. Introduction

2.1. Context and relevance

The current agricultural system is facing several challenges: the increase of the global population and, consequently, the growing demand for food have to cope with the limited resources of the planet. FAO stated that, in 2050, the world population will reach 9 billion people and the food demand will grow by 70% (Alexandratos et al., 2012). At the same time, it is necessary to consider the scarcity of resources as arable land and water, and the issue of climate change that, causing drought, on the one hand, and dramatic events as sudden floods, is endangering crop yields. Without any doubt, it is fundamental to react to these challenges: indeed, the UN 2030 agenda within its 17 Sustainable Development Goals (SDGs) has planned, among other objectives, to reach sustainable food production systems via agricultural practices that increase productivity and that adapt to climate change (UN, 2015).

Although the last two decades have seen a proliferation of indicator-based methods to assess various aspects of sustainability (Diazabakana et al., 2014; Bockstaller et al., 2009; Rosnoblet, 2006) in agri-food chains, no specific contribution was found in literature that covers the agri-food chains' heterogeneity, geographical conditions, harvesting seasonality, and the use or not of the technology; therefore, QuantiFarm's intention is to develop an assessment framework that considers such variables in order to provide an appropriate and practical tool that is relevant and useful for actors working under different conditions.

Specifically, regarding technology, starting from the '90s, with the concept of Precision Farming, and going on with terms as "Smart Agriculture", "Digital Agriculture" or, more recently, "Agriculture 4.0", the digitalization of agriculture is nowadays widely recognized as one of the driving forces helping the agricultural systems to tackle these problems. Communication technologies, Internet of Things, data analytics and big data, Artificial intelligence and Machine Learning, Cloud Computing, Geographic Information System (GIS), image processing, drones and UAVs, Blockchain etc., are generally recognized as technologies that enable a wide range of solutions that in turn are transforming the global agriculture, increasing productivity while reducing the impact on natural resources and alleviating the intense work of farmers. This is mainly due to the ability of these technologies of capturing, analysing and sharing data, in order to return to farmers valuable pieces of information that can improve decision-making and practices' implementation, with clear benefits on efficiency, productivity and sustainability. The relevance of data, allowed by DATs, is the core of the paradigm of "Agriculture 4.0" defined as "the evolution of Precision Farming, realized through the automated collection, integration and analysis of previously separated data silos coming from the field, equipment sensors and other third-party sources, enabled by the use of smart and digital technologies of Industry 4.0, making in this way possible the generation of knowledge, to support the farmer in the decision-making process in the farm enterprise and when dealing with different players in the agricultural and food value chain, therefore breaking the boundaries of the single farm enterprise. The final aim is to enhance profitability and economic-environmental-social sustainability of agriculture" (Sponchioni et al., 2019)
Indeed, the use of DATs has the potential to bring numerous benefits for all the stakeholders involved in the agri-food supply chain. Considering the principles of the triple bottom line (TBL) – the accounting framework developed to evaluate the sustainability performances according to three different lenses: people, planet and profits (Hacking et al., 2008) – DATs can have positive impacts on economic, social and environmental sustainability. To mention some examples[1]:

[1] A comprehensive list of benefits under the three domains are presented in the section dedicated to the Assessment Framework

- Planet: the use reduction of production inputs can lead to a decrease in the environmental impacts linked to a reduced use of highly polluting inputs as agrochemicals, an increase in the efficiency of water use, or the enhancement of biodiversity. Also, the level of animal welfare can be increased thanks to the use of digital tools (as sensors to promptly detect animal illness, cameras and data management platform to analyse animal behaviours, etc.)
- People: DATs can help in reducing time and efforts while carrying out operations, or in making the certifications and administrative processes more efficient (for example: web platforms dedicated to data sharing among farmers, Public Administrations and certification bodies), resulting in the alleviation of physical and intellectual work for farmers (Osservatorio Smart AgriFood, 2020). Additionally, the use of DATs can help sustaining products and territories - promoting a sustainable local growth - and to preserve the quality and safety of food.
- Profit: DATs can lead to an increase in productivity and cost reduction. The latter is related to input use reduction (agrochemicals, water, etc.) and the former refers mainly to process efficiency. Additionally, enhancement of farm productivity and increase in food quality can led to a growth in profits.

Despite the widely recognized benefits of DATs, digital innovation in agriculture has been relatively slow, for several reasons. Some authors argue that solutions are often more complex and less scalable than optimization processes in other industries, like manufacturing or communications (Cornell University, INSEAD, & WIPO, 2017). Farm size is also considered a parameter affecting adoption: large farms tend to engage in digital agriculture more readily because capital investments provide earlier returns on investments as a result of scale efficiencies (Castle et al., 2015). Data property and privacy are also concerns for farmers, resulting in a resistance to share their data with technology providers that may repurpose them for corporate interests. Education, technological competences of farmers, connectivity are also seen as barriers to a full adoption of Agriculture 4.0; and above all – to our knowledge–, there is a lack of holistic analysis regarding the benefits of adopting the paradigm of digitalization of agriculture, coupling the combinatorial effect of categorization of technologies and application domains (Maffezzoli et al., 2022). This means that nowadays, despite the promising growth of the "Agriculture 4.0" market and the increase in the adoption rate by farmers (MarketsandMarkets, 2021), the benefits of adopting a specific digital solution are still not always clear when plunged into the specific reality of a single farm, with its own specificity in terms of production, bio-geographical region and business, and – as a consequence – not only the adoption of digital innovation is slowed down, but DATs are not always used at their full potential.

To cope with these criticalities and to help farmers assessing the real benefits and potentials of DATs, QuantiFarm aims to build a framework for the assessment of the impact of DATs, which is lowered into the specifics of 30 Test Cases. The framework has its roots in the TBL approach, hence it aims to understand costs and benefits of DATs along the three dimensions of sustainability, looking not only at the single farm, but assuming a wider perspective that includes the impact on the environment and the society. Additionally, the framework should also ensure its credibility and functionality when it is applied by a specific user within a TC. Therefore, the framework – by following a set of credibility, impartiality and accountability principles – determines the rules, procedures and responsibilities under which it will be applied in the Test Case. These rules and procedures are commonly considered as the "governance" of a framework. By means of a robust governance structure, the TC Owner can be hold accountable for the delivery of accurate, consistent, reliable, and verifiable data respectively Test Case results.

The credibility and impartiality principles which have been applied to the design of this governance framework will be further detailed in section 2.4 "Overall Methodology". The principles have been

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developed and laid down by different organizations, NGOs, standard owners, and standard setting organizations. The principles are either formulated in a generic way to address a broad range of crops and products, agriculture practices, supply chains and supply chain actors (e.g. to govern a framework/standard that is designed to verify good agricultural practices globally, c.), or are formulated more concrete addressing a particular situation for which the standard is designed (e.g. to govern a framework/standard that is designed to verify specifically sustainably harvested timber, like the Forest Stewardship Council (FSC)). Hereunder, we list some of the relevant organizations that have formulated such fundamental governance principles, however, acknowledging there are other organizations at national or international level that designed similar principles:

- **ISEAL** (https://www.isealalliance.org/);
- **WWF** (https://wwf.panda.org/wwf_news/?246871/WWF-Forest-Certification-Assessment-Tool-CAT);
- **EU Code of Conduct on agricultural data sharing by contractual agreement;**
- **International Organization for Standardization (ISO)** (ISO 17020 and ISO 17025)**.**

These principles are consistently applied in the areas of both standard setting as well as conformity assessment. Whenever sustainability frameworks/standards are newly introduced to the market or existing frameworks/standards being extended the standard setting organization will adhere to these governance principles and processes. Adherence to these principles largely contributes to the credibility and acceptance of a framework.

The governance mechanism section is a living document that will be updated regularly to address upcoming issues and fairly reflect the progress made by the Test Case Owners to deliver better outcomes and to ensure improved measurement and monitoring of data.

2.2. The Assessment and Governance Frameworks in the context of the project

2.2.1. Assessment Framework

The principle of sustainability has been integrated into the objectives of the Common Agricultural Policy (CAP) of the European Union (EU), the application of this concept to agriculture has resulted in a multiplicity of definitions. Efforts have been made to produce an integrated definition of this term: the application of the concept of sustainable development in agriculture is interesting both for the sustainability of the agricultural system itself and for its contribution to (Olsson, 2009). For farms, the contribution to sustainable agriculture often involves:

- production efficiency (economic domain);
- management of natural resources and preservation of the mid-environment (environmental domain);
- contribution to the dynamics inside and outside the farm (social domain).

In particular, as the agricultural sector is heavily dominated by resource scarcity, ever-increasing demands and production uncertainty, economic sustainability implies the use of labour, natural resources and capital to produce goods and services that meet people's needs (Troskie et al., 2000). Regarding social sustainability in agriculture, the 2030 Agenda for Sustainable Development defines it as the actions to achieve social equality through the elimination of poverty and the realisation of decent living conditions for every individual. Lastly, the environmental sustainability pillar involves several aspects as in the agricultural activities the access, use and care of natural resources play a crucial role. Agriculture is both an active and passive part of climate change: on the one hand, it influences it by

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releasing greenhouse gases into the atmosphere and pollutants; on the other hand, it suffers it by depending on both weather conditions and soil and water quality (Jacobs et al., 2019). Or, regarding biodiversity that is the diversity of ecosystems, of species within these ecosystems and of the genome within these species (Wilson, 1988).
The harmonious combination of these three interconnected domains or dimensions constitutes the backbone of sustainable agriculture. Although sustainability can be implemented with a wide array of practices, projects, initiatives or actions, the assessment of such activities that is frequently motivated by strict regulations and public awareness, remains a grey area for actors in the food chain to implement. In this line, the Food and Agriculture Organization of the United Nations (FAO) calls all actors in the food chain, from farm to fork, to perform an assessment that allows for the identification and eventual quantification of their sustainability impacts and in turn design strategies for enhancing the economic, environmental and social costs and benefits, along with food quality and safety (FAO, 2018). Given that agri-food chains deal with a range of concerns regarding sustainability, there is a sense of urgency to establish methods for assessing performance and eventually re-direct actions that could address the sustainability challenges according to each actor need´s and objectives (Kirwan et al., 2017; León-Bravo et al., 2021). Indeed, sustainability assessment and evaluation could also stimulate changes in practice, support decision making, conceptualization of strategies or business models (FAO, 2018; León-Bravo et al., 2021).

Assessing sustainability along the food supply chains is a complex task that requires not only raising awareness along the chain but also to develop capabilities for systematically evaluating the achievement of the expected performances and impacts on agriculture (FAO, 2018; Kirwan et al. 2017). In their study, León-Bravo & Caniato (2021) found that sustainability assessment in the agri-food supply chain is present but rarely structured, that is, different actors in the chain focus on a single sustainability dimension (often in economic productivity terms), struggling to identify the appropriate methods according to their objectives or capabilities. Actually, assessing the sustainability practices implies the application of different measures in the environmental, social and economic areas, which given the diversity of sustainability indicators in the literature, assessments are ineffective when companies do not know how practices should be evaluated and for what reasons (Bourne et al., 2002), and even more complex when indicators on the environmental and social spheres cannot be easily translated into economic indicators (León-Bravo et al., 2021; Tahir et al., 2010).

Sustainability assessment for agri-food chains is usually structured in terms of frameworks and tools that intend to guide actors to collect data and analyse it and define action plans (Kirwan et al. 2017; (Brunori et al., 2016; D'Eusanio et al., 2018; Baur, 2022). The first challenge to overcome is to identify the measures that explain the actual actions implemented for sustainability. Kirwan et al (2017) also underlines the need of understanding the socio-economic and geographical context in order to define the assessment methods that are more appropriate. Consequently, the sustainability assessment system (methods/techniques applied for measuring, monitoring and controlling sustainability) will vary between companies in the supply chain according to the scope or range of issues to be measured and how are they measured, if they are (León-Bravo et al., 2021).

In this complex scenario, it is fundamental to consider the issue of the intangible benefits evaluation in the technology field. Historically, the discussion about the concepts of tangible and intangible benefits has been brought to the attention by many authors, arguing about the fact that intangible benefits are something "difficult to measure" (Hares and Royle, 1994), while tangible benefit is "one which directly affects the firm's profitability" (Remenyi et al., 1993) and that can be evaluated at an actual or approximate value (Webster, 1994), leaving open the question whether the word "value" refers to monetary value or other measures. The issue is particularly relevant in the case of investments in the

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technology arena where many projects deliver benefits that cannot be easily quantified and, thus, evaluated with monetary parameters (related, for example, to better information access, reduction of errors in data management, use of information for an effective decision-making (Murphy et al, 2002); but also – considering the specific agricultural context – the improved well-being of operators whose work can be alleviated thanks to digital solutions in fields and farms.

Is within this complex scenario - assessment of cost and benefits of DATs in agriculture considering a triple bottom line approach, taking into consideration tangible and intangible benefits - that QuantiFarm assessment framework is developed. The framework aims at providing an actionable tool that, building on the adoption of DATs, could pave the way for farmers and stakeholders in the chain to the assessment journey . The QuantiFarm assessment framework takes into consideration a highly heterogenous range of cases that allow to overview the reality of sustainability assessment in agriculture in Europe. Therefore, the relevant indicators in the environmental, social and economic dimension will be identified, along with their methods of calculation. These indicators form the basis for the second part of the Framework: they will be validated, refined and updated together with the test cases along the QuantiFarm project duration and information will be processed into a cost and benefits analysis, that will bring to a composite indicator consisting of a monetary index and a set of other indicators that will be used to assess the benefits of certain variables that cannot find a monetary evaluation.

The assessment framework development is accompanied by the Governance Framework that will provide the detailed guidelines to follow for the consistent and replicable sustainability assessment. Several work packages are involved in the follow up with the test cases in order to gather the relevant information that will allow the best use of DATs for sustainability.

2.2.2. Governance Framework

As mentioned above, the QuantiFarm assessment framework is designed to capture a broad set of sustainability criteria based on the TBL approach. The intention of measuring the performance of DATs on all different sustainability dimensions is to capture to the maximum extent possible the potential benefits or adverse effects of its application over time. By ensuring the impacts of the DATs, whether positive or negative, are measured accurately, consistently, unbiased, and timely the cost/benefit analysis will deliver meaningful and reliable results for each DAT.

