# D2.2: Assessment Framework and Governance Mechanisms - first updated version

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| **Abstract:** | D2.2 presents the updated version of the Assessment Framework and the Governance Mechanisms for Independent Evaluation. The report describes the methodology used to develop and to update the QuantiFarm Framework to assess the monetary costs and benefit of DATSs and the impact on sustainability on the three pillars of sustainability (economic, environmental, and social). The entire structure of the Framework is presented: areas and categories of impacts, KPIs and calculation methodology. A governance structure was designed both to reflect the interests of farmers, consultants, DATS providers, third-party verifiers and policymakers and to ensure that evaluation results are unbiased and uphold a high level of trust and confidence. Moreover, the application of the Assessment Framework to the 30 Test Cases (TCs) is presented, including the results of the first year of evaluation for all the Cases. |

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| 2 | NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO | TNO | NL |
| 3 | POLITECNICO DI MILANO | POLIMI | IT |
| 4 | NEUROPUBLIC AE PLIROFORIKIS & EPIKOINONION | NP | GR |
| 5 | CONSULAI, CONSULTORIA AGROINDUSTRIAL LDA | CONSULAI | PT |
| 6 | CONFEDERAZIONE GENERALE DELL AGRICOLTURA ITALIANA | CONFAGRICOLTURA | IT |
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| 17 | KATHOLIEKE UNIVERSITEIT LEUVEN | KUL | BE |
| 18 | DELPHY BV | DELPHY | NL |
| 19 | INSTITUT DE L'ELEVAGE | IDELE | FR |
| 20 | AUGMENTA AGRICULTURE TECHNOLOGIES MONOPROSOPI IDIOTIKI KEFALAIOUCHIKI ETAIREIA | AUGMENTA | GR |
| 21 | ASOCIATIA NATIONALA A INDUSTRIILORDE MORARIT SI PANIFICATIE DIN ROMANIA | ANAMOB | RO |
| 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 |
| 26 | AGROMAIS PLUS COMERCIO E SERVICOSAGRICOLAS S.A. | AGROMAIS | PT |
| 27 | KMETIJSKO GOZDARSKA ZBORNICA SLOVENIJE KMETIJSKO GOZDARSKI ZAVOD MURSKA SOBOT | KGZS | SI |
| 28 | TERRA LITTERA DO0 | Terra | RS |
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# Table of Contents


Executive Summary ........ 13

1. Preface ........ 15
   1.1. Project Summary ........ 15
   1.2. Document Scope ........ 15
   1.3. Document Structure ........ 15
2. Introduction ........ 17
   2.1. Context and relevance ........ 17
   2.2. Presentation of TCs and DATSs ........ 20
3. QuantiFarm Assessment Framework: introduction and methodology ........ 24
   3.1. Introduction ........ 24
   3.2. Methodology ........ 26
      3.2.1. Identification of performance measures ........ 27
      3.2.2. Framework design ........ 32
      3.2.3. Application of the Framework ........ 32
4. QuantiFarm Assessment Framework ........ 33
   4.1. Cost-benefit analysis and monetary impact ........ 33
      4.1.1. The assessment of costs ........ 34
      4.1.2. The assessment of benefits ........ 35
      4.1.3. Cost-benefit assessment and monetary impact (short and middle-long term) ........ 40
   4.2. Sustainability impact evaluation ........ 41
      4.2.1. Environmental Domain ........ 42
      4.2.2. Economic Domain ........ 43
      4.2.3. Social Domain ........ 44
   4.3. Assessing the impact of sustainability indicators ........ 46
5. Framework application to the 30 Test Cases ........ 48
   5.1. TC 1 – Arable, Potatoes, SF-DSS, Greece ........ 49
   5.2. TC 2 – Arable, Corn, Precision Irrigation, Portugal ........ 53
   5.3. TC 3 – Arable, Wheat, SF DSS / Agri-environmental Monitoring, Spain ........ 57