Certain challenges are inherent to the design of a broad multi-facetted triple bottom line framework. More specifically, these challenges are related to the fact that the framework is covering an extensive range of KPIs and indicators since it is applicable to different crops and products, in different geographies, addressing different farming practices and farm sizes while introducing diverging technologies for the various DATs. For instance, data collection for the variable fertilization DAT will differ significantly from an AI or Farm Management System DAT. The first Test Case needs to collect a representative amount of soil samples from determined points in the field at a certain point in time to evidence the efficiency of the fertilization technology and has to deal with divergent governance topics compared to the DAT introducing AI. The latter one will focus more on efficiency topics and cover questions around the right data metrices to gain insight in the added value of the specific AI application. Moreover, farms (Test Cases) might rely on the DAT provider to collect data. Since the DAT Provider has a specific interest in promoting his own technology there is an inherent risk that the data set collected is not completely unbiased. Therefore, the governance foresees in specific measures and mechanisms to address the risk of a potential conflict of interest.

Another topic that is addressed under the governance is the question whether the collected and analysed data are meaningful and appropriate to assess specific DAT. For instance, for analysing the benefits of

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a DAT introducing GIS technology, the KPIs related to yield improvement, infrastructure or energy costs/reduction in fuel costs will be of more relevance compared to quality KPIs for a DAT measuring the quality of oysters on a fishery farm. Identifying the proper impact KPIs respectively the causality of the DAT for determining an improved or reduced performance is essential.

Finally, the governance also foresees a clause where the Producer or the Test Case Owner needs to evidence legality. This means that the case has to evidence compliance to the existing applicable laws and regulations. Despite the fact that legality should be a given fact for all participants we consider the inclusion of this KPI a minimum requirement to build a robust framework foundation.

2.3. Presentation of the Test Cases (TCs) and DATs

As previously mentioned, the QuantiFarm assessment framework is built considering a number of TCs in different bio-geographical conditions and different types of farms and farmers, also with different business models and under different political environments. A heterogeneous group of 30 TCs was selected representing more than 20 countries across 10 European Biogeographic Regions (as presented by the European Environment Agency (2022)). In total, more than 100 farms of different type, size, and ownership are participating in the project. This group includes farms that are directly involved in the project, as well as larger cooperatives and umbrella organisations that support the QuantiFarm project development. The TCs operate in seven agricultural sectors focusing on 20 different crops or animals. All TCs are conducted on commercial farms that use a single technology or a combination of DATs thus allowing to assess the impacts of DATs in real production conditions. An overview of TCs of QuantiFarm is presented in Table 1.

TC Number	Sector	Crop/ Animals	Type of DATs (DAT provider))	Country	Area managed with DATs
1	Arable	Potatoes	DSS (NEUROPUBLIC)	Greece	TBD [2]
2	Arable	Corn	Precision Irrigation system (Agromais); VRT (Agroanalitica)	Portugal	300 ha
3	Arable	Barley, Wheat	DSS (ITACyL)	Spain	20.58 ha
4	Arable	Cotton	VRT (Augmenta)	Greece	13,24 ha
5	Arable	Wheat	DSS (HORTA)	Turkey	TBD
6	Arable	Wheat, Onion and Potato	DSS (Delphy Development + Agrovision)	The Netherlands	5.5 ha
7	Arable	Potatoes	DSS (NEUROPUBLIC)	Poland	160 ha
8	Arable	Wheat, Rapeseed, Rye, Barley	DSS (Agrosmart SIA)	Latvia	30 silos
9	Arable	Barley, Corn, Wheat	DSS (KGZS, ITC)	Slovenia	72.89 ha
10	Arable	Wheat	DSS (Cropwise)	Romania	484 ha
11	Horticulture	Olives	DSS (NEUROPUBLIC)	Greece	8.6 ha
12	Horticulture	Apples	DSS (Delphy); Digital pest control System (Trapview)	Poland	6 ha
13	Horticulture	Grapevine	DSS (Horta)	Italy	TBD

[2] Detailed information on the area managed with DATs is yet to be provided by the TC

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14	Horticulture-In-door farming	Strawberries and Blueberries	DSS (Avital)	Serbia	7.35 ha
15	Horticulture	Olives	DSS (NEUROPUBLIC)	Cyprus	37.1 ha
16	Horticulture	Apples	DSS (Delphy); Digital pest control System (Trapview)	The Netherlands	4 ha
17	Horticulture	Grapevine	DSS (AGRICLOUD)	Romania	58 ha
18	Horticulture	Tomatoes	DSS (Horta)	Italy	TBD
19	Horticulture-In-door farming	Tomatoes	Automated Greenhouses (Priva)	The Netherlands	6 ha
20	Horticulture	Bananas and Grapes	Precision Irrigation System (AnySolution, Vinotech)	Spain	39.18 ha
21	Horticulture-In-door farming	Tomatoes	Automated Greenhouses (Priva + Trutina)	Finland	2.22 ha
22	Meat	Poultry	Farm management system (Flox)	UK	613,000 birds
23	Meat	Cows	Feeding robot (Lely); Heat detectors (Lely); Calving detectors (Evolution)	France	60 – 320 cows
24	Meat	Pigs	Farm management system (ISAGRI, Acerva)	Belgium	500 finishers + 220 sows
25	Dairy	Cows	Feeding robotics (Lely) + Activity Sensors (Allflex)	France	250 cows
26	Dairy	Cows	Milking Robot (DeLaval Dairy Services)	Ireland	201 cows
27	Dairy	Cows	Automated monitoring (smaXtec animal care GmbH)	Germany	100 cows + 140 young stock
28	Dairy	Cows	Milking Robot (BouMatic); Feeding robotics (Dinamica Generale)	Romania	638 cows
29	Apiculture	Bees	Automated Monitoring (ART21)	Lithuania	> 20 bees' colonies
30	Aquaculture	Oysters	Sensors for quality assessment (Benco Baltic d.o.o.)	Croatia	4,174 m^2

Table 1: Overview of the Test Cases (TCs), Type of DATs and Area managed with DATs

The following types of DATs (intended as single solution in the QuantiFarm project) are adopted across the 30 TCs:

A. Horticulture and Arable:

- **Decision Support System (DSS)**. DSS can be defined as "interactive software-based systems to help decision makers compile useful information from a combination of raw data, documents and personal knowledge to identify and solve problems and to optimize decisions (Iffat Ara et al., 2021). In agriculture, these tools can guide farmers in programming the treatments: thanks to a DSS, farmers do not apply inputs as water, fertilizers and pesticides uniformly across entire

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fields but they can take data-supported decisions, using the minimum quantities of resources than the plants requires (Bertoglio et al., 2021) In QuantiFarm, DSSs represent the most used DAT, provided by NEUROPUBLIC, ITACyL, Horta, AGRICLOUD, Augmenta, Agrovision, Agrosmart SIA, Delphy. In general, they are all used to obtain information on irrigation, fertilisation and pesticide management.

- **Farm Management System (FMS).** Considering that farm management deals with the overall organization and operation of a farm (e.g., production, trade, traceability, meeting consumer and legal requirements, e.g., for certifications, agricultural policies etc.), an FMS - or, a Farm Management Information Systems (FMIS) - is a software for collecting, processing, storing and disseminating data in the form needed to carry out farm's operations and functions (Nugawela et al., 2020).
- **Variable Rate Technology (VRT)**. It identifies the technologies that allow the automatic and variable application of inputs in a land in compliance with specific prescriptions. The way in which products such as fertilizers, seeds or crop protection products are distributed is based on data collected from maps, sensors and GPS. Among the objectives of optimizing distribution there may be, for example, the reduction of inputs and the increase or homogenization of the productivity of crops (Osservatorio Smart AgriFood, 2020). In the QuantiFarm project, this DAT- provided by Augmenta - is mainly used for fertiliser distribution based on data collected from maps, sensors and GPS.
- **Precision irrigation system**. It uses plant, soil and water sensors, together with weather stations, satellite images and hydraulic models to gather information. These are crucial in determining the precise amount of water and the optimal time of use (Khriji et al., 2014)
- **Digital pest control system**. It is a system based on data analysis, Artificial Intelligence and Cloud, aiming to help farmers in monitoring plants' health and controlling pests. In the system adopted in the Test Case, data gathered by specific devices are analysed; the real-time data returned to the farmers help them in promptly reacting. Additionally, the system can forecast future pest situation and simulate different plant protection measure scenario (Trapview, 2022).
- **Automated Greenhouses.** Two TCs deal with the cultivation of vegetables in greenhouses, and they use DATs enabled by Artificial Intelligence (AI) and IoT that, with the help of humidity, heat and brightness sensors, detect the conditions inside the greenhouse. Based on data collected, the DATs regulate heat, brightness and humidity for the crops (Kodali et al., 2016). In fact, the automated greenhouse systems make suggestions on the amount of light, ventilation and reheating, ensuring an accuracy not achievable with conventional systems.

B. Livestock, Apiculture and Aquaculture:

- **Farm Management Systems (for livestock and poultry)**. The importance of data and their usability is crucial in the livestock sector (Khan et al., 2004). Indeed, many TCs use a FMS that allows the management and processing of the data obtained from sensors inside the barn (poultry coop). The information obtained allows decisions to be made that are functional to the needs of the farm.
- **Automated monitoring, Activity sensors, Heat box collar**: these DATs can be used to make animal management more effective and rational, automating the monitoring of animals' status and health through the analysis of their movements, vital parameters, etc. Activity sensors, in particular, measure the movement of the neck or head of a cow, times dedicated to rumination, feeding, resting, etc. The Heat box collar, through a sensor that monitors the movement of the animal (in QuantiFarm used only for cattle) at all times, makes it possible to identify precisely when the animal is ready for insemination. With alerts sent to the mobile device (phone) or fixed device (PC) the farmer is always informed about the activity report, periods of increased

activity and also the real-time location. Other DATs make it possible to both manage and monitor animal feeding. Again, with the support of sensors it is possible, on the one hand, to feed the animals precisely, providing the right amount of feed; on the other hand, to detect specific movement patterns related to forage intake, changes in feeding behaviour and rumination.

- **Milking robots**. With the support of Internet of Things and sensors, this DAT guides the cows to the milking barn, identifies each cow individually, disinfects the udders, milks the cow, performs a milk check and records data on individual cows.
- **Sensors for quality assessment**. In oyster farming, real-time data can provide significant benefits to enhance current farm management practices, monitoring water quality (e.g., salinity, temperature, microclimate) and providing early warnings for events that can compromise the quality of the product (Bates, 2021).

2.4. Overall Methodology

2.4.1. Methodology for the assessment framework

Bourne et al. (2000) suggest that the development of any performance assessment systems is generally built in three main phases, i) identification of performance measures, ii) the implementation of the measures and iii) the use of performance measures. Accordingly, the QuantiFarm project intends to build an assessment framework that, basing on a mixed-method approach, could provide a concrete tool to assess the cost and benefits of DATs implementation, including the relevant and appropriate measures to be implemented and further be able to count with concrete information that could help farmers in Europe to advance in their journey towards sustainable innovation. Considering that costs and benefits are assessed according to the three dimensions of sustainability – because it is fundamental to consider the impacts not only on the single farms, but also on the environment and the society – the methodology for building the assessment framework has its roots first of all in the quantification of the impacts on the three domains of sustainability. As a second step, indicators and information will be analysed and wil constitute the base for a composite multidimensional index, consisting in a set of a monetary quantitative measure and a set of descriptive and qualitative indicators.

The following methodology focuses in particular on the first step of the assessment framework, that is the identification of all the indicators necessary to monitor the impacts of DATs along the years, comparing farms using and not using DATs. Considering the first phase proposed by Bourne et al. (2000), the identification of sustainability performance measures (SPM) is a crucial step that will influence the applicability of the QuantiFarm assessment framework. Hence, in this phase, the development of QuantiFarm's assessment framework follows dual approach. Firstly, a top-down perspective that deductively constructs the main elements of the framework. In this first approach, a state-of-the-art literature review of sustainability indicators in food chains, with a special focus on the upstream agricultural stage is conducted. Hence, the sustainability dimensions, categories and sub-categories of performance assessment along the TBL are identified and selected as appropriate to the context of study. This initial review is also extended to the sustainability indicators linked to the use of DATs in agriculture.

Is pointed out in literature that one of the main challenges for food companies when assessing sustainability performance is to identify which indicators to apply without overloading users with too many measures and avoiding information redundancies, thus evidencing the need for simpler assessment with core indicators (Genovese et al., 2017). Addressing this challenge, in QuantiFarm, the objective is to develop a framework that could be as close as possible to the needs of European farmers working in different conditions and using different DATs. Therefore, a bottom-up perspective for SPM

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identification and selection is applied, intending to include in the framework the particularities of the test cases in terms of: crop/product, geographical location, harvesting season, DAT applied (to be applied) and specific processes impacted by the DAT. The literature review performed in the first steps is then to be completed, refined and updated considering the cases characteristics.

In order to gather a further understanding of the cases and each particular need, the QuantiFarm assessment framework development needs primary data from the cases including on one side the descriptive information in terms of location, crops, seasonality, DAT used, and on the other side about the farm's motivations for DAT implementation, expectations for sustainability performance impacts, the priorities set when adopting DATs and assessing sustainability. This type of information becomes a key aspect for the framework development as the SPM needs to be relevant for the cases to be implemented and consequently used appropriately (as suggested by Bourne et al. 2000). With this aim in mind, the questionnaire developed by WP4 included also the inputs relevant for the assessment framework design (WP2). The questionnaire has been already sent out and first wave of data is being processed.

Following the sequence of phases suggested by Bourne et al. (2000), once the indicators are identified, the implementation and use of information is to be carried out. Nonetheless, regardless of how specific the indicators are, it has been observed in literature that actors in food chains struggle when numerous metrics are to be implemented and used, especially when multiple objectives are considered and multiple stakeholders are involved, as is the case of sustainability performance assessment (León-Bravo et al., 2021; Bourne et al., 2000; Genovese et al., 2017). The QuantiFarm assessment framework development hence intends to also address such challenge in the agriculture stage of the food chain by guiding users on the SPM implementation. With this purpose in mind, the test cases are carefully analysed with a high level of detail for having a clearer overview of the potential areas of impact as well as interests for assessment along the TBL considering the particularities that could influence the adoption of SPM (e.g., location, crop, seasonality, DAT implemented). Having this overview allows to identify commonalities and differences among cases, to identify synergies and also case specific needs to be addressed in the framework. Then, the following step is to integrate SPM data collection mode into the framework. Thus, a detailed data collection form is designed, with a medium level of customization according to the cases clustered with similar characteristics.