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

5.4. TC 4 – Arable, Cotton, VRA, Greece ........ 61

5.5. TC 5 – Arable, Wheat, SF DSS, Turkey ........ 65

5.6. TC 6 – Arable, Wheat, Machinery with VRA / data analytics, The Netherlands ........ 69

5.7. TC 7 – Arable, Potatoes, SF DSS, Poland ........ 73

5.8. TC 8 – Silos Management, Grains, Silo management, Latvia ........ 77

5.9. TC 9 – Arable, Corn for silage and wheat, FMIS/ Financial Modelling, Slovenia ........ 81

5.10. TC 10 – Arable, Wheat, SF DSS, Romania ........ 86

5.11. TC 11 – Fruit, Olives, SF DSS, Greece ........ 90

5.12. TC12 – Fruit, Apple, Drones and soil sensors, Poland ........ 94

5.13. TC 13 – Fruit, Grapevine, SF DSS, Italy ........ 96

5.14. TC 14 – Fruit, Blueberries and strawberries, Precision fertigation/ Variable root pruning, Serbia 100

5.15. TC 15 – Fruit, Olives, SF DSS, Cyprus ........ 106

5.16. TC16 – Fruit, Apple, Drones and soil sensors, The Netherlands ........ 111

5.17. TC 17 – Fruit, Vineyard, FMIS, Romania ........ 115

5.18. TC 18 – Vegetables, Tomatoes, SF DSS, Italy ........ 119

5.19. TC 19 – Vegetables, Tomatoes, Automated greenhouse, The Netherlands ........ 123

5.20. TC 20 – Fruit, Bananas, Precision irrigation, Spain ........ 126

5.21. TC 21 – Vegetables, Tomatoes, Automated greenhouse, Finland ........ 129

5.22. TC 22 – Meat, Poultry, Cleaning robot, United Kingdom ........ 135

5.23. TC 23 – Meat, Cows, Feeding robot/ Heat detector/ Calving detectors, France ........ 139

5.24. TC 24 – Meat, Pigs, Automated monitoring, Belgium ........ 143

5.25. TC 25 – Dairy, Cows, Feeding robot/ Heat detector/ Calving detectors, France ........ 146

5.26. TC 26 – Dairy, Cows, Milking robot, Ireland ........ 150

5.27. TC 27 – Dairy, Cows, Automated monitoring, Germany ........ 154

5.28. TC 28 – Dairy, Cows, Livestock management, Romania ........ 155

5.29. TC 29 – Apiculture, Bees, Automated monitoring, Lithuania ........ 159

5.30. TC 30 – Aquaculture, Oysters, Sensors for quality assessment, Croatia ........ 161

6. Lesson learned from Test Cases analysis ........ 165

7. Governance Framework ........ 169

7.1. Methodology for the Governance Framework ........ 169


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

7.2. Introduction to the Governance Framework ... 171
7.3. Stakeholders, Roles and Definitions ... 171
7.4. Baseline Conditions ... 171
7.5. Producer's Consent ... 172
7.6. TC Leader Declaration ... 172
7.7. Competence of TC Leaders and Verifiers ... 173
7.8. Qualification of TC Verifiers ... 173
7.9. Application of the Assessment Framework ... 173
7.10. DATS Test Case Evaluation ... 175
8. Conclusion and next steps ... 176
Reference list ... 177
Annex 1 – Review of Test Cases ... 182
Annex 2 – KPI and guidelines ... 190
Annex 3 – The social questionnaire ... 210
Annex 4: QuantiFarm – Producer's Consent ... 215
Annex 5: QuantiFarm Test Case Leader Declaration ... 216
Annex 6: Test Case Verifier Declaration ... 217

# List of tables

Table 1: Overview of the Test Cases (TCs), Type of DATSs and Area managed with DATSs ... 21
Table 2: Sustainability Sub-categories ... 30
Table 3: Costs considered in the cost-benefit analysis ... 36
Table 4: Revenues considered in the cost-benefit analysis ... 36
Table 5: The list of costs included in QuantiFarm Assessment Framework ... 39
Table 6: Recommended indicators to assess the impact of DATSs on environmental sustainability ... 43
Table 7: Recommended indicators to assess the impact of DATSs on economic sustainability ... 44
Table 8: Recommended indicators to assess the impact of DATSs on social sustainability ... 44
Table 9: Activities impacted by the DATSs ... 184

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

Table 10: Specific provider of DATSs and impacted activities in the arable, horticultural and horticultural in-door farming sector ... 186

Table 11: Specific provider of DATSs and impacted activities in the livestock and dairy sector ... 188

Table 12: Specific provider of DATSs and impacted activities in the apiculture ... 189

Table 13: Specific provider of DATSs and impacted activities in the aquaculture ... 189

Table 14: Greenhouse gases emissions ... 192

Table 15: Water Consumption, Water Productivity and Dependence on Water ... 193

Table 16: Total Soil Nitrogen, Available Soil Phosphorus and Available Soil Potassium ... 195

Table 17: Fuel oil/diesel/propane consumption, Gas consumption and Electricity consumption ... 195

Table 18: Share of renewable energy ... 196

Table 19: Nitrogen applied/Nitrogen use, Phosphorus applied/Phosphorus use, Potassium applied and Nutrient use efficiency ... 197

Table 20: Herbicides use, Insecticides use and Fungicides use ... 198

Table 21: Amount of waste generated ... 199

Table 22: Ease of movements and Total indoor area ... 200

Table 23: Mortality rate, Mortality rate at birth, Cows with high SCC and Quantity of drugs used ... 201

Table 24: Production costs ... 202

Table 25: Sales revenue ... 202

Table 26: Other income ... 203

Table 27: Productivity ... 203

Table 28: Feed Conversion Ratio ... 204

Table 29: Rate of time for quality analysis ... 204

Table 30: Rate of on-time fulfilled orders ... 205

Table 31: Number of wrong orders ... 205

Table 32: Intrinsic product quality ... 206

Table 33: Training hours (for the use of DATS) ... 206

Table 34: Working time ... 207

Table 35: Frequency rate of occupational injuries ... 207

Table 36: Incidence of occupational injuries ... 208

Table 37: Working conditions index ... 208

Table 38: Contribution to local employment ... 209

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

# List of figures

Figure 1: Summary of methodological steps conducted for the assessment framework development. ................ 27

Figure 2: Sustainability categories tree ........................................................................................................ 29

Figure 3: QuantiFarm Assessment Framework Structure ................................................................................ 33

Figure 4: The cost-benefit analysis implemented in QuantiFarm Assessment Framework ................................ 34

Figure 5 – Benefit experienced from the implementation of DATS in potatoes cultivation (TC 1). .................... 50

Figure 6 - Cost-benefit analysis for TC 1 ...................................................................................................... 50

Figure 7 - Sustainability impacts for TC 1 ..................................................................................................... 51

Figure 8 - Benefits experienced from the implementation of DATS in corn cultivation (TC 2) ......................... 54

Figure 9 – Cost–benefit analysis for TC 2 ...................................................................................................... 54

Figure 10 - Sustainability impacts for TC 2 ................................................................................................... 55

Figure 11 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 3) ..................... 58

Figure 12 – Cost-benefit analysis for TC 3 .................................................................................................... 58

Figure 13 - Sustainability impacts for TC 3 ................................................................................................... 59

Figure 14 - Benefits experienced from the implementation of DATS in cotton cultivation (TC 4) .................... 62

Figure 15 - Cost-benefit analysis for TC 4 .................................................................................................... 62

Figure 16 - Sustainability impacts for TC 4 ................................................................................................... 63

Figure 17 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 5) ..................... 66

Figure 18 - Cost-benefit analysis for TC 5 .................................................................................................... 67

Figure 19 - Sustainability impacts for TC 5 ................................................................................................... 67

Figure 20 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 6) ..................... 70

Figure 21 - Cost-benefit analysis for TC 6 .................................................................................................... 71

Figure 22 – Sustainability impacts for TC 6 ................................................................................................... 71

Figure 23 - Benefits experienced from the implementation of DATS in corn cultivation (TC 7) ....................... 74

Figure 24 - Cost-benefit analysis for TC 7 .................................................................................................... 74

Figure 25 - Sustainability impacts for TC 7 ................................................................................................... 75

Figure 26 - Benefits experienced from the implementation of DATS in silos management (TC 8) .................... 78

Figure 27 - Cost-benefit analysis for TC 8 .................................................................................................... 79

Figure 28 - Sustainability impacts for TC 8 ................................................................................................... 79

Figure 29 - Benefits experienced from the implementation of DATS in corn for silage and wheat cultivation (TC 9) ........................................................................................................................................... 82

Figure 30 - Cost-benefit analysis for TC 9 (Corn for silage) ............................................................................ 82

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

Figure 31 - Sustainability impacts for TC 9 (Corn for silage) ... 83

Figure 32 - Cost-benefit analysis for TC 9 (Wheat) ... 83

Figure 33 - Sustainability impacts for TC 9 (Wheat) ... 84

Figure 34 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 10) ... 87

Figure 35 - Cost-benefit analysis for TC 10 ... 88

Figure 36 - Sustainability impacts for TC 10 ... 88

Figure 37 - Benefits experienced from the implementation of DATS in olives cultivation (TC 11) ... 91

Figure 38 - Cost-benefit analysis for TC 11 ... 92

Figure 39- Sustainability impact for TC 11 ... 92

Figure 40 – Benefits experienced from the implementation of DATS in grapevine cultivation (TC 13) ... 97

Figure 41 - Cost-benefit analysis for TC 13 ... 98

Figure 42 - Sustainability impacts for TC 13 ... 98

Figure 43 - Benefits experienced from the implementation of DATS in blueberries and strawberries cultivation (TC 14) ... 101

Figure 44 - Cost-benefit analysis for TC 14 (blueberries) ... 101

Figure 45 - Sustainability impacts for TC 14 (blueberries) ... 102

Figure 46 - Cost-benefit analysis for TC 14 (strawberries) ... 103

Figure 47 - Sustainability impacts for TC 14 (strawberries) ... 104

Figure 48 - Benefits experienced from the implementation of DATS in olives cultivation (TC 15) ... 107

Figure 49 - Cost-benefit analysis for TC 15 ... 108

Figure 50 - Sustainability impacts for TC 15 ... 109

Figure 51 – Benefits experienced from the implementation of DATS in apple cultivation (TC 16) ... 112

Figure 52 – Cost-benefit analysis for TC 16 ... 113

Figure 53 – Sustainability impacts for TC 1 ... 113

Figure 54 - Benefits experienced from the implementation of DATS in vineyard (TC 17) ... 116

Figure 55 - Cost-benefit analysis for TC 17 ... 116

Figure 56 - Sustainability impacts for TC 17 ... 117

Figure 57 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 18) ... 120

Figure 58 - Cost-benefit analysis for TC 18 ... 120

Figure 59 - Sustainability impacts for TC 18 ... 121

Figure 60 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 19) ... 124

Figure 61 - Cost-benefit analysis for TC 19 ... 124

Figure 62 - Sustainability impacts for TC 19 ... 125

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

Figure 63 - Benefits experienced from the implementation of DATS in bananas cultivation (TC 20) .............. 126
Figure 64 - Cost-benefit analysis for TC 20 .......................................................................................... 127
Figure 65 - Sustainability impacts for TC 20.......................................................................................... 128
Figure 66 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 21) ............. 131
Figure 67 - Cost-benefit analysis for TC 21 .......................................................................................... 132
Figure 68 - Sustainability impacts for TC 21.......................................................................................... 133
Figure 69 - Benefits experienced from the implementation of DATS in a poultry farming system (TC 22) ..... 136
Figure 70 - Cost-benefit analysis for TC 22 .......................................................................................... 137
Figure 71 - Sustainability impacts for TC 22.......................................................................................... 137
Figure 72 - Benefits experienced from the implementation of DATS in cattle farm (TC 23) ........................... 140
Figure 73 - Cost-benefit analysis for TC 23 .......................................................................................... 141
Figure 74 - Sustainability impacts for TC 23.......................................................................................... 141
Figure 75 - Benefits experienced from the implementation of DATS in the swine farm (TC 24)...................... 143
Figure 76 - Cost-benefit analysis for TC 24 .......................................................................................... 144
Figure 77 - Sustainability impacts for TC 24.......................................................................................... 144
Figure 78 - Benefits experienced from the implementation of DATS in the dairy farm (TC 25)....................... 147
Figure 79 - Cost-benefit analysis for TC 25 .......................................................................................... 148
Figure 80 - Sustainability impacts for TC 25.......................................................................................... 148
Figure 81 - Benefits experienced from the implementation of DATS in the dairy farm (TC 26)....................... 151
Figure 82 - Cost-benefit analysis for TC 26 .......................................................................................... 152
Figure 83 - Sustainability impacts for TC 26.......................................................................................... 152
Figure 84 - Benefits experienced from the implementation of DATS in the dairy farm (TC 28)....................... 156
Figure 85 - Cost-benefit analysis for TC 28 .......................................................................................... 157
Figure 86 - Sustainability impacts for TC 28.......................................................................................... 157
Figure 87 - Benefits experienced from the implementation of DATS in the aquaculture system (TC 30)......... 162
Figure 88 - Cost-benefit analysis for TC 30 .......................................................................................... 162
Figure 89 - Sustainability impacts for TC 30.......................................................................................... 163
Figure 90 – Main benefits experienced from DATSs implementation (sample: 30 TCs)................................. 166
Figure 91 - Impact of DATSs on working activities (sample: 60 farmers)................................................... 167
Figure 92 - Perception of the difficulty in learning to use DATSs (sample: 52 farmers) .................................. 167
Figure 93 - Impact of DATSs in generational change (sample: 60 farmers) ................................................. 167

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| List of Abbreviations and Acronyms | |
|---|---|
| AI | Artificial Intelligence |
| C | Carbon |
| CAP | Common Agricultural Policy |
| DATS | Digital Agricultural Technology Solutions |
| 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 |
| TBL | Triple Bottom Line |
| TC | Test Case |
| 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 of the costs and benefits of Digital Agricultural Technology Solutions (DATSs), considering the sustainability Triple Bottom Line (TBL). Although the last two decades have seen a proliferation of indicator-based methods to assess various aspects of sustainability 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 – particularly farmers, agronomists, farmers' advisors and technology providers - working under different conditions. Hence, QuantiFarm aims to develop a comprehensive and all-encompassing assessment framework that considers performance according to both the economic-financial perspective (through the cost-benefit analysis) and the three sustainability dimensions (environmental, social and economic).

Within the project, WP2 aims at developing an assessment framework that has the objective to enable the quantitative and qualitative assessment of DATSs when applying in real conditions. In turn, the purpose of this second version of the deliverable *Assessment Framework and Governance Mechanisms (D2.2)*, is to present the updated version of the Assessment Framework and of the Governance Mechanisms that can be adopted by farmers to assess the monetary costs and benefits of DATSs, as well as the sustainability impacts on the Triple Bottom Line. QuantiFarm is developing such framework with 32 partners, building upon 30 Test Cases (TCs) that are committed to the development of the project. The application of the Assessment Framework to real TCs, indeed, and the process of continuous feedback from farmers during the first 18 months of the Project (which will continue during the next months) are fundamental to build an effective framework, able to really capture the impact of DATSs on farms, environment and society.