This form is in pilot version being currently refined thanks to the TCs participation in a training workshop and providing further details to be input into the data collection form.

The following figure summarizes the steps carried out to date for the framework development in its first version.

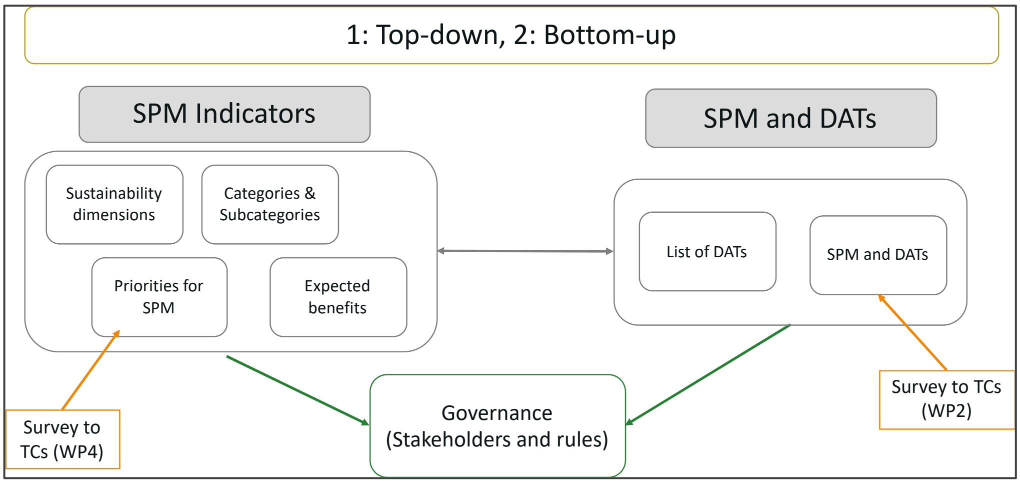

Figure 1: Summary of methodological steps conducted for the assessment framework development

Consequently, with this dual approach (i.e., top down, and bottom up) in the QuantiFarm assessment framework development, a rigorous methodology is carried out, ensuring validity for the users and reliability on the information to be gathered and used. Accordingly, the governance framework is integrated for ensuring the rigor and transparency in the sustainability assessment.

In the next steps of the assessment framework design, consisting in the evaluation of performances of DATs (cost and benefit analysis), the tool will be complemented with valuation methods to translate in practical terms the economic impact of digital technologies (using indicators well-grounded in the management and financial literature for the evalutation of the investments, as for example the Discounted Cash Flow) and other qualitative measures deriving from the analysis of the set of environmental and social indicators retrieved in the first phase.

2.4.2. Methodology for the Governance Framework

The design of the governance structure is following internationally recognized credibility and impartiality principles to ensure accurate, consistent, reliable, and verifiable data. This is reflected not only in the way how the KPIs for the framework have been formulated, but also in the clear definition of roles and functions, responsibilities, and procedures, including a complaints mechanism.
In the following paragraph the principles that are guiding the design of the governance structure are listed:

- *Transparency*: The selection of KPIs following a TBL approach is based on international research data to cover the most relevant and science based KPIs. A more specific selection is the outcome of internal discussion and workshops hold at the research institute. In this context a stakeholder consultation would not have been appropriate since this specific framework is not aimed at improving the overall sustainability performance of a company but to analyse the efficiency of a DAT in a given context. Therefore, research-based definition of KPIs is the most appropriate way. Transparency principles also apply to the way how data will be collected and assessed on its validity as well as appropriateness for the cost/benefit analysis. In his/her verification function the verifier must not only confirm the correctness of the collected data but also in his capacity as subject matter expert confirm the relevancy of the collected data for determining the efficiency of the DAT and subsequently for performing the cost/benefit analysis.
- *Impartiality:* The data will be collected by different participants of the Test Case, either the Producer or the DAT Provider or in case of various functions the DAT Test Case Owner. To ensure unbiased data the governance structure foresees in a verification function, which means that the "four-eyes-principle" applies: next to the data provider itself a third-party verifier resp. reviewer

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should verify the data and confirm its correctness and meaningfulness with respect to the impact assessment. This two-tier data collection process can also be seen as a useful preparatory step for future certification or an independent verification process for potential claims.

- *Efficiency/Credibility:* Specific KPIs might require a specific data collection process or sampling procedure. For instance, for KPIs related to the soil quality, or the wellbeing of animals on a dairy farm, such samples have to be collected according to internationally recognized practices. i.e., the samples should be taken on different places of the field so as to be representative, in a timely manner to not dilute the effects of the application, or covering a representative number of animals and in case of required laboratory analysis must be analysed by a recognized laboratory. In addition, the DAT might need to take samples or collect data over a certain period of time, not only once a year but multiple times or only on specific dates.
- *Credibility:* KPIs need to be evidenced by appropriate means. Given the divergent nature of DATs and the respective context, the means could differ significantly between the various DATs. As suitable means to evidence the amount of applied agrochemicals the respective purchase order and invoice could be considered; for evidencing the reduction of energy the electricity bill for the respective period could be considered. Potentially also interviews with supply chain participants or the producer could be an appropriate evidence tool. Which means will be selected depends from each DAT and will be further determined in the governance framework itself.
- *Relevance:* Since the framework is addressing a great variety of KPIs it must be ensured that the focus for each DAT is put on the right set of KPIs allowing for a well-grounded cost/benefit analysis of the DAT. For instance, collecting a huge set of data related to social compliance in the context of a GIS or smart farming DAT is not efficient and will not allow to identify the potential benefits of the DAT. Therefore, the verifier must cross check the focus of the selected KPIs and confirm in his verification statement, next to the correctness of presented data.

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3. Assessment Framework and Governance Mechanisms

3.1. Literature review

To develop the QuantiFarm assessment framework, a state-of-the-art literature review explored theories, tools, previous frameworks and other insights. This activity identified, evaluated and defined the list of categories, sub-categories and indicators. The literature review was conducted in a 5-step analysis.

The first step was devoted to the identification and detailed definition of the research topic based on the available literature, both white and grey, related to the quantification of impacts related to the use of DATs. In the second step, the databases used to select the papers were defined. In this instance, given the need to review not only scientific articles, but also books and professional reports, Scopus and Google Scholar were chosen to proceed with the identification of research papers.

The third step defined the search terms. In particular, the search was performed using several keywords, namely:

- Agriculture: (“agriculture”; “farming”; “farmers”)
- Framework: (“framework”; “assessment framework”; “structure”)
- Indicators: (“indicators”; “KPIs”; “measure”)
- DATs: (“DAT”; “digital technologies”; “digital solutions”)
- Method: (“quantify”; “quantification”; “impact”; “value”)

The fourth step was devoted to a screening by analysing the content of the abstracts. The authors scrutinised the topics of the selected articles in order to identify only those that met the project's objective. Finally, once the screening phase had been carried out, it was possible to conduct a review of the articles' contents and the extraction of useful information for the development of the assessment framework.

The methodology presented was instrumental in identifying categories, sub-categories and indicators to assess the impact of DATs. The results of the literature review are presented in Table 2.

Authors\Organisation	Year	Dimensions/domain	Categories	Indicators
Arandia et al.	2011	3		98
Batalla et al.	2014	3	11	64
Zahm et al.	2008	3	9	41
Vilain	2008	3	10	42
Dantsis et al.	2010	3	13	21
Lebacq et al.	2013	3	20	50
FAO	2013	4	21	57
Fourrié et al.	2013	1	9	49
Ripoll-Bosch et al.	2012	3		40
OECD	2017	3	18	154
Pineau	2009	3		50
Sadok et al.	2009	3		31

Table 2: Results of literature reviews on dimensions, categories and indicator

The literature review shows that most frameworks identify indicators related to the three domains of sustainable agriculture:

- production efficiency (economic domain);

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- management of natural resources and preservation of the mid-environment (environmental domain);
- contribution to the dynamics inside and outside the farm (social domain).

It is pertinent to point out that SAFA (FAO, 2013b) is the only one among the results of this literature review that develops its assessment framework including an additional domain, the institutional one. This addition is justified by the fact that the framework proposed by the FAO aims to measure the private sector's contribution to the SDGs in the field of food and agriculture. This dimension will not be included in the QuantiFarm assessment framework, as it is not directly impacted by the use of DATs. Alternatively, Fourrié et al (2013) focus exclusively on the social sustainability dimension, favouring the development of social indicators measuring social cohesion, for instance, the number of associations in which the farmer is involved.

Most of the frameworks analysed are aimed at rating the overall performance of farm sustainability. The methods that are used are various: some use a combination of accounting data from advisory centres and complementary surveys (Arandia et al., 2011; Batalla et al., 2014); others compare by scoring on the basis of a set of indicators (Vilain et al., 2008; Zahm et al., 2008). Even though both quantitative and qualitative indicators are present within the different frameworks, many authors emphasise the importance of using precisely and objectively quantifiable indicators as much as possible (Lebacq et al., 2013), limiting the use of scores, which do not have a dimensional unit (van der Werf et al., 2002). In literature, almost all of the frameworks analysed present the three dimensions/domains of sustainability. Although the environmental dimension is largely developed – in terms of the number of indicators identified - in the last decade, many academics have focused on the social and economic dimensions. With reference to the social domain, based on the IFOAM principles (IFOAM, 2005) Fourrié et al. (2013) introduced some new categories such as resilience, equity, autonomy and diversity. When referring to the economic domain, most of the calculated indicators are largely related to farm profitability and productivity (Dillon et al., 2008). Many authors try to put the environmental performance of farms in perspective with economic performance (Diazabakana et al., 2014).
After the identification of domains and categories, to develop a solid framework, it is necessary to define threshold values or indicators that enable their interpretation (Bockstaller et al., 2008; Meul et al., 2008; van Cauwenbergh et al., 2007). The indicators make it possible to identify preferable states and distinguish them from unsatisfactory ones. Different types of indicators have been analysed in the literature:

- Fixed absolute values, the range of accepted values between a minimum and a maximum. Absolute values include both scientific values (van Cauwenbergh et al., 2007) and values defined by stakeholders (Bockstaller et al., 2008);
- Target values, the combination of values that identify a desirable condition (Diazabakana et al., 2014);
- Relative values, the comparison of the indicator's current value with its initial value, sample average, industry average, etc. (Bockstaller et al., 2008; van Cauwenbergh et al., 2007).

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3.2. Framework structure

Building upon the findings of the literature review and the descriptions of the TCs, the QuantiFarm assessment framework combines different quantitative and qualitative methodologies to conduct a comprehensive analysis of the costs and benefits of DATs implementation in the agricultural context. Due to the complexity and impacts of farming activities on the environment and society, and the difficulty of quantifying all the benefits in monetary values (for the theory of "intangible benefits" the use of different methodologies and categories of indicators is necessary to include and capture the impact not only on the single farm, but on the environment and the society.

Basing on the literature and existing framework, the first step for the framework development is the identification of categories, sub-categories and indicators of impact. In QuantiFarm, the development of the assessment framework followed a three-step approach summarised in Figure 2: i) identification of categories within in each domain (Enviromental, Economic, Social), ii) division of categories in sub-categories (where relevant), and iii) identification of indicators within each category/sub-category.

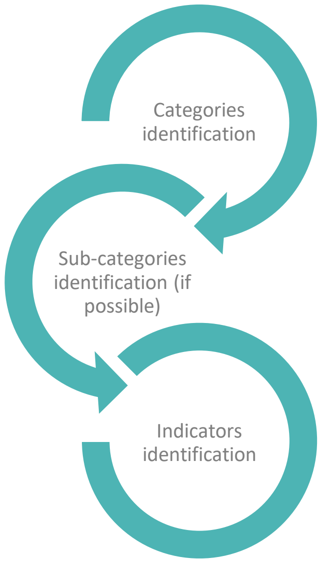

Figure 2: Overview of the steps performed to develop the assessment framework

Firstly, based on the categorisations proposed by several sustainable performance frameworks, presented earlier in section 3.1, 13 main categories for environmental, economic and social sustainability have been identified, as listed in Figure 3.

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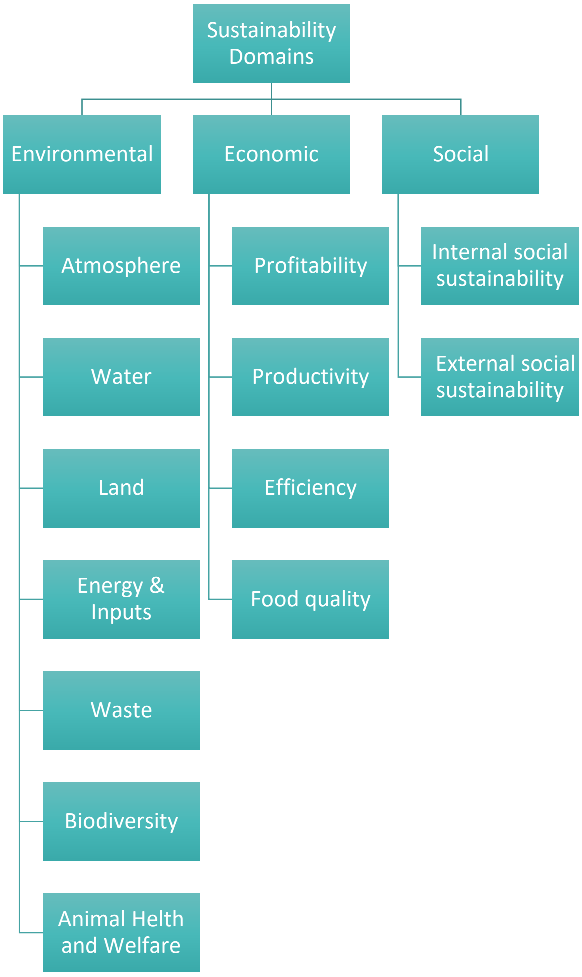

Figure 3: Sustainability categories tree

Subsequently, the main categories were split into 18 sub-categories with the aim of disaggregating the main categories into the most relevant areas to be considered for the assessment. Sub-categories were created only for the environmental and social domains (14 and 6, respectively), while no sub-categories were included in the economic domain as the level of aggregation defined by the category was considered sufficient with no need to further split the level, as presented in Table 3.