This second version of the Assessment Framework and Governance Mechanisms considers the significance of monetary and sustainability performance assessment in agri-food supply chains and details the different principles of governance that the assessment should follow (compliance, impartiality, reliability, transparency, credibility, meaningfulness). Compared to the initial version, the Framework has been then revised to better capture the impact of DATSs, particularly on the monetary impacts. While the first version of the Framework was mostly focused on sustainability impacts, following mainly a top-down approach (review of the literature and existing frameworks), the second version is strongly leveraging on a bottom-up approach (including interviews and continuous feedback from TCs). This has allowed us to take into account all the TCs' peculiarities, to gain a deep understating of processes and activities specifically impacted by the DATSs and, finally, to include in the framework the most applicable and relevant KPIs to capture DATSs impacts.

Particularly, the cost-benefit analysis has been better defined, to assess the monetary impact of digital solutions' application on farming. Economic-financial indicators have been added, to understand the impacts in the mid-long term (Net Present Value, Return on Investment, Pay-Back period). Finally, the Framework has been applied and tested on the 30 TCs, after an accurate process of data collection, validation and analysis. The process of application of the Framework after the first round of data collection is returning important results and feedback that will be the base for the forthcoming version of the Assessment Framework.

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

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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 responsibilities and procedures .

The results obtained by the first round of analysis has provided a first idea about the overall impacts of DATSs, but it is necessary to collect more data and information to have a clearer picture. For this reason, the process of data collection from Test Cases, as well as the application of the Framework to these Test Cases, will continue in the next phases of the QuantiFarm project. Feedback and interviews with Test Cases will be conducted, as a fundamental part in the comprehension of DATSs impact. Additionally, a process of “data normalization” will be carried on, to have a more precise view of the impact, thus excluding all the unexpected and external factors (as weather conditions or price fluctuations) that can influence the results.

# 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 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, DATSs providers, certification experts and policy makers as well. In line with QuantiFarm 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 updated versions of the Assessment Framework and of the governance mechanisms that are adopted to assess the impact of DATSs adopted in the TCs. Additionally, results of the application of the Framework to the 30 TCs are presented.

Building upon a literature review of the most widely used assessment frameworks and methodologies to assess the monetary and sustainability impacts of DATSs, as well as on continuous feedback received during the first 18 Project’s months, this document describes the refined version of the QuantiFarm Assessment Framework and illustrates in detail how the Framework has been adapted to reflect the specificity of each TCs and applied. In particular, the monetary impact has been better defined, implementing the methodology of the cost-benefit analysis and the use of mid-long term economic indicators. The document also introduces the methodology that will be followed to present the aggregated results of sustainability indicators (that will be better detailed in the subsequent Deliverables (D2.3 and D2.4 to be completed by M30 and M42, respectively).

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.

## 1.3. Document Structure

The document is comprised of the following chapters:

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

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**Chapter 2** introduces the Assessment Framework and the Governance Mechanisms focusing on the scope of use within and beyond the project. The chapter also presents a brief description of the TCs where the framework will be applied.

**Chapter 3** presents the methodology that has been followed to build the QuantiFarm Assessment Framework.

**Chapter 4** presents the QuantiFarm Assessment Framework, its components, KPIs and methods to calculate the monetary (cost-benefit) and sustainability impacts of DATSs.

**Chapter 5** presents the results of the application of the Assessment Framework to the 30 Test Cases participating to the project.

**Chapter 6** illustrates the "lesson learnt" in these 18 months of projects, as derived from the first round of data collection and Framework application.

**Chapter 7** presents the Governance Framework, focusing on its methodology, roles, functions, responsibilities, and procedures.

**Chapter 8** draws the conclusions and next steps in the development and application of the QuantiFarm Assessment Framework.

**Annex 1** provides an overview of the results obtained from the review of Test Cases, presenting the implemented DATSs and their impact on activities and processes.

**Annex 2** provides guidelines for the calculation of the sustainability indicators.

**Annex 3** contains the form of the Social Indicator Questionnaire.

**Annexes 4, 5, and 6** report the Producer's Consent, the Test Case Leader Declaration and the Verifier Declaration.

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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 & Bruinsma, 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 (United Nations, 2015).

The challenge toward a more sustainable agriculture needs integration and synergies between sectors, technologies and combination of social, economic and environmental issues. It is a process that includes the involvements of technical, governance and financial aspects, hence there is not a single solution but rather multiple pathways (FAO, 2017). Nonetheless, **there is a wide consensus about the relevant role of digital technologies in increasing the sustainability of agriculture**. Starting from the '90s with the concept of Precision Farming, indeed, 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 (AI) 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 DATSs, 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. This process is 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, 2019).

Indeed, the use of DATSs 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 & Guthrie, 2008) – DATSs can have positive impacts on economic, social and environmental sustainability. To mention some examples[1]:

- 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 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: DATSs 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 DATSs can help sustaining products and territories - promoting a sustainable local growth - and to preserve the quality and safety of food.
- Profit: DATSs 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 DATSs, 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 , Lubben, & Luck, 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. In general, farmers struggle in understanding the clear benefits of adopting digital agricultural solutions, not only in terms of those considered more "intangible" (as in the case of the effects on the environment or the society at a broad level) but also, and particularly, for the monetary impacts, namely the reduction of costs and the increase in revenues. To our knowledge, indeed, 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, Ardolino, Bacchetti , Perona, & Renga, 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 DATSs are not always used to their full potential.