DOMAIN	DOMAIN ID	CATEGORY	CATEGORY ID	SUB-CATEGORY
Environmental	EN	Atmosphere	AT	Greenhouse Gases
				Air quality
		Water	WA	Water withdrawal
				Water quality
		Land	LA	Soil chemical properties
				Soil biological properties
		Energy & Inputs	EI	Energy use
				Renewable energy
				Nutrients use
				Pesticides use
		Waste	WS	Generated waste

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		Biodiversity	BI	Biodiversity conservation
		Animal Health and Welfare	AHW	Animal health
				Animal welfare
Economic	EC	Profitability	PF	-
		Productivity	PD	-
		Efficiency	EF	-
		Food Quality	FQ	-
Social	SO	Internal social sustainability	IS	Education
				Working conditions
				Food safety
		External social sustainability	ES	Local community
				Involvement and participation
				Transparency and visibility

Table 3: Sustainability Sub-categories

Thirdly, once the categories and sub-categories had been identified, the next step was to build the list of indicators that are relevant, feasible and measurable (Neely et al., 2011) for the actors in the TCs. A review of academic and grey literature as well as international standards and reports focusing on the three dimensions of sustainability was carried out. This activity allowed us to obtain a comprehensive overview of possible indicators to measure sustainability. Although this analysis mainly focused on the agri-food context, other sources were also explored for completeness (e.g., OECD, Sustainable Development Goals).

This initial listing included those indicators belonging to the environmental, economic and social dimensions. Subsequently, a further refinement step was conducted in order to select only the sustainability indicators that could be linked to the use of DATs. For instance, indicators related to child labour and gender equality were omitted from the list as these couldn't be associated to the adoption of any technology type in literature nor in the international standards. Following this skimming process, we analysed a total of 616 indicators - 354 environmental, 81 economic and 181 social – and selected a total of 80 indicators - 48 environmental, 16 economic and 16 social.

In the next phases of the QuantiFarm project, the development of a composite indicator is foreseen, considering a combination of monetary quantitative measures (as, for example, Discounted Cash Flow, Real Option Analysis and/or asset-based valuations) with qualitative and descriptive indicators, currently included in the assessment framework, that will be used to capture all those aspects that are not easy to translate into economic values as, for example, the wellness of workers and the impact on local communities.

In the following sections, the indicators selection is described in detail per sustainability dimension, category and sub-category.

3.2.1. Environmental Domain

A critical aspect of the environmental dimension is maintaining the life-support systems that are essential for the survival of all living species. This is because it is about minimizing negative environmental impacts and promoting positive ones in an effort to ensure the survival of all living

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species. Within the assessment framework, the following categories are addressed: Atmosphere, Water, Land, Energy & Input, Waste, Biodiversity and Animal Welfare as shown in Table 3.

Atmosphere (EN-AT)

The term atmosphere within the QuantiFarm's assessment framework refers to the integrity and preservation of clean air. While agricultural activities and the food sector are strongly influenced by climate change, at the same time they are primarily responsible for it. The sub-categories included are: Greenhouse gases and Air quality as shown in Table 4. Four group of recommended indicators under two sub-categories are selected, as follows:

SUB-CATEGORY	INDICATOR
Greenhouse Gases	Total greenhouse gas (GHG) emissions
	GHG emissions intensity ratio
Air Quality	Ozone depleting substances (ODS)
	Nitrogen oxides (NOX), sulfur oxides (SOX), and other significant air emissions regarded as pollutants (persistent organic pollutants; volatile organic compounds; hazardous air pollutants; particulate matter)

Table 4: Atmosphere recommended indicators

Water (EN-WA)

The water category intends to aggregate the indicators that assess the emission and quality of water used for irrigating fields, for watering livestock and for aquaculture. A subset of recommended indicators is presented in Table 5:

SUB-CATEGORY	INDICATOR
Water Withdrawal	Water Consumption
	Water Productivity
	Total water discharge
Water Quality	Total oxidised nitrogen (river)
	Nitrate (groundwater)
	Orthophosphate
	pH
	Dissolved oxygen
	Biological oxygen demand
	Chemical oxygen demand
	Electrical conductivity
	Pesticides content
	Heavy metals

Table 5: Water recommended indicators

Land (EN-LA)

The land used for cultivation, animal husbandry, or animal feeding is fundamental within QuantiFarm's assessment framework. The sub-category is overall defined as Soil quality. Six indicators under two sub-categories could be used to assess the impacts of specific DATs as shown in Table 6:

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SUB-CATEGORY	INDICATOR
Soil chemical properties	Soil Organic Carbon
	Total Nitrogen
	Available Phosphorus
	Available Potassium
	Soil salinity
Soil biological properties	Soil respiration rate

Table 6: Land recommended indicators

Energy & Inputs (EN-EI)

Energy and Input category refers to all those materials or inputs - with the exception of water - required to carry out operations and processes in the farms. Eleven indicators under four sub-categories are recommended as shown in Table 7:

SUB-CATEGORY	INDICATOR
Energy use	Fuel oil/diesel/propane consumption
	Gas consumption
	Wood consumption
	Electricity consumption
Renewable energy	Share of renewable energy
Nutrients use	Nitrogen use
	Phosphorus use
	Potassium use
Pesticides use	Herbicides use
	Insecticides use
	Fungicides use

Table 7: Energy and Inputs recommended indicators

Waste (EN-WS)

Waste management within QuantiFarm's assessment framework refers to the efficient use of resources in order to minimise the amount of waste generated. A subset of recommended indicators is presented in Table 8:

SUB-CATEGORY	INDICATOR
Generated waste	Amount of waste generated
	Amount of hazardous waste generated
	Amount of waste reused and recycled

Table 8: Generated waste recommended indicators

Biodiversity (EN-BI)

Agricultural biodiversity encompasses the variety and variability of animals, plants and microorganisms that are required to support agroecosystem functions, structure and processes for and in support of food security. A subset of recommended indicators is presented in Table 9:

SUB-CATEGORY	INDICATOR
Biodiversity conservation	Rate of biodiversity loss
	Rate of habitat loss
	Protected areas and land with significant biodiversity values, and biodiversity conservation and management
	Biodiversity index
	Red list index

Table 9: Biodiversity recommended indicators

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Animal Health and Welfare (EN-AHW)

At QuantiFarm, animal welfare is understood as the way an animal copes with the conditions in which it lives. Animal welfare is achieved if the animal is healthy, well fed, safe, able to express innate behaviour, free of distress and pain. A subset of recommended indicators is presented in Table 10:

SUB-CATEGORY	INDICATOR
Animal Welfare	Ease of movements
	Total indoor area
Animal Health	Mortality rate
	Mortality rate at birth
	Cows with high SCC
	Quantity of drugs used

Table 10: Animal health and welfare recommended indicators

3.2.2. Economic Domain

The economic dimension in QuantiFarm's assessment framework includes the following categories: Profitability, Productivity, Efficiency and Food Quality.

Profitability Category (EC-PF)

Profitability is an indispensable attribute to ensure the operation and growth of the farm over the long term and throughout its life cycle. Profitability considers the income and costs incurred by the different productive activities in the farm. The indicators proposed in the QuantiFarm's assessment framework are expected to be aggregated from the different processes and activities and issued in the farm's financial reports. A subset of recommended indicators is presented in Table 11:

CATEGORY	INDICATOR
Profitability	Net Farm Income
	Production costs
	Gross profit margin
	Net profit margin
	Net value added
	Sales revenue
	Cash flow

Table 11: Profitability recommended indicators

Productivity (EC-PD)

For QuantiFarm productivity refers to the product obtained for each unit of productive factor (be it labour or land). A subset of recommended indicators is presented in Table 12:

CATEGORY	INDICATOR
Productivity	Land productivity
	Labour productivity
	Milk productivity
	Bees productivity
	Oyster productivity

Table 12: Productivity recommended indicators

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Efficiency (EC-EF)

Efficiency refers to the ability of an activity to achieve its goal whilst minimising resource use. In the context of QuantiFarm, efficiency refers particularity in the ability of DATs to gain better performances in certain kind of activities (e.g.: reducing errors, reducing the time requested to complete a certain activity, etc.). A subset of recommended indicators is presented in Table 13 (please note that in the TCs assessment templates, the indicators are adapted for the specific context):

CATEGORY	INDICATOR
Efficiency	Feed conversion ratio
	Rate of time (to complete an activity)
	Precision & Accuracy

Table 13: Efficiency recommended indicators

Food Quality (EC-FQ)

Food quality comprises the combinations of attributes or characteristics of a product that significantly determine the degree of acceptability of the product to the consumer. A recommended indicator is presented in Table 14:

CATEGORY	INDICATOR
Food quality	"Intrinsic" product quality

Table 14: Food quality recommended indicators

3.2.3. Social Domain

Within the QuantiFarm's Assessment Framework, the social dimension involves the social and cultural context within which farmers can express themselves freely, improving working conditions, strengthening social cohesion and fostering the development of communities close to the farm. The categories addressed are: Internal social sustainability and External social sustainability.

Internal social sustainability (SO-IS)

Internal social sustainability refers to the social impact within the farm linked to the use of DATs. A subset of recommended indicators is presented in Table 15:

SUB-CATEGORY	INDICATOR
Education	Training hours
	Working time
Working Conditions	Working Conditions
	Frequency rate of rates of occupational injuries
	Incidence of occupational injuries
	Remuneration and benefits
	Physical wellbeing
	Psychological wellbeing
Food safety	Food contamination (organo halogen)
	Food contamination (heavy metals)

Table 15: Internal social sustainability recommended indicators

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External social sustainability (SO-ES)
External social sustainability refers to the farm's organised activities and spill over to the communities close to the farm. In Table 16, six indicators under three sub-categories are recommended:

SUB-CATEGORY	INDICATOR
Local community	Contribution to rural economy
	Contribution to employment
Involvement and participation	Farmers social involvement
	Meetings with stakeholders
Transparency and visibility	Information on labels
	Sustainability certifications and labels

Table 16: External social sustainability recommended indicators

3.3. TCs analysis

As presented in section 2.3, the 30 TCs are heterogeneous in terms of sector, geographical location and DATs used. Aiming at further characterizing the TCs and identifying the areas of activity DATs impact on, a deeper analysis of the TCs was carried out.
The first analysis was conducted using the first descriptions of TCs provided by WP4. Within the document, the most useful information for conducting the analysis was as follows:

- Country and Biogeographical Region
- Agricultural Sector and crop/animal
- Digital Technology Type
- Digital Technology Description

This information gave us a general idea of the type of activities and benefits expected from the use of DATs in each TC. Subsequently, when information on the specific technology provider was available, the information presented in the documents was cross-referenced with that available on the web (provider's websites, brochures, specialised magazines). This process allowed us to better understand and classify DATs more rigorously for identifying which activities are impacted by such DATs.
Thereafter, the 30 TCs were grouped into four categories according to their sector with the aim of counting with similar processes and activities that could be impacted by the use of specific DATs. This clustering is:

- Arable (8 TCs)
- Horticulture (10 TCs)
- Horticulture-In-door farming (3 TCs)
- Livestock (4 TCs)
- Dairy (3 TCs)
- Silos management (1 TC)
- Apiculture (1 TC)
- Aquaculture (1 TC)

Hence, health and animal breeding is an activity common only to animal management sectors. Certainly, some activities are cross-cutting and independent of the sector, such as logistics management, administrative tasks and DAT training.

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Moreover, regarding the activities identified as being impacted by the use of the DAT implemented are, six for the arable and horticulture sector. This number is reduced to five for livestock, two for aquaculture and one for apiculture. The identified activities, divided by sector, impacted by DAT are summarised in the following Table 17.

Sector	Activity impacted by the DATs	Description	# TCs per activity
Arable, Horticulture and Horticulture in-door farming	Irrigation management	Monitoring the application of water to crops. It is used to manage the volume, flow rate and timing of water application (Pereira et al., 2002).	16
	Fertilisers management	Application of commercial fertilisers, manure, amendments and organic by-products to agricultural land as a source of nutrients for crops (Benbrook, 1996).	17
	Pesticides management	Effective pests' containment using prevention, avoidance and monitoring strategies to manage weeds, pests and fungi (USDA, 2020).	10
	Crop monitoring	Surveying the growth status of crops and predicting their yield (Ali et al., 2019)	16
	Heating, cooling and ventilation management	All activities that control temperature and humidity inside a greenhouse (Castilla, 2013).	2
Livestock and Dairy	Feed management	Animal nutrition-related activities, from the supply phase to the feeding phase (Khan et al., 2011).	2
	Heat detection	Methods used to identify the signs and symptoms that an animal shows before ovulation (Khan et al., 2004).	5
	Animal tracking	Keeping records on individual farm animals or groups of farm animals so that they can be easily monitored from birth to the marketing chain (Khan et al., 2004).	5
	Manure/sewage/litter management	Activities related to the capture, storage, treatment and use of animal manure/sewage/litter (Burton et al., 2004).	1
	Milking management	Ensures that udders are cleaned and stimulated before the units are applied, milk is collected efficiently and effectively and the animal is moved after milking is completed (Schroeder, 1997).	1
Aquaculture	Nutrients management	Activities of receiving and processing qualitative and quantitative information on the nutritional status of the aquaculture animal.	1
	Water management	Monitoring water temperature and physical and chemical properties to ensure the proper animal growth (Boyd et al., 1985).	1
Apiculture	Hive maintenance	Techniques and activities needed to ensure the survival of the hive and maximise its production (Bonney, 1990).	1
Cross-sectoral (only animals)	Animal health and growth management	The activities aimed at fostering animal welfare, the reduction of animal stress and healthy growth (Khan et al., 2004).	9
Cross-sectoral	Logistics management	Ensures an optimal and monitored flow of products from producers to consumers (Bosona et al., 2013).	2

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	Warehouse management	Refers to the principles and processes in warehouse administration (Hompel et al., 2008)	2
	Administrative tasks management	Includes activities to organise schedules and manage payroll, personnel databases, costs and farm book.	26
	Training on DATs	All the activities (programmes, courses, etc.), funded by the employer, providing meaningful information on the use of DATs.	30

Table 17: Activities impacted by the DATs

Before proceeding with the presentation of the DATs grouped by sector, it is essential to underline that to-date:

1. In many of the TCs, the implemented solutions are presented as a combination of more than one DAT;
2. The main DATs are always supported by other solutions/technologies, without which the implemented solution could not work;
3. Not all TCs are aware of, use or are interested in all the functionalities of the DATs they are implementing.
4. In many cases, the category of DAT provided by TCs does not match the categorisation presented in Table 1, Section 2.3. For example, in some cases it is referred to as FMIS when, after careful analysis of the solution, it is actually a DSS.

In particular, regarding to the arable, horticulture and horticulture in-door farming cluster, five main categories of DATs were identified: automated greenhouses, DSS, precision irrigation systems, VRT, digital pest control systems. These DATs impact the activities presented in Table 16.
In the following tables (17, 18, 19, 20, 21), the DATs and the activities impacted are presented. An "O" indicates those activities that could be impacted by DATs but which the TC has decided not to exploit or where the information available is too limited to ascertain the real interest in using it. Instead, an "X" marks all activities impacted by DATs and being actually used by the TC.

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TCs #	Main DATs	Irrigation Management	Fertilisers Management	Pesticides management	Crop monitoring	Warehouse management	Logistics management	Heating, cooling and ventilation management	Administrative tasks	Training on DATs
1	DSS	X	X	X	X				X	X
2	Precision Irrigation system + VRT	X	X						X	X
3	DSS		X						X	X
4	VRT		X						X	X
5	DSS	O	X	X	X				X	X
6	DSS (water) + DSS (fertilisation)	X	X		X				X	X
7	DSS	X	O	O	O				X	X
8	DSS				X	X	X		X	X
9	DSS		X						X	X
10	DSS	X	X	X	X				X	X
11	DSS	X	X	X	X				X	X
12	DSS (water) + DSS (fertilisation) + digital pest control system	X	X	X	X				X	X

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13	DSS	O	X	X	X				X	X
14	DSS	X	X		O				X	X
15	DSS	X	X	X	X				X	X
16	DSS (water) + DSS (fertilisation) + digital pest control system	X	X	X	X				X	X
17	DSS	X	X	X	X				X	X
18	DSS	X	X	X	X				X	X
19	Automated Greenhouses	X			X			X	X	X
20	Precision Irrigation System	X								X
21	Automated Greenhouses	X	X		X			X	X	X

Where X= all activities impacted by DATs and O= activities that could be impacted by DATs but which the TC has decided not to exploit

Table 18: Specific provider of DATs and impacted activities in the arable, horticultural and horticultural in-door farming sector

In the livestock and dairy cluster, 6 main categories of DAT were identified: farm management system, heat box collar, feeding robotics, milking robots, automated monitoring. These DATs impact the activities presented in Table 16.

TCs #	Main DAT	Feed management	Heat detection	Animal health and growth	Animal tracking	Manure/sewage/litter management	Milking management	Warehouse management	Administrative tasks	Training on DATs
22	Farm management system			X	X	X				

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23	Heat box collar		X	X	X					X
24	Farm management system		X	X	X				X	X
25	Feeding robotics + Activity Sensors	X	X	X	X				X	X
26	Milking Robot			X			X		X	X
27	Automated monitoring		X	X					X	X
28	Farm management system	X	X	X	X			X	X	X

Where X= all activities impacted by DATs and O= activities that could be impacted by DATs but which the TC has decided not to exploit

Table 19: Specific provider of DATs and impacted activities in the livestock and dairy sector

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In the apiculture cluster a category of DAT was identified: automated monitoring. This DAT has an impact on the activities presented in Table 16.

TCs #	Main DATs	Hive maintenance	Health and welfare management	Administrative tasks	Training on DATs
29	Automated Monitoring	X	X		X

Where X= all activities impacted by DATs and O= activities that could be impacted by DATs but which the TC has decided not to exploit

Table 20: Specific provider of DATs and impacted activities in the apiculture

With respect to the aquaculture cluster, the DATs identified are sensors for quality assessment.

TCs #	Main DATs	Nutrients management	Water management	Logistics management	Health management	Administrative tasks
30	Sensors for quality assessment	X	X	X	X	X

Where X= all activities impacted by DATs and O= activities that could be impacted by DATs but which the TC has decided not to exploit

Table 21: Specific provider of DATs and impacted activities in the aquaculture

In addition, is relevant to highlight that the Test Case (TC) Description Forms administered by WP4, were key for consolidating our analysis. In particular, it allowed us to identify the technology provider and the specific technology implemented; moreover, it contributed to consolidate the activities impacted by the use of DATs and assess whether there were other activities that we had not previously considered.

The analysis of TCs was preparatory to the methodological identification of all activities on which a specific DAT has (could have) an impact. This approach allowed us to identify all the data that the TCs must monitor, avoiding overlooking any of them. The development of the data list and the application of the assessment framework will be developed in the next section.

3.4. Model application

As explained in the previous sections, a top-down methodology was applied to create the overall assessment framework. The identification of the categories and their respective sub-categories – starting from the academic and professional literature, reports and frameworks - allowed to get a general idea of which are the main indicators presented in the literature and to identify those most related to the implementation of DATs. However, an additional analysis of the TCs was necessary to expand the knowledge of the specific DATs used and on which activities they have an influence, hence a bottom-up methodology was applied when the model had to be applied to each single TC. This methodology has been used to analyse the TCs, identifying which data should be monitored by the TCs, to carefully assess the impacts of the use of DATs.

The heterogeneity of the TCs required a deep analysis of the indicators and the data that should be monitored by each TC. The basic assumption for the QuantiFarm assessment framework, indeed, is that only the sustainability indicators connected to the use of the DATs should be monitored; for this reason, an analysis in terms of specific processes impacted by the DAT has been conducted for each TC. We cross-referenced the sub-categories (categories for the economic domain) and activities presented in

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Table 17. This analysis focuses on two levels of impact between sub-categories and activities: 1. the direct one, linked to the process and immediate in time; 2. the indirect one, unrelated to the process and needing a significant time frame before it occurs. For example, when considering a DAT that have an impact on irrigation management (e.g.: a Decision Support System), all the sub-categories that are directly related to the activity (water withdrawal, water quality) were analysed. It is evident that any change in irrigation management has a direct impact on water withdrawal. The same concept applies for energy use, profitability, productivity, etc. Whereas, a variation in irrigation management could have an impact on the sub-category of greenhouse gases that can only be verified after a significant time frame.

Although this analysis represented well the link between activities and sub-categories, it didn't not allow us to identify precisely which data to request from the various TCs. This is because this analysis did not consider the type of culture, the geographical area and, above all, the DATs used. In fact, this information is only present in the description of the TCs provided by WP4. To address this issue, a process of interaction with TCs was started, to allow a proper data collection. Data collection indeed is a fundamental activity in order to obtain results on the real impact of DATs in agriculture, therefore, the second phase of the "Model application" consisted of adapting the templates for data collection to the characteristics of each TC, hence, including only the indicators related to the processes impacted by the specific DAT used in a specific TC.

TCs have been grouped in 8 different clusters and 8 templates for data collection - specific for each cluster - have been prepared (see Table 22). A group of indicators is common for all the 30 TCs, in particular the social sustainability indicators; whereas economic indicators, linked to efficiency and productivity, can vary according to the product and context (e.g.: in apiculture, productivity can be measured through "average yield per colony", in arable and horticultural sector is useful to calculate the "land productivity", in dairy sector productivity is calculated using the "milk productivity"). Similarly, environmental sustainability KPIs can differ from TCs since their calculation is linked – other than the product and sector – to the used DATs and the expected impact.

Once each TC leader has received the proper template, in accordance with WP4 leaders, feedback from TCs have been collected by calls and/or emails, particularly regarding the coherence of the indicators with the product/sector and the processes impacted by the DATs, the possibility to collect or not the requested data and the timing for data collection. Although data will be required at M4, M8, and M12 from the launch of each TC, not all the data could be collected every time, according to seasonality and farming activities. After their consolidation, definitive templates have been sent to the TCs to start the data collection.

Cluster	TC number
Arable	TC2, TC3, TC4, TC5, TC6, TC7, TC9, TC10
Horticulture	TC1, TC11, TC12, TC13, TC14, TC15, TC16, TC17, TC19, TC20
Horticulture – Indoor Farming	TC14, TC19, TC21
Meat-Livestock	TC22, TC23, TC24

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Dairy	TC25, TC26, TC27, TC28
Apiculture	TC29
Aquaculture	TC30
Silos Management	TC8

Table 22: TCs clusters for data collection

3.5. Governance Framework

3.5.1. Introduction

The purpose of the governance is to ensure that outcomes of the Test Cases assessment framework application are accurate, consistent, reliable and verifiable, upholding a high level of trust and confidence. A strong governance structure contributes to a level playing field for all DATs and by clearly determining the rules and procedures to support transparency and unbiased credible results. These rules and procedures laid down in the governance are covering all phases of the process, starting with the data collection till monitoring of data and subsequent DAT assessments. The governance will be followed by all participants involved in the execution and evaluation of the DATs.

3.5.2. Stakeholders, Roles and Definitions

For the aims of the governance framework, the following definitions will apply:
DAT: A Digital Agriculture Technology ("DAT") is a data based digital technological solution to support producers with improving the efficiency, productivity or the sustainability performance of their farms, such as automated greenhouses, drones, smart irrigation, farm management information systems, self-driving tractors etc.

Producers: Refers to producers of agricultural products such as individual farmers and/or companies whose business is centred on agricultural and/or aquaculture operations

DAT Providers: Refers to companies developing and/or supplying DATs to producers.

DAT Test Case: ("DAT TC") Refers to a testing scenario with the purpose of comparing the benefits or drawbacks of a specific DAT between producers applying a DAT with other producers not applying the same DAT (clausula rebus sic stantibus). The DAT Test Case therefore implies the inclusion of both, the producer testing the DAT and the control producer not applying the DAT whereby it is also possible that producer and control producer is the same party.

DAT Test Case Leader: Refers to a single entity responsible for conducting the DAT Test Case Assessments and collecting the data for the assessment. The data that will be collected are determined by the KPIs of the QuantiFarm assessment framework.

DAT Test Case Assessment: Refers to the process of collecting data and documents required by QuantiFarm's assessment framework to evaluate the benefits of the DAT in real conditions.

DAT Test Case Assessment Verification: Refers to the process of verification of a DAT TC Assessment to ensure that it was performed in a way complying with the assessment framework.

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QuantiFarm: An EU funded multi-stakeholder project to evaluate the benefits and efficiency of DATs used in real conditions. Ultimately, the objective of QuantiFarm is to support the further deployment of DATs as key enablers for enhancing the sustainability performance and competitiveness of the agricultural sector.

3.5.3. Baseline Conditions

A safeguard mechanism is required to ensure that baseline conditions of the DAT Test Cases. More specifically historical records comparing yields, profitability as well as the environmental impact of the producers with and without DATs for the past 3 years must be collected and presented. This will ensure the outcome of the Test Case Assessment is well grounded and based on proper (causal) criteria. In addition, it will also ensure the selection process of producers for DAT Test Cases was not biased.

Furthermore, for the governance framework, it is relevant to note that TCs should ideally include a diverse range of producers to ensure the results derived TC application of the assessment framework have accounted at least the following considerations:

Farm size:
Benefits of a DAT can vary depending on the size of farms, therefore, any benefits derived from a DAT Test Case should clearly state the farm size that is required to demonstrate the beneficial results of the DAT. For example, the economic benefits of a sprayer drone or a self-driving tractor will not be identical on a small farm as compared to a larger farm where the economic payback metrics is different.

Product type:
The evaluation of DATs should also be able to state for which product type (e.g. specific crop, dairy, livestock, honey etc.) a certain DAT yields optimal results. For example, to state whether the variable rate application has the same benefits for Canola as for Wheat.
In case it is known through literature review, expert interview or TC that a specific DAT is not suitable for either specific product type or farm size, this should be mentioned in the final evaluation report to avoid any misrepresentation of DAT results.

3.5.4. Producer’s Consent and TC owner’s declaration

DAT Test Case Leaders should ensure that the producers of both DAT case and control case are informed about the QuantiFarm project and its objectives. This should be done in the form of a written document explaining in short and comprehensible way the objectives of the assessments and where the producers are required to:

1. Declare with their signature to have read and understand the purpose of the DAT Test Case,
2. Approve QuantiFarm’s use of any data associated with their farm,
3. Confirm that any data they provide during the assessment phase is accurate and complete,
4. Declare the identity of the person and/or company details as well as their contact.
5. Allows access to the premises where the DAT is being used

Additionally, the DAT Test Case Leader(s) should in a signed form:

1. Declare the full identity of the company and persons responsible for overseeing the DAT Test Case and collecting relevant data.
2. Declare any affiliation with companies developing or providing any of the DATs which they are assessing.
3. Declare the nature of any previous relationship with the producer.
4. Agree to share the results of the DAT Test Case Assessments with the producer.

3.5.5. Competences and Qualifications

Appropriate records of the education, training, skills, and experience of each DAT Test Case Leader and Verifier working within QuantiFarm should be maintained. Prior to the assessments, participants will receive training on the requirements and procedures of the QuantiFarm assessment framework as well as its governance implications.

Training and competency records must include:

1. Proven understanding and experience in applying the assessment framework and its governance;
2. Proven training and experiences for the relevant DAT, agricultural and/or agri-related industries;
3. Specific reference, where applicable, to training on amendments and changes within the assessment framework and its governance.

DAT Test Case Assessment Verification shall

1. Be independent of the DAT being assessed;
2. Be free from any potential conflict of interest;
3. Be competent, specifically with respect to the above criteria 6.7.1.1. and 6.7.1.2;
4. Receive training and demonstrate understanding and compliance with the training requirements in the technical area(s) he is active in. This will happen prior to conducting DAT Test Case assessment verifications.
5. Have the appropriate specific skills required for conducting the assessment verifications related to the assessment framework and its governance, as well as a good understanding of the DAT Test Case scope.

3.5.6. TC application of the assessment framework

DAT Test Case Assessments should ensure that all required data to evaluate the costs and benefits as well as the efficiency of the DAT are collected in a reliable, verifiable, accurate and timely way.

Type of data to be collected:

i. *Operational costs*: Data related to reductions in operational costs such as labour, agrochemicals, energy, water bills etc.
ii. *Production:* Data related to production parameters such as yield, quality of produce as well as revenues.
iii. *Environmental emissions:* Data related to emissions such as GHG and Nitrogen.
iv. *Environmental impact:* Soil and water quality indicators include waste generation and their management, as well as release of harmful agrochemicals.
v. *Animal welfare:* Indicators covering the general wellbeing of animals such as disease prevalence, adequate shelter, space, nutrition, pain-free handling, and humane slaughter.
vi. *Biodiversity and Land use:* Indicators that measure the impact of DATs on the preservation of species diversity, avoidance of land use conversion and restoration of natural landscapes.
vii. *Social impact:* Data related to the social benefits of DATs such as on child/forced labour, worker and community rights and benefits etc.