To cope with these criticalities and to help farmers assessing the real benefits and potentials of DATSs, QuantiFarm aims to build a framework for the assessment of the impact of DATSs, which is lowered into the specifics of 30 Test Cases. Although the last two decades have seen a proliferation of indicator-

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

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based methods to assess various aspects of sustainability in agri-food chains (Diazabakana, et al., 2014); (Bockstaller, et al., 2009); (Rosnoblet, Girardin, Weinzaepflen, & Bockstaller, 2006), no specific contribution was found in literature on how to quantify the impacts of digital agriculture technologies applied in different agri-food value chains and under geographical conditions. **To fill this gap, QuantiFarm's intention is to develop a framework to assess the monetary costs and benefits and the impacts on sustainability resulting from the use of DATSs, which can be used as practical tool for actors working under different conditions**. The framework has its roots in the TBL approach: it aims to understand the impacts of DATSs along the three dimensions of sustainability, assuming at the same time the perspective of the single farm (particularly for what concern the economic level, understanding the monetary impact in the short and medium-long term), and 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 Leader can be held accountable for the delivery of accurate, consistent, reliable, and verifiable data of the 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 7.1 "Methodology for Governance Framework". The principles have been 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 to be 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 Leaders to deliver better outcomes and to ensure improved measurement and monitoring of data.

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## 2.2. Presentation of TCs and DATSs

The QuantiFarm Assessment Framework is built also considering several TCs in different bio-geographical conditions and different types of farms and farmers, 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 7 agricultural sectors focusing on 20 different crops or animals. All TCs are conducted on commercial farms: for each TC, farms that use a single technology or a combination of DATSs are compared with farms not using DATSs, thus allowing to assess the impacts of DATSs in real production conditions. An overview of TCs of QuantiFarm is presented in Table 1.

| TC Number | Sector | Crop/ Animals | Type of DATSs (DATS provider) | Country | Farm size managed with DATSs |
|---|---|---|---|---|---|
| 1 | Arable | Potatoes | DSS (NEUROPUBLIC) | Greece | 0.85 ha |
| 2 | Arable | Corn | Precision Irrigation system (Agromais); VRT (Agroanalitica) | Portugal | 29.17 ha |
| 3 | Arable | Barley, Wheat | DSS (SATIVUM) | Spain | 30.58 ha |
| 4 | Arable | Cotton | VRT (Augmenta) | Greece | 5.13 ha |
| 5 | Arable | Wheat | DSS (HORTA) | Turkey | 105 ha |
| 6 | Arable | Wheat, Onion and Potato | DSS (Delphy Development + Agrovision) | The Netherlands | 3.5 ha |
| 7 | Arable | Potatoes | DSS (NEUROPUBLIC) | Poland | 98.0 ha |
| 8 | Arable | Wheat, Rapeseed, Rye, Barley | DSS (Agrosmart SIA) | Latvia | 1 silo |
| 9 | Arable | Corn for sillage, Wheat | DSS (KGZS, ITC) | Slovenia | 16.97 ha |
| 10 | Arable | Wheat | DSS (Cropwise) | Romania | 552.67 ha |
| 11 | Horticulture | Olives | DSS (NEUROPUBLIC) | Greece | 8.6 ha |
| 12 | Horticulture | Apples | DSS (Delphy); Digital pest control System (Trapview) | Poland | 1.0 ha |
| 13 | Horticulture | Grapevine | DSS (Horta) | Italy | 1.09 ha |
| 14 | Horticulture-In-door farming | Strawberries and Blueberries | DSS (Avital) | Serbia | 3.45 ha |
| 15 | Horticulture | Olives | DSS (NEUROPUBLIC) | Cyprus | 5.13 ha |
| 16 | Horticulture | Apples | DSS (Delphy); Digital pest control System (Trapview) | The Netherlands | 1.0 ha |
| 17 | Horticulture | Grapevine | DSS (AGRICLOUD) | Romania | 14.0 ha |
| 18 | Horticulture | Tomatoes | DSS (Horta) | Italy | 60.47 ha |
| 19 | Horticulture-In-door farming | Tomatoes | Automated Greenhouses (Delphy) | The Netherlands | 6.0 ha |

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| TC Number | Sector | Crop/ Animals | Type of DATSs (DATS provider) | Country | Farm size managed with DATSs |
|---|---|---|---|---|---|
| 20 | Horticulture | Bananas | Precision Irrigation System (NADIA) | Spain | 2.24 ha |
| 21 | Horticulture-In-door farming | Tomatoes | Automated Greenhouses (Priva + Trutina) | Finland | 1.2 ha |
| 22 | Meat | Poultry | Farm management system (Flox) | UK | 64,000 birds |
| 23 | Meat | Cows | Feeding robot (Lely); Heat detectors (Lely); Calving detectors (Evolution) | France | 302 cows |
| 24 | Meat | Pigs | Farm management system (ISAGRI, Acerva) | Belgium | 682 pigs |
| 25 | Dairy | Cows | Feeding robotics (Lely) + Activity Sensors (Allflex) | France | 207 cows |
| 26 | Dairy | Cows | Milking Robot (DeLaval Dairy Services) | Ireland | 180 cows |
| 27 | Dairy | Cows | Automated monitoring (smaXtec animal care GmbH) | Germany | 250 cows |
| 28 | Dairy | Cows | Milking Robot (BouMatic); Feeding robotics (Dinamica Generale) | Romania | 803 cows |
| 29 | Apiculture | Bees | Automated Monitoring (ART21) | Lithuania | 10 beehives |
| 30 | Aquaculture | Oysters | Sensors for quality assessment (Benco Baltic d.o.o.) | Croatia | 5,000.0 $m^2$ |

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

The following types of DATSs (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 such as water, fertilizers and pesticides uniformly across entire fields but they can take data-supported decisions, using the minimum quantities of resources than the plants require (Bertoglio , Corbo, Renga, & Matteucci, 2021). In QuantiFarm, DSSs represent the most used DATS, 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

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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 & Sedera, 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 (Observatory Smart AgriFood , 2020). In the QuantiFarm project, this DATS - 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, AI 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 DATSs enabled by AI and Internet of Things (IoT) that, with the help of humidity, heat and brightness sensors, detect the conditions inside the greenhouse. Based on data collected, the DATSs regulate heat, brightness and humidity for the crops. 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, Husain, & Hejazi, 2004). Indeed, many TCs use an 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 DATSs 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 DATSs 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.

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- **Milking robots**. With the support of Internet of Things and AI, this DATS 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 , Benter, & Pierce, 2021).

The results of the review for all 30 Test Cases, detailing implemented DATSs and impact presenting their impact on farm processes and outcomes are presented in the Annex 1.

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# 3. QuantiFarm Assessment Framework: introduction and methodology

## 3.1. Introduction

Over time, the application of the principle of sustainability 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).