Means of data collection:

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DAT Test Case Assessments should be conducted on-site via the use of well-defined and preferable digital questionnaires prepared in accordance with the DAT assessment framework and covering all topics listed in 6.a.

Sampling:
Adequate samples (such as soil and water) should be collected in a way to represent the actual condition of the measured KPIs and preferably adhering to applicable ISO standards such as ISO 18400 for sampling procedures or ISO 17020 and ISO 17025 for audit procedures. Special attention should be given to the:

i. Location on the field where samples are collected from, either randomly, or otherwise from the most suitable location if specific knowledge is available.
ii. Frequency and timing of samples also considering the proximity to the time where agrochemicals have been applied.
iii. Proper sealing of the samples and recording the seal ID prior to dispatching to the Laboratory for analysis

The DAT Test Case Leaders shall provide a sampling report with the number and type of samples collected, the seal IDs, the laboratory where it has been dispatched including instructions for analysis, as well as an explanation and justification about the sampling location and the time of sampling.

Documentary Evidence:
DAT Test Case Leaders should ensure that the DAT Test Case assessments are supported with adequate documentary evidence such as but not limited to:

i. *Invoices:* For evidencing production claims, yield, quantity and type of agrichemicals used;
ii. *Utility bills:* For evidencing usage of energy and water;
iii. *Pay slips:* For evidencing labour costs;
iv. *Farm maps:* For evidencing the size and location of farms;
v. *Laboratory analysis:* For evidencing improvements in water and soil quality and detection of agrochemical residues.

Frequency of assessments:

i. *Initial:* Conducted at the beginning of the DAT Test Case, when necessary, baseline data should also be collected. Producers should be informed about the next visit date and be requested to prepare the necessary information.
ii. *Follow-up:* Conducted at least once a year.

Producer's review and signature:
Every DAT Test Case assessment should be signed by the producer confirming the veracity and accuracy of all submitted data and records as well as providing the producer an opportunity to comment on the results.

3.5.7. DAT Test Case Evaluation

In alignment with the initial goals of the QuantiFarm submission, the DAT evaluations should present a composite multidimensional index, consisting of a monetary quantitative measure, in combination with a set of descriptive indicators on the impact of DATs to reflect the complexity of the social and environmental aspects.

Preferably, a harmonized scoring mechanism should also be developed allowing the efficient measurement of the direct and indirect impacts of the DAT compared to producers who are not using the respective DAT.

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3.5.8. Verification and Non-Conformities Management

Upon completion assessment framework application, the Test Case Leader shall submit the material to a verifier who could be any participant member in the QuantiFarm project and whose organization is not affiliated with rendering of DAT services specific to the DAT Test Case being verified. This non-affiliation will be documented in a declaration form.

The Test Case Verification is conducted in a well-designed Excel based checklist that will include investigative questions to ensure that the DAT Test Case Assessment was conducted in compliance with the rules governing the assessment framework.

Non-conformities grading:

During the DAT Test Case verification process, findings of discrepancy with the requirements can be detected in 2 grades, as defined below:

i. Minor non-conformities are findings that do not adversely affect the accuracy and integrity of compliance with QuantiFarm governance principles, and which can be corrected without any effect on further incorrectness of the DAT Test Case. Examples could be the inconsistency of reported KPIs with the documentary evidence.
ii. Major non-conformities are findings that may significantly affect the accuracy and integrity of compliance with QuantiFarm governance principles, and which can no longer be corrected after the assessment. Examples could be the absence of documentary evidence to support the reported KPI claims, or omissions of certain key topics that should have been addressed during the assessment.

Non-conformities resolution timelines and consequences:

i. Minor non-conformities must be communicated by the verifier to the DAT Test Case Leader who in turn should have them resolved within 60 days.
ii. Major non-conformities must be communicated by the verifier to the DAT Test Case Leader who in turn should have them resolved within 30 days. Failure to resolve a major non-conformity within the specified timeframe will result in the exclusion of DAT Test Case results from QuantiFarm.

3.5.9. Complaints Mechanism

Attention to complaints and the resulting potential conflicts in QuantiFarm is an important base for the reliability, continuous improvement, and transparency to the participants and stakeholders. A formal complaint procedure in accordance with the principles specified in this section can be used in case the conflict is not directly resolved by the parties.

A complaint is defined as the formal listing of a potential violation of QuantiFarm's governance principles and requesting remedy of the situation causing the conflict.

Conflicts can occur on different levels between stakeholders, organisations, or individuals in relation to the procedures and decisions within QuantiFarm and could include:

i. Conflicts between a DAT Test Case Leader and DAT Test Case Verifier;
ii. Conflicts between a DAT Test Case Leader and a producer;
iii. Conflicts brought up by stakeholders when they are affected by activities performed by the DAT Test Case Leader;
iv. Conflicts that arise from decisions and procedures of the QuantiFarm Project Management Team.

Principles for conflict resolution

The Project Management Team will:

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i. Encourage parties to resolve the conflict between themselves first;
ii. Encourage parties to resolve conflicts in a timely manner;
iii. Gather the underlying facts from the parties involved;
iv. Be as transparent in the decision-making process as possible;
v. Maintain formal records of the complaints;
vi. Ensure an appeal process is in place;
vii. Act in the best interest of the integrity of QuantiFarm project, undertaking decisions in an unbiased and impartial manner; and
viii. If any Project Management team member has a conflict of interest with the respective case, he or she will be excluded from the decision-making process.

Admission of complaints

Complaints and appeals will only be filed when they meet the following criteria:

i. The reason for the complaint or appeal is a substantial and presents a non-negligible risk to the integrity of the QuantiFarm's governance principles with clear reference to the parties or documents involved.
ii. The text of the complaint or appeal is addressed to QuantiFarm's Project Management Team.

The Project Management Team reserves the right to dismiss complaints that do not meet the above criteria.

Complaints submission and processing

Complaints and appeals need to be submitted in writing in the English language to complaints@quantifarm.com.

a. Complaints and appeals must contain the following information:
   i. The name of the organisation and contact person;
   ii. Additional contact information;
   iii. Name of the organisation and/or the individual against which the complaint is raised;
   iv. Explanation regarding the breach in question;
   v. Documented evidence to substantiate the submitted claim and providing contextual information on the rationale in such a way that a third party can obtain a clear idea and form a judgement on the situation; and
   vi. A proposed solution to resolve the conflict.

b. The Project Management Team will acknowledge the complaint within 10 working days by confirming the receipt of the complaint. The complaint resolution will be proposed within 20 working days after the acknowledgement date, unless the team has justified a longer assessment process, such as requesting the response of other involved or affected parties.

Complaints follow-up process

a. The Project Management Team will perform a review of the presented documentary evidence and hearing all parties involved: the party submitting the complaint, and the counter-party, the party/parties causing, or which might have been affected by, the complaint and will subsequently propose a decision within 20 working days.
b. If required, the decision could cause corrective actions to be required by the counterparty.

Appeal procedure

a. The decision from the Project Management Team can be appealed by both parties, the issuer of the complaint and the counter-party. The convened panel will make a decision which will be communicated directly after meeting. Written communication can follow within five days after the meeting.
b. This decision is the final decision and is not subject to further appeal. The team will monitor any corrective actions. required by the decision

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Documentation

The Project Management Team keeps a register of all complaints and appeals, including the steps taken for resolving the complaint.

4. Conclusion and next steps

The aims of this report deliverable D2.1 were to thoroughly explain and describe the step by step processes and considerations taken in WP2 for developing the assessment framework and Governance Mechanisms. In this way, this document firstly introduced the relevance of sustainability performance assessment in agriculture considering the key role of digital technologies for advancing sustainability and improving conditions in the agricultural sector. Similarly, the governance principles of compliance, impartiality, reliability, transparency, credibility, meaningfulness are presented as crucial elements for ensuring an effective and unbiased credible assessment. Then, for the development of the assessment framework, a top-down and bottom-up approach was followed. Following, this report described the main characteristics of the 30 TCs and the DATs associated to each of them. A detailed and exhaustive analysis of TC, DAT, sustainability domain, agricultural sector and processed on which the DAT has an impact was developed with the purpose of adapting the framework to the very heterogeneous realities where the TC work on. The results of this analysis allowed to build 8 clusters of TCs for which the framework and data collection instrument is customized, also thanks to the inputs provided directly by TCs during a training session. Lastly, for the assessment framework, this report described the model application to the different clusters and the data collection forms generated. Whereas, the current development of the Governance Mechanisms that are presented in this report include the main definitions to be considered in the governance structure, it identifies the baseline in the TCs, the considerations for the assessment framework application, and its corresponding evaluation and verification. An initial description of the non-conformities and complaints management procedures are also included in this report. Hence, the current versions of the assessment framework and Governance Mechanisms follow the QuantiFarm objectives of contributing with actionable tools for measuring sustainability performance in the agriculture sector with the key contribution of DAT adoption for enhancing sustainability goals in the sector.

Subsequently, as the QuantiFarm project progresses, the assessment framework and Governance Mechanisms will be revised and updated. The inputs from TCs will be incorporated, when each of the sectors start collecting data and processing it, as well as with the inputs from WP3, WP1 and WP4. The methodology for the final evaluation of TCs will be refined, incorporating the economic cost and benefit analysis by the use of financial valuation methods; and a first model for the composite index that combines the monetary index with qualitative variables will be proposed.

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Appendix 1 – KPI and guidelines

In this appendix, the descriptions of the KPI and indications for data reporting and KPI calculation are provided.

EN-AT-1	**Greenhouse gases emissions**
Domain	Environmental
Category	Atmosphere
Sub-category	Greenhouse gases
Description	This indicator refers to the volume of the entity's direct GHG emissions (scope 1) and indirect GHG emissions (scope 2) during the reporting period. Emissions sources are categorized as direct or indirect and then further divided into '*scopes*': • Direct sources: Owned or controlled by the reporting company. All direct sources are classified as scope 1. • Indirect sources: Owned or controlled by another company, but a portion of whose emissions are a consequence of the activities of the reporting company. Indirect sources are either scope 2 or scope 3: scope 2 emissions stem from the generation of electricity, heat, or steam that is purchased by the reporting company, while scope 3 emissions are all other indirect emissions.
Metrics	See the *Notes* section
Unit of measurement	t CO_2-equivalent (CO_2e) for all seven GHGs (CO_2, CH_4, N_2O, SF6, PFCs, HFCs and NF3)
Notes	Guidelines provided in this section are a brief summary of the procedure reported in "**GHG Protocol Agriculture Guidance"** that should be consulted for further details (see the *Reference* section in this table). <u>Overview of agricultural emission sources</u> (p. 24-32) Many different types of emission sources are associated with agriculture, such as fuel use, soils, and manure management. An important distinction for the agricultural sector is between *mechanical* and *non-mechanical sources*. *Mechanical sources* are equipment or machinery operated on farms, such as mobile machinery (e.g., harvesters), stationary equipment (e.g., boilers), and refrigeration and air-conditioning equipment. These sources emit CO_2, CH_4, and N_2O, or HFCs and PFCs, and their emissions are wholly determined by the properties of the source equipment and material inputs (e.g., fuel composition). *Non-mechanical sources* are either biological processes shaped by climatic and soil conditions (e.g., decomposition) or the burning of crop residues. They are often connected by complex patterns of N and C flows through farms. Non-mechanical sources emit CO_2, CH_4 and N_2O (or precursors of these GHGs) through different routes. CO_2 fluxes are mostly controlled by uptake through plant photosynthesis and releases via respiration, decomposition and the combustion of organic matter. In turn, N_2O emissions result from nitrification and denitrification, and CH4 emissions result from methanogenesis under anaerobic conditions in soils and manure storage, enteric fermentation, and the incomplete combustion of organic matter. <u>Setting organisational boundaries</u> (p. 34-41) Summary of requirements and main recommendations: • Companies shall separately account for and report on scope 1 and 2 minimum.

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- When setting operational boundaries, companies should take appropriate account of production contracts and other forms of agricultural contracting, land and equipment leases, and membership of co-operatives.

Tracking GHG fluxes over Time (p. 42-45)
Summary of requirements and main recommendations:

- Companies shall choose and establish a base period, and specify the reasons for choosing that period.
- The base period shall be the earliest point in time for which verifiable data are available on scope 1 and scope 2 emissions.
- Multi-year base periods are recommended for many companies.
  Due to the limited duration of the project, the base period will be 1 year.
- Companies shall develop a base period emissions recalculation policy, and clearly articulate the basis and context for any recalculations. If applicable, the policy shall state any "significant threshold".
  Not applicable in the QuantiFarm time frame
- Companies shall recalculate the base period inventory to reflect changes in organizational structures or calculation methods, or the discovery of errors, which significantly impact the base period inventory.
  Not applicable in the QuantiFarm time frame

Calculating GHG fluxes (p. 46-59)
Summary of requirements and main recommendations:

- When high-quality activity data are not available for all of the emissions sources that need to be included in an inventory, companies should prioritize their data collection efforts based on source magnitude.
- Companies should select a calculation approach that best meets their objectives for compiling an inventory and the GHG accounting and reporting principles.
- When managing inventory quality, companies should focus on reducing parameter uncertainty.
- Information on GHG data uncertainty should be reported in inventories.

Note: Prior to calculating GHG fluxes, companies should also consult the next section which details the specific types of C stock changes that should be included in an inventory and for which calculations are therefore recommended.

Accounting for carbon stocks (p.60-69)
Summary of requirements and main recommendations:

- Companies should report the net CO_2 fluxes (in tonnes CO_2) to/from organic C stocks in mineral/organic soils and above-ground and below-ground woody biomass, as well as the CO_2 emissions from DOM (Dead organic matter) and biomass combustion.
- Natural disturbances, Payments for Environmental Services (PESs), and conservation areas should be accounted for equivalently to other agricultural activities.
- Companies should use peer-reviewed methods for CO_2 flux calculations.
- When relevant, companies should amortize changes in C stocks evenly over time using a fixed-rate approach.
- Companies should account for historical changes in land use or management occurring on or after the base period.
  Not applicable in the QuantiFarm time frame

Reporting on GHG data (p.70-75)
Summary of requirements and main recommendations:

- Companies shall report descriptive information on inventory boundaries and base periods.
- Companies shall report quantitative information on GHG fluxes following requirements in the Corporate Standard.
- Companies should follow a set of additional 'best practice' recommendations for reporting agricultural GHG fluxes.