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, Mathijs, & Vink, 2000), never forgetting the issue of profitability and competitiveness. Indeed, if farming is not able to deliver a stable and rewarding income in the short and long term to farmers, agriculture itself would not be able to supply its products and services to the society (European Commission, 2020). 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 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).

The harmonious combination of these three interconnected domains or dimensions constitutes the backbone of profitable and 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’s needs and objectives (Kirwan, Maye, & Brunori, 2017); (León-Bravo & Caniato, 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, Moretto, & Caniato, 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). 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



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sustainability indicators in the literature, assessments are ineffective when companies do not know how practices should be evaluated and for what reasons (Bourne, Neely, Platts, & Mills, 2002). It becomes even more complex when indicators on the environmental and social spheres cannot be easily translated into economic indicators (León-Bravo & Caniato, 2021); (Tahir & Darton, 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, Maye, & Brunori, 2017) (Brunori , et al., 2016) (D'Eusanio, Serreli, & Zamagni, 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 & Caniato, 2021).

Additionally, 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 & Royle, 1994), while tangible benefit is “one which directly affects the firm’s profitability” (Remenyi & Sutherland, 1993) and that can be evaluated at an actual or approximate value (Webster & Hung, 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 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 effective decision-making (Murphy & Simon, 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.

It is within this scenario - assessment of cost and benefits of DATSs in agriculture considering a triple bottom line approach, taking into consideration tangible and intangible benefits as well as monetary and non-monetary effects - that QuantiFarm Assessment Framework has been developed. **The Framework aims at providing an actionable tool that, building on the adoption of DATSs, could pave the way for farmers and stakeholders in the chain to the assessment journey.** The outcome of the assessment is a multidimensional composite set of indicators, consisting of a monetary quantitative measure, in combination with a set of descriptive indicators on the impact of DATSs to reflect the complexity of the social and environmental aspects. Additionally, the QuantiFarm Assessment Framework needs to take into consideration a highly heterogenous range of cases that allow an overview of the reality of sustainability assessment in agriculture in Europe.

For all these reasons, the Assessment Framework in QuantiFarm has been developed in different steps:

1. Identified the key processes and activities in farming sector, the costs and revenues sources and the sustainability aspects that could be affected by the introduction of DATSs, based on a literature review and interviews with TCs;
2. developed the cost-benefit analysis to quantify the positive or negative monetary value resulting from the use of DATSs. This analysis is complemented with a mid-long term evaluation on the investment, using indicators as the Return on Investment (ROI) and Net Present Value (NPV);

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3. defined a set of appropriate indicators to quantify the possible sustainability impacts based on the TBL concept, i.e., with a focus on economic, social and environmental domains (top-down approach based on the literature review);
4. checked/validated the list of costs and revenues, and of sustainability KPIs, and designed a shortlist of the most relevant for the sector.

The final result is a set of indicators consisting of a monetary index (the “net benefit”, deriving from the cost-benefit analysis) and a set of indicators that can be used to assess the impact on the three dimensions of sustainability: environmental, social and also economic.

**The Assessment Framework development is accompanied by the Governance Framework that provides the detailed guidelines to follow for consistent, transparent, and a replicable sustainability assessment.**

Several work packages have been involved in the Assessment Framework definition and in the follow up with the test cases, in order to gather the relevant information that will allow the best use of DATSs for sustainability. In particular:

- WP1: questionnaire on social impacts has been reviewed together with experts from WP1 to make sure the most relevant areas of impact are tackled. Results of questionnaire will be evaluated together with WP1 / will be sent to WP1 to support in the development of behavioural guidelines.
- WP3: formulas of the Assessment Framework and templates for data collection have been revised together with WP3 that is in charge of implementing the Framework in the QuantiFarm Toolkit. Results of the assessment will be made available through the QuantiFarm Toolkit.
- WP4 has played a pivotal role in the interaction with TCs and in the data gathering process, making sure that all TC leaders are informed in a timely manner about procedures and deadlines and facilitating the collection of information to assess DATSs. This intense collaboration with WP4 will continue throughout the course of the project.
- WP5: evidence on the impacts of DATSs on sustainability gathered through the AF will contribute to the development of Policy Recommendations for Sustainability drafted in WP5.

## 3.2. Methodology

**The overall objective of the QuantiFarm Assessment Framework is to provide a practical tool to guide farmers in the assessment of monetary costs and benefits of DATSs, as well as their impact on sustainability**. In other words, by the application of the Framework a farmer could be able to have a clear view of the net benefits (if existing) of the implementation of a digital solution, the profitability of the investment and the impact on sustainability at the environmental, social and economic level, hence considering the effects not only on the single farms, but also on the environment and the society.

The overall process of Framework design has been guided by two needs. On the one hand, to clearly express in monetary terms the costs and, above all, the benefits of DATSs (net benefit), knowing – from previous studies and research – that the lack of understanding of monetary benefits is one of the main barriers to the adoption of DATSs. On the other hand, the need to include aspects particularly related to the environmental and social dimensions, that cannot be easily expressed in monetary terms, that go beyond the farm dimension and are more in general attributable to the category of “intangible” costs and benefits. To cope with these needs, different quantitative and qualitative methodologies have been

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combined in the phase of Assessment Framework design to allow for a comprehensive assessment of the economic, social and environmental benefits and costs of DATSs.

The development of the Framework has been inspired by the three phases that Bourne et al. (2000) suggest when developing any "performance assessment systems":

1. the identification of performance measures (that led to the identification of a wide set of KPIs; a list of areas, processes and impacts directly affected using DATSs, and a set of KPIs and measures to be included in the cost-benefit analysis);
2. the implementation of the measures (here defined as "Framework Design;
3. the use of performance measures (here "Application of Framework").

A graphic representation of the overall methodology is presented in Figure 1.

**It is important to underline that the QuantiFarm Assessment Framework is a "living" framework**. As it is already changed in some parts during the first year of the project to improve its consistency, reflecting on users' feedback[2], it could slightly change in the next period, according to the feedback and results retrieved, maintaining the main structure based on the two "blocks" of cost-benefit analysis and sustainability impacts.