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	• Any offset credits or renewable energy that are generated on farmland but sold off-site shall not be reflected in inventory totals. Tool for calculating GHG fluxes (p. 88-96) The document lists some tools suitable for farm managers.
Reference	GHG Protocol. 2021. GHG Protocol Agriculture Guidance. In: GHG Protocol website [online]. Washington, D.C. https://ghgprotocol.org/agriculture-guidance

Table 23: Greenhouse gases emissions

EN-WA-1	**Water consumption** **Water productivity** **Dependence on water**
Domain	Environmental
Category	Water
Sub-category	Water withdrawal
Description	This sub-category of indicators refers to the amount of water withdrawn within the boundaries of the organization, from all sources (surface water, groundwater and third-party fresh water) and for any use during the reporting period. Based on the type of farming activity, the indicator may different. In **arable and horticulture**, for example, *Water consumption* is generally expressed in terms of volume of irrigation water per hectare of cropped area, while in other sectors (e.g., **dairy** and **livestock**) water consumption often refers to the total amount of water used by the organisation within the reporting period. *Water productivity*, instead, relates to the amount of yield per unit of water used. Finally, *Dependence on water* is used in **aquaculture** and it measures the volume of water used per unit of production.
Metrics	**Arable and horticulture** *Water consumption:* – *Irrigated crops:* volume of water applied for irrigation or other purposes / irrigated area – *Non irrigated crops*: volume of water used / cultivated area *Water productivity:* – *Irrigated crops:* crop yield / volume of water applied for irrigation – *Non irrigated crops*: crop yield / volume of water used **Dairy and livestock** *Water consumption:* total volume of water used **Apiculture** *Water consumption:* total volume of water used / number of beehives **Aquaculture** *Dependence on water:* total volume of water consumed / production
Unit of measurement	**Arable and horticulture** *Water consumption:* m^3 / ha; l / m^2 *Water productivity:* t / m^3; kg / l **Dairy and livestock** *Water consumption:* m^3; l **Apiculture** *Water consumption:* m^3 / beehive **Aquaculture** *Dependence on water:* m^3 / t

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Notes	**Arable and horticulture** Water use for non-irrigated crops includes water used for pesticides and fertilizer applications, crop cooling (for example, light irrigation), and frost control (the same applies for irrigated crops when it is mentioned "water used for other purposes). **Dairy and livestock** Water use for livestock and other animals includes water used to raise animals. Under this category, water used by the animals for drinking, dairy sanitation, cleaning and waste-disposal systems, cooling of an animal or a product and processing animal products is included. **Aquaculture** Only the consumed water should be considered. The water that returns to the environment in a similar condition to which it was withdrawn is not considered consumed, but if it returns polluted, it should be considered consumed.
Reference	Kilemo, D. B. (2022). The Review of Water Use Efficiency and Water Productivity Metrics and Their Role in Sustainable Water Resources Management. Open Access Library Journal, 9(1), 1-2 Valenti, W.C., Kimpara, J M, Preto, B. D. L., Moraes-Valenti, P. (2018). Indicators of sustainability to assess aquaculture systems. Ecological indicators, 88, 402-413.

Table 24: Water Consumption, Water Productivity and Dependence on Water

EN-SO-1	**Total Soil Nitrogen** **Available Soil Phosphorus** **Available Soil Potassium**
Domain	Environmental
Category	Soil
Sub-category	Soil chemical properties
Description	This sub-category of indicators relates to soil nutrients (Nitrogen, Phosphorus, Potassium) and it provides baselines for evaluating the status of agricultural soils.
Metrics	Laboratory analysis
Unit of measurement	ppm
Notes	General Sampling Guidelines: For nutrient management, soil sampling is done to collect a soil sample that represents the spatial area for which nutrient information (e.g., fertilizer recommendations) is needed. To do this many samples will be collected and mixed together to make one composite sample for each field. Any soil sample can be analysed to give lab results, but results are meaningful only if appropriate sampling and handling procedures are used. Composite samples are the mixtures of numerous individual samples that will represent a sampling area. To make a composite sample, collect at least 15 soil cores (or slices) in each sampling area. The recommended maximum area is 10 hectares per 15 cores. Place all cores in a clean plastic pail or container. About 0.5 kg is usually more than enough. Then the sample must be mixed well and precautions need to be taken to minimize changes before lab analysis. Take always three samples, one for the laboratory, one for the verifier and one stays with the farmer. There are two options to do this: 1) Keeping the soil cool (but not frozen) This assumes the sample is dry enough to be mixed well. After mixing the composite sample well, fill a bag or other clean container with soil. Clearly label

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	samples with the date, field or sample unit name, and sampling depth (0-15 cm or other). Keep the samples cool (e.g., refrigerated in a cooler but not frozen) until they reach the lab and they should reach the lab as quickly as possible. Freezing soil samples is not recommended as soil nitrogen can change forms while freezing/thawing. 2) Air drying the soil Keep samples cool as described above until they can be spread on plastic sheets in a clean, ventilated room at room temperature. Dry thoroughly for one to two days, and then mix each sample well and send to the lab in clean and labelled containers. How often to sample: Collecting a sample for a nitrate-nitrogen test should be done every year prior to planting non legume crops. For Phosphorus and Potassium, sampling every 2 years is often sufficient. Time of Sampling: Collect soil samples after one crop matures and before seeding the next one. Spring sampling prior to planting is ideal, especially for nitrate-nitrogen test. However, soil sampling is generally done in the fall, which allows more time to collect samples and get results from the laboratory. Sampling fields at approximately the same time every year is recommend for more consistent results. Sampling depth Nitrogen > The recommended sampling depth is 30 cm Phosphorus and Potassium > The recommended sampling depth is 15 cm deep Laboratory analysis • Total Soil Nitrogen Dumas dry combustion method (FAO, 2021a) or Kjeldahl method (FAO, 2021b) • Available Phosphorus Bray I and II, Mehlich I, Olsen (FAO, 2021c; FAO, 2021d; FAO, 2021e) • Available Potassium Mehlich III (Mehlich, 1984)
Reference	**Sampling procedure** Poon D., Schmidt O. (2010) Soil Sampling for Nutrient Management. Nutrient Management Factsheet – No. 2 in Series. **Laboratory analysis** FAO (2022) Country guidelines and technical specifications for global soil nutrient and nutrient budget maps – GSNmap: Phase 1. Rome. https://doi.org/10.4060/cc1717en FAO (2021a) Standard operating procedure for soil total nitrogen – Dumas dry combustion method. Rome, FAO. Available at: https://www.fao.org/3/cb3646en/cb3646en.pdf FAO (2021b) Standard operating procedure for soil nitrogen – Kjeldahl method. Rome, FAO. Available at: https://www.fao.org/3/cb3642en/cb3642en.pdf FAO (2021c) Standard operating procedure for soil available phosphorus, Bray I and Bray II method. Rome, FAO. Available at: https://www.fao.org/3/cb3460en/cb3460en.pdf FAO (2021d) Standard operating Procedure for soil available phosphorus – Mehlich I method. Rome, FAO. Available at: https://www.fao.org/3/cb5427en/cb5427en.pdf FAO (2021e) Standard operating procedure for soil available phosphorus – Olsen method. Rome, FAO. Available at: https://www.fao.org/3/cb3644en/cb3644en.pdf Mehlich, A (1984) Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in soil science and plant analysis, 15(12): 1409–1416

Table 25: Total Soil Nitrogen, Available Soil Phosphorus and Available Soil potassium

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EN-EI-1	**Fuel oil/diesel/propane consumption** **Gas consumption** **Electricity consumption**
Domain	Environmental
Category	Energy & Inputs
Sub-category	Energy use
Description	This sub-category of indicators refers to the direct consumption of energy by energy source (*Fuel oil/diesel/propane*, *Gas* and *Electricity*) used for crop and animal production during the reporting period.
Metrics	*Fuel oil/diesel/propane*: total consumption *Gas*: total consumption *Electricity*: total consumption
Unit of measurement	*Fuel oil/diesel/propane*: l *Gas*: m^3 *Electricity*: kWh
Notes	Direct energy use in agriculture is primarily petroleum-based fuels to operate cars, pickups, and trucks as well as machinery for preparing fields, planting and harvesting crops, applying chemicals, and transporting inputs and outputs to and from market. Natural gas, liquid propane, and electricity also are used to power crop dryers and irrigation equipment. Electricity is used largely for lighting, heating, and cooling in homes and barns. Dairies also require electricity for operating milking systems, cooling milk, and supplying hot water for sanitation.
Reference	Adapted from Schnepf, R. (2004) Energy Use in Agriculture: Background and Issues. CRS Report for Congress.

Table 26: Fuel oil/diesel/propane consumption, Gas consumption and Electricity consumption

EN-EI-2	**Share of renewable energy**

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700

Domain	Environmental
Category	Energy & Inputs
Sub-category	Renewable Energy
Description	This indicator refers to the proportion of an entity's consumption of renewable energy compared to its total energy consumption during the reporting period. Types of renewable energy include solar energy, biomass, hydropower, geothermal energy and ocean energy.
Metrics	renewable energy consumption / total energy consumption * 100
Unit of measurement	%
Notes	This indicator is computed as the total amount of renewable energy consumed by the reporting entity divided by its total energy consumption in the reporting period. Energy consumption is expressed in joules. The indicator is expressed as a percentage (%). To better understand enterprises' energy use, it is suggested that the entity also report total renewable energy consumption as an absolute amount (expressed in joules). If possible, the indicator should be reported with a further breakdown by type of renewable energy sources (biofuels, solar energy, biomass, etc.).
Reference	FAO (2021). Guidance on core indicators for agri-food systems – Measuring the private sector's contribution to the Sustainable Development Goals. Rome. https://doi.org/10.4060/cb6526en

Table 27: Share of renewable energ

EN-EI-3	**Nitrogen applied / Nitrogen use** **Phosphorus applied / Phosphorus use** **Potassium applied**

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Domain	Environmental
Category	Energy & Inputs
Sub-category	Nutrients use
Description	This sub-category of indicators refers to the volume nutrients (Nitrogen, Phosphorus and Potassium) used in crop or aquaculture production. For **arable and horticulture**, *Nitrogen applied*, *Phosphorus applied* and *Potassium applied* refer to the volume and intensity (as a proportion of the total cropped area) of nutrients used by the entity during the reporting period. For **aquaculture**, *Nitrogen use* and *Phosphorus use* measure the amount of nutrient given per unit of production.
Metrics	**Arable and horticulture** *Nitrogen applied*: amount of nitrogen applied / cultivated area *Phosphorus applied*: amount of phosphorus applied / cultivated area *Potassium applied*: amount of phosphorus applied / cultivated area **Aquaculture** *Nitrogen use*: amount of nitrogen applied / production *Phosphorus use*: amount of phosphorus applied / production
Unit of measurement	**Arable and horticulture** *Nitrogen applied*: kg N / ha *Phosphorus applied*: kg P / ha *Potassium applied*: kg K / ha **Aquaculture** *Nitrogen use*: kg N / kg *Phosphorus use*: kg P / kg
Notes	To calculate how much of a nutrient is applied, consider the following: Amount of nutrient applied (e.g., kg N / ha) = Amount of fertiliser (kg / ha) * % nutrient in fertiliser ÷100
Reference	FAO (2021). Guidance on core indicators for agrifood systems – Measuring the private sector's contribution to the Sustainable Development Goals. Rome. https://doi.org/10.4060/cb6526en Valenti, W.C., Kimpara, J M, Preto, B. D. L., Moraes-Valenti, P. (2018). Indicators of sustainability to assess aquaculture systems. Ecological indicators, 88, 402-413.

Table 28: Nitrogen applied/Nitrogen use, Phosphorus applied/Phosphorus use and Potassium applied

EN-EI-4	**Herbicides use** **Insecticides use** **Fungicides use**
Domain	Environmental

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700

Category	Energy & Inputs
Sub-category	Pesticides use
Description	This sub-category of indicators refers to the volume and intensity (as a proportion of the total cropped area) of pesticides (Herbicides, Insecticides, Fungicides) used by the entity during the reporting period.
Metrics	*Herbicides use:* amount of active ingredient / cultivated area *Insecticides use:* amount of active ingredient / cultivated area *Fungicides use:* amount of active ingredient / cultivated area
Unit of measurement	*Herbicides use:* kg a.i. / ha *Insecticides use:* kg a.i. / ha *Fungicides use:* kg a.i. / ha
Notes	To calculate the amount of active ingredient, consider the following: Amount of active ingredient applied (e.g., kg a.i. / ha) = Amount of product applied (kg / ha or l / ha) * % active ingredient ÷100
Reference	Adapted from FAO (2021). Guidance on core indicators for agrifood systems – Measuring the private sector's contribution to the Sustainable Development Goals. Rome. https://doi.org/10.4060/cb6526en

Table 29: Herbicides use, Insecticides use and Fungicides use

EN-WA-1	**Amount of waste generated**
Domain	Environmental

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700

Category	Waste
Sub-category	Generated waste
Description	This indicator measures the intensity of waste generated by the reporting entity during the reporting period. It is calculated as the total amount of waste generated.
Metrics	Total amount of waste generated
Unit of measurement	kg; t
Notes	The sum of the amounts of all solid waste generated during production and operation activities in the entity during the reporting period. Although agriculture waste can exist in different forms, waste gas and wastewater are not included in the definition. Possible solid waste includes: crop residues (i.e., stalks, stubble, stems, leaves, seed pods and other material left on farmlands and plantations after the crop has been harvested), animal manure, fish faecal matter, waste feed, feathers, bedding material, wastewater with high solid content, and other solid waste generated during livestock and poultry breeding; agriculture films, pesticide packaging and other plastic waste; animal remains and carcasses, etc. Considering internal reuse and recycling in the production processes, the total waste generated excludes the amount of waste material that has been treated through a closed-loop process, i.e., recycled, reused and returned to the production process of the reporting period. Closed loop means that the recycled, reused and remanufactured material is returned to the production process of the reporting entity. An open loop process, instead, means that that the recycled, reused and remanufactured material is returned to the market, but not to the production processes of the reporting entity.
Reference	FAO (2021). Guidance on core indicators for agrifood systems – Measuring the private sector's contribution to the Sustainable Development Goals. Rome. https://doi.org/10.4060/cb6526en

Table 30: Amount of waste generated

EN-AHW-1	**Ease of movements** **Total indoor area**

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Domain	Environmental
Category	Animal health and welfare
Sub-category	Animal welfare
Description	This sub-category of indicators is used to the evaluate the housing conditions of animals in terms of ease of movement and stocking density.
Metrics	*Ease of movements*: number of days per year with access to pasture and outdoor loafing area; number of hours per day with access to pasture and outdoor loafing area *Total indoor area*: net area available to animals / number of animals
Unit of measurement	*Ease of movements:* d / y; h / d *Total indoor area:* m^2 / animal
Notes	
Reference	De Vries, M., Bokkers, E. A. M., Dijkstra, T., Van Schaik, G., & De Boer, I. J. M. (2011). Invited review: Associations between variables of routine herd data and dairy cattle welfare indicators. Journal of Dairy Science, 94(7), 3213-3228. Ruckli, A. K., Hörtenhuber, S. J., Ferrari, P., Guy, J., Helmerichs, J., Hoste, R., ... & Dippel, S. (2022). Integrative Sustainability Analysis of European Pig Farms: Development of a Multi-Criteria Assessment Tool. Sustainability, 14(10), 5988.

Table 31: Ease of movements and Total indoor area

EN-AHW-2	**Mortality rate** **Mortality rate at birth** **Cows with high SCC**

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	Quantity of drugs used
Domain	Environmental
Category	Animal health and welfare
Sub-category	Animal health
Description	This sub-category of indicators is used to the evaluate the health conditions of animals.
Metrics	*Mortality rate:* number of deaths in a year / Total number of animals * 100 *Mortality rate at birth:* number of animals died in the first 24 h / Total number of animals born * 100 *Cows with high SCC:* number of cows producing high SCC milk / Total number of cows * 100 *Quantity of drugs used:* total quantity of drugs used per type of drug
Unit of measurement	*Mortality rate:* % *Mortality rate at birth:* % *Cows with high SCC:* % *Quantity of drugs used:* mg, g, ml, ...
Notes	High SCC milk: >400,000 SCC/mL of milk
Reference	M. Brennan, T. Hennessy and E. Dillon. Embedding animal welfare in sustainability assessment: an indicator approach. Irish Journal of Agricultural and Food Research. DOI: 10.15212/ijafr-2020-0133 Warner, D., Vasseur, E., Villettaz Robichaud, M., Adam, S., Pellerin, D., Lefebvre, D. M., & Lacroix, R. (2020). Development of a benchmarking tool for dairy herd management using routinely collected herd records. Animals, 10(9), 1689.

Table 32: Mortality rate, Mortality rate at birth, Cows with high SCC and Quantity of drugs used

EC-PF-1	Production costs
Domain	Economic
Category	Profitability
Description	It measures the costs incurred by a business from manufacturing a product or providing a service.
Metrics	direct dabour (including imputed labour costs) + direct material + overhead costs on manufacturing
Unit of measurement	€
Notes	For unpaid labour (e.g., farm owner, family members), consider the opportunity cost for labour e.g., the corresponding average off-farm wages in the region or locality (“next best alternative”).
Reference	Pellegrini, G., Sala, P. L., Camposeo, S., & Contò, F. (2017). Economic sustainability of the olive oil high and super-high density cropping systems in Italy. Global Business and Economics Review, 19(5), 553-569. Tsolakis N, Anastasiadis F, Srai JS (2018) Sustainability performance in food supply networks: Insights from the UK industry. Sustainability, 10(9), 3148

Table 33: Production costs

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101059700

EC-PF-2	Sales revenue
Domain	Economic
Category	Profitability
Description	It measures the income received by a company from its sales of goods or the provision of services. In other word, it is the total amount of sales recognized for the reporting period (prior to any deductions).
Metrics	number of units sold x average price
Unit of measurement	€
Notes	*Sales revenue* is the total amount of sales recognized for the reporting period (prior to any deductions). The output to be considered will depend on the typology of business and will vary per test case (e.g., for arable, it is the amount of crops; for dairy, the amount of milk; etc.)
Reference	Vivas, R., Sant'anna, Â., Esquerre, K., & Freires, F. (2019). Measuring sustainability performance with multi criteria model: A case study. Sustainability, 11(21), 6113.

Table 34: Sales revenue

EC-PF-3	Other income
Domain	Economic
Category	Profitability
Description	It indicates the amount of other income (e.g., subsidies, payments from CAP funds, …) directly related to the purchase and implementation of DATs
Metrics	amount of income received
Unit of measurement	€ / ha
Notes	
Reference	Latruffe, L., Diazabakana, A., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., ... & Uthes, S. (2016). Measurement of sustainability in agriculture: a review of indicators. Studies in Agricultural Economics, 118(3), 123-130.

Table 35: Other income

EC-PD-1	Productivity

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Domain	Economic
Category	Productivity
Description	It measures the ability of the factors of production to generate output. It is generally measured as a "partial" productivity indicator, which is ratio of output of one input.
Metrics	*Land Productivity*: total production / harvested area *Labour productivity*: total production / hours of labour employed *Milk productivity*: total milk production / total number of cows *Bees productivity*: total production / colony *Oyster productivity*: area used / production
Unit of measurement	**Arable and horticulture** *Land productivity*: tons / ha or kg / m^2 *Labour productivity*: kg / h **Dairy** *Milk productivity*: kg / cow / day **Apiculture** *Bees productivity*: kg / colony **Oyster** *Oyster productivity*: m^2 / kg
Notes	The calculation of this KPI depends on the type of product/supply chain. Please refer to the *Metrics* to know how to calculate this indicator in your TC.
Reference	Latruffe, L., Diazabakana, A., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., ... & Uthes, S. (2016) Measurement of sustainability in agriculture: a review of indicators. Studies in Agricultural Economics, 118(3), 123-130.

Table 36: Productivit

EC-EF-1	Feed Conversion Ratio
Domain	Economic
Category	Efficiency
Description	This indicator is a measure that can define the efficiency of feed formulation. It is a ratio of given feed weight over animal weight gain in a certain period of time or feed input per unit of fresh product. Lower FCR values indicate that a feed is efficiently converted into animal weight gain while overfeeding or underfeeding increases the ratio.
Metrics	feed eaten / animal weight gain or mass of input / mass of output
Unit of measurement	number
Notes	
Reference	Wilkinson, J.M., 2011. Re-defining efficiency of feed use by livestock. animal, 5(7), pp.1014-1022.

Table 37: Feed Conversion Ratio

EC-EF-2	Rate of time for quality analysis

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Domain	Economic
Category	Efficiency
Description	This indicator describes the percentage of time devoted by operators to conduct quality analysis on the final product.
Metrics	(hours spent for quality analysis / total number of working hours) *100
Unit of measurement	%
Notes	Example of operations for quality analysis include time to collect data, to send data to the laboratory analysis, etc.
Reference	Adapted from the most common used indicators in the sector

Table 38: Rate of time for quality analysis

EC-EF-3	Rate of on-time fulfilled orders
Domain	Economic
Category	Efficiency
Description	It indicates the percentage of orders shipped within the expected deadline
Metrics	(number of on-time fulfilled orders / number of orders received) * 100
Unit of measurement	%
Notes	n.a.
Reference	Adapted from the most common used indicators in the sector

Table 39: Rate of on-time fulfilled orders

EC-EF-4	Number of wrong orders
Domain	Economic
Category	Efficiency
Description	It indicates the number of wrong orders in a certain time span. The most frequent errors when preparing shipments made by trucks are: 1. Picking incorrect products, i.e.: others than indicated in the order. 2. Picking correct products in wrong quantities, i.e., orders are delivered in greater or lesser quantities than ordered.3. Picking correct products and quantities but with defective quality, i.e., products that do not meet the corresponding quality requirements.
Metrics	Number of wrong orders
Unit of measurement	number
Notes	n.a.
Reference	Adapted from Marzialia M., Rossit D.A., Toncovicha A. (2022). Order picking and loading-dock arrival punctuality performance indicators for supply chain management: A case study. Engineering Management in Production and Services, 26-37

Table 40: Number of wrong orders

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EC-FQ-1	Intrinsic product quality
Domain	Economic
Category	Product quality
Description	It measures the intrinsic (physical) attributes of the product. “Quality standards” refers to the set of rules defined to guarantee food quality and to meet the highest nutritional standards respective to the type of product. This is a qualitative/quantitative indicator, relying on specific parameters defined for each product. For example: dimensions and colours of vegetables, fruit, etc. Attributes to be measured will be defined based on the specific product
Metrics	e.g., humidity, protein content, alcohol content, pesticide residues, tenderness, colour etc.
Unit of measurement	Based on the *Metric*
Notes	In the template for DATs impact assessment, from one to three parameters which are considered fundamental by the market to assess the quality of your product (e.g.: dimension, weight, colour, absence of defects, grade of sweetness…) have to be reported, with the corresponding value. Please note the chosen requirements have to be addressed by the use of DATs
Reference	Aramyan, L., Ondersteijn, C. J., Van Kooten, O., & Lansink, A. O. (2006). Performance indicators in agri-food production chains. Frontis, 47-64.

Table 41: Intrinsic product quality

SO-IS-1	Training hours (for the use of DAT)
Domain	Social
Category	Internal social sustainability
Sub-category	Training and education
Description	It measures the average hours of training per year per employee specifically dedicated to the use of DAT. *Training* refers to: • all types of vocational education and training; • paid leave for study purposes offered by the organization to its employees; • training or education provided externally and paid for, in whole or in part, by the organisation; • training on specific topics The training does not include on-site coaching activities by supervisors. Training hours can be also calculated specifically for gender (male or female) and for category of employee.
Metrics	number of training hours for all employees / number of employees
Unit of measurement	hours / employee
Notes	n.a.
Reference	GRI Standards (2016) GRI 404: Training and Education 2016.

Table 42: Intrinsic product quality

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SO-IS-2	Working time
Domain	Social
Category	Internal social sustainability
Sub-category	Labour
Description	It measures the average weekly working time per category of worker
Metrics	Hours worked by each category of worker in a time interval/number of weeks in the time interval
Unit of measurement	hours / week
Notes	Categories of workers include unpaid labour (farm owner, family members) and hired labour. The time interval is defined taking into consideration seasonality of work (in case of non-seasonality it is equal to one year). For some TCs, working time has to be referred to other parameters (e.g., for arable sector, it refers to hectares; for dairy, to kilos of milk; etc. Please see instructions in the template).
Reference	Lebacq, T., Baret, P.V. and Stilmant, D. (2013): Sustainability indicators for livestock farming. A review. Agronomy for Sustainable Development 33, 311-327. https://doi.org/10.1007/s13593-012-0121-x

Table 43: Working time

SO-IS-3	Frequency rate of occupational injuries
Domain	Social
Category	Internal social sustainability
Sub-Category	Working Conditions
Description	It measures the frequency rate of occupational injuries by the reporting entity. It refers to the ratio of the number of new injury cases to the total working hours. It is expressed in terms of cases per hour. The number of new injury cases should be reported separately, as an absolute amount.
Metrics	number of new injury cases / total number of working hours
Unit of measurement	%
Notes	An *occupational injury* refers to any personal injury, disease or death resulting from an occupational accident. An occupational injury is different from an occupational disease, which develops as a result of exposure over a period of time to risk factors linked to the work activity. Diseases are included only in cases where the disease arose as a direct result of an accident. An occupational injury can be fatal or non-fatal (and non-fatal injuries can entail the loss of work days). Total number of lost working hours due to occupational injuries: The relevant data can be collected and compiled by specific occupational injuries records. Alternatively, it could be calculated as the number of days lost due to occupational injuries multiplied by the number of regulated working hours per day.
Reference	FAO (2014)

Table 44: Frequency rate of occupational injuries

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700

SO-IS-4	Incidence of occupational injuries
Domain	Social
Category	Internal social sustainability
Sub-Category	Working Conditions
Description	It measures the incidence of occupational injuries by the reporting entity. Incidence is defined as the ratio between the working hours lost due to occupational injuries and the total working hours. It indicates the consequences and impact of occupational injuries on the labour force, which can indirectly reflect economic losses incurred by the entity.
Metrics	total number of lost working hours due to occupational injuries / total number of working hours
Unit of measurement	%
Notes	An *occupational injury* refers to any personal injury, disease or death resulting from an occupational accident. An occupational injury is different from an occupational disease, which develops as a result of exposure over a period of time to risk factors linked to the work activity. Diseases are included only in cases where the disease arose as a direct result of an accident. An occupational injury can be fatal or non-fatal (and non-fatal injuries can entail the loss of workdays). Total number of lost working hours due to occupational injuries: The relevant data can be collected and compiled by specific occupational injuries records. Alternatively, it could be calculated as the number of days lost due to occupational injuries multiplied by the number of regulated working hours per day.
Reference	FAO (2014)

Table 45: Incidence of occupational injuries

SO-IS-5	Working conditions index
Domain	Social
Category	Internal social sustainability
Sub-Category	Working Conditions
Description	It measures the work intensity by work category by considering three sub-indicators: the quantitative demands in terms of work intensity, the autonomy over the pace of work, and the emotional demands
Metrics	Questionnaire to be filled
Unit of measurement	0 - 1
Notes	Categories of workers include unpaid labour (farm owner, family members) and hired labour.
Reference	Eurofound (2016b). Sixth European Working Conditions Survey – Overview Report. Luxembourg: Publications Office of the European Union. Horodnic, Ioana Alexandra, and Colin C. Williams. "Evaluating the working conditions of the dependent self-employed." International Journal of Entrepreneurial Behavior & Research (2019).

Table 46: Working conditions index

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SO-ES-1	Contribution to local employment
Domain	Social
Category	External social sustainability
Sub-category	Local community
Description	It measures the percentage of local workers on the total number of employees
Metrics	number of new local workers/total new local employees * 100
Unit of measurement	%
Notes	The definition of the distance considered for the 'local' attribute is agreed with the Test Cases depending on the specific features of the area in which the company operates
Reference	Diazabakana, A., Latruffe, L., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., Ryan, M., Uthes, S. (2014). A review of farm level indicators of sustainability with a focus on CAP and FADN.

Table 47: Contribution to local employment

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059700