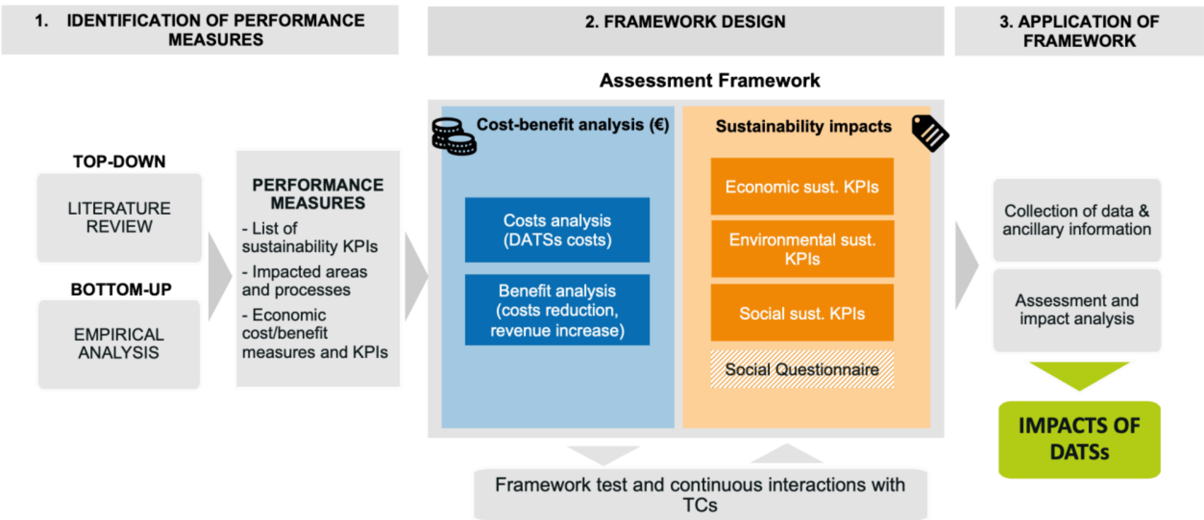


*Figure 1: Summary of methodological steps conducted for the assessment framework development.*

### 3.2.1. Identification of performance measures

The first phase, the identification of performance measures, is a crucial step that has a strong influence on the applicability of the QuantiFarm Assessment Framework. **Two different approaches have been followed to understand the performance measures and KPIs to include in the framework, adopting both a top-down and bottom-up approach.**

[2] Please refer to the chapter "Lesson learned" chapter to know how feedback from Partners and TCs affected the first version of the QuantiFarm Assessment Framework.

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#### 3.2.1.1. Top-down approach

**Through the top-down approach, the main elements of the Framework have been deductively constructed.** A state-of-the-art literature review explored theories, tools, previous frameworks and other insights related to the impact of digital technologies in agriculture, on different dimensions: economic (monetary costs and benefits, productivity, efficiency etc.), environmental and social, together with a review of possible existing frameworks related to the evaluation of monetary costs and benefits.

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 linked to the use of DATSs. 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”)
- DATSs: (“DAT”; “DATS”; “digital technologies”; “digital solutions”; “precision farming”)
- Method: (“quantify”; “quantification”; “impact”; “value”)
- Cost-benefit: (“cost-benefit”; “analysis”; “economic evaluation”, “economic impact”)

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 DATSs as well as the existing methodologies and framework to assess costs and benefits of the use of DATSs.

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, Pinto, & del Hierro, 2014); others compare by scoring on the basis of a set of indicators (Vilain, 2008); (Zahm, Vaux, Vilain, Girardin, & Mouchet, 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, Baret, & Stilmant, 2013), limiting the use of scores, which do not have a dimensional unit (van der Werf & Petit, 2002).

In literature, almost all 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

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referring to the economic domain, most of the calculated indicators are largely related to farm profitability and productivity (Dillon, Hennessy, Hynes, & Commins, 2008).

Based on the categorisations proposed by the sustainable performance frameworks, 13 main categories for environmental, economic, and social sustainability have been identified, as listed in Figure 2.

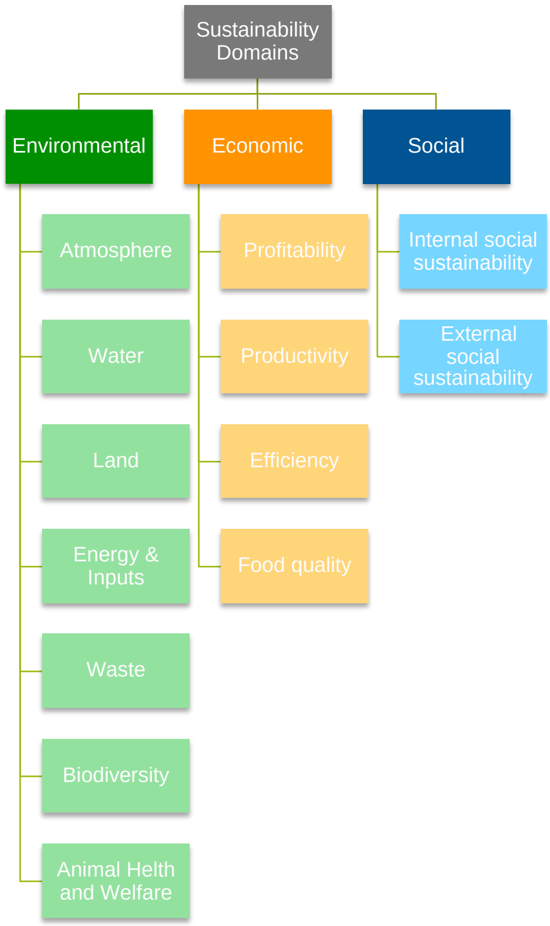


*Figure 2: Sustainability categories tree*

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 2.

| 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 |

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| DOMAIN | DOMAIN ID | CATEGORY | CATEGORY ID | SUB-CATEGORY |
|---|---|---|---|---|
| | | | | Renewable energy |
| | | | | Nutrients use |
| | | | | Pesticides use |
| | | Waste | WS | Generated waste |
| | | 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 2: 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, Benedetinni, & Visnjic, 2011) to understand the impact of DATSs, following the top-down approach. 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 clearly linked to the use of DATSs. For instance, indicators related to child labour and gender equality were omitted from the list as these cannot be associated to the adoption of any technology type in the literature nor in the international standards. Following this skimming process, we analysed a total of 617 indicators - 355 environmental, 81 economic and 181 social – and selected a total of 81 indicators - 49 environmental, 16 economic and 16 social. It is important to underline that, compared with the first version of the Deliverable "Assessment Framework and Governance Mechanism", the list of KPIs has been further refined, basing them on the first year of research, data collection and analysis, always having in mind that the objective of the QuantiFarm Framework is to provide a practical tool to be used by farmers. We therefore decided to use only a subset of all the indicators identified, i.e. to consider only those indicators on which DATSs could have generated clear effects. In fact, many of the indicators we identified through the literature review are also impacted by a number of variables and management factors unrelated to DATS that make it difficult to isolate the effect of DATS. Including these indicators in our analysis would have introduced complexities in interpretation and could have resulted in misunderstandings regarding the indicators output. In particular, the indicators regarding Water Quality, Biodiversity conservation and Land have not been assessed for the following reasons:

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- difficulty of assessing them and understanding variations in the short and medium term, particularly in commercial (and not experimental) farms;
- uncertainty in directly linking changes in KPIs to the use of a DATS, excluding all the external factors. For example, to assess KPIs related to the quality of water, the use of a DATS is partially relevant, since other aspects as the characteristics of the water body, the use of substances from neighbouring farmers, etc. should be known and considered;
- relevance of these KPIs more at a wide scale, rather on the single farm.

Despite this, due to their relevance these indicators have been maintained in the QuantiFarm Assessment Framework for the sake of completeness; in the next phase of data collection and analysis, if feasible, the understanding of the impact of DATSs on these areas could be attempted thought the theories related to the Ecosystem Services.

In other cases, as for the Waste Generated, indicators have not been calculated because we did not see a direct linked with the DATSs, at least at the moment; but they could be calculated, in the next future, if a direct impact is seen.

**In order to give a clear idea of the impact of DATSs from the financial perspective, at the farm level, a fundamental part of the Framework – beside the sustainability impact indicators - is the cost-benefit analysis**. Cost-benefit analysis is a well-known methodological tool to evaluate an investment and to estimate its costs and benefits, with the final objective to determine its opportunity from a business perspective. In cost-benefit analysis, different kind of costs are evaluated for the analysis: direct costs (e.g. labour costs, material costs, etc.), indirect costs (e.g. utilities and rent), intangible and opportunity costs. Similarly, direct revenues are considered, as well as indirect, intangible, competitive revenues (Stobierski, 2023). Authors have applied the methodology also to the investments in digital agricultural solutions, to evaluate the profitability of the investment, resulting – at the end of the evaluation – in indicators as Cost/Benefit Ratio, Net Present Value and Internal Rate of Return (Kiropoulos, Bibi, Vakouftsi, & Pantzios, 2021). Basing on the literature and the results from interviews to test cases, the main economic benefits from the implementation of DATSs are input savings, fuel savings, labour savings, yield increase (Medici M., 2021).

#### 3.2.1.2. Bottom-up approach

The top-down approach has then been necessary to identify the sustainability dimensions, categories and sub-categories of sustainability assessment, as well as the categories of costs and revenues related to the implementation of DATSs to be included in the framework. However, all the analysed frameworks are intended to address the evaluation of the overall sustainability performance of the farms, without a clear and direct connection with digital technologies. Additionally, as pointed out in the literature, one of the main challenges for agri-food companies and farmers 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, Morris, Piccolo, & Koh, 2017). For this reason, **the bottom-up approach was needed to build a framework that could be as close as possible to the needs of European farmers working in different conditions and using different DATSs** and to include in the framework KPIs related to the processes and activities directly impacted by digital solutions. The work made through the literature review in the first steps was then completed and refined through interviews to Test Case Leaders and farmers involved in the project, with a high level of detail for having a clearer overview of the potential areas of impact and the impact of variables as location, crop, seasonality, DATS implemented. Moreover, to gather a further understanding of the cases and each particular need, also data about the farm's motivations for DATSs implementation, expectations for sustainability


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performance impacts, the priorities set when adopting DATSs and assessing sustainability were collected. This type of information becomes a key aspect for the framework development as any performance assessment 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 also included the inputs relevant for the assessment framework design (WP2).

### 3.2.2. Framework design

**The second step of the methodology has been the Framework Design**. **The approach followed previously has then brought to the definition of the Framework in its two main components**:

1. **the cost-benefit analysis (monetary impact)**, based on the methods and indicators typical of the "cost-benefit analysis" theory, to express in monetary terms the costs and benefits of implementing a digital solution, in the short and in medium-long term.
2. **the sustainability evaluation**, including a set of sustainability KPIs to assess the economic, environmental and social impacts of DATSs in agriculture and a questionnaire specifically dedicated to the social impacts (for a better understanding of the impact of digital solutions on physical work, psychological well-being, stress, etc.).

**An important part of the design of the framework has been the collection of feedback from the Test Cases, the Project Partners and from stakeholders in the agricultural sector**. Indeed, the Framework, during the overall process of definition, has been presented in several meetings with partners, ad-hoc calls and workshops. It has been also showed in international conferences and external workshops to gain feedback and inputs directly from farmers and stakeholders in the agri-food chain. Particularly, the QuantiFarm Assessment Framework has been presented in 2 plenary training sessions with Test Cases and Partners, 1 external event (Synergy Days held in Thessaloniki) and 1 workshop of the Smart AgriFood Observatory of Politecnico di Milano with stakeholders (farmers, technology provider, National Farmers' Associations). Additionally, more than 80 calls have been organized with TCs to gain data and feedback and obtain clarifications on data provided.

### 3.2.3. Application of the Framework

**The third step of the methodology involved applying the Framework**. **In essence, the Framework underwent testing, refinement and validation through an iterative approach involving the 30 Test Cases**. In order to gather all the data necessary for KPIs calculation, to test the framework and to start with the first wave of data collection, a detailed data collection form has been designed, with a medium level of customization according to the cases clustered with similar characteristics. This form has been changed in some parts during the first year of the Project, according to the feedback from Test Cases participants and Partners. Additionally, during the process of data collection and analysis, continuous interactions with TCs have been carried out, to collect additional information to better understand the quality of data sent, and to collect all the ancillary information that could be useful to evaluate the real impact of DATSs for every specific case. This process analysis has finally brought to the first results on the DATSs impacts (presented in chapter 5).

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# 4. QuantiFarm Assessment Framework

**The QuantiFarm Assessment Framework is composed by two parts**:

- **The cost-benefit analysis**, resulting in a monetary value expressing the net benefit of implementing a DATS;
- **The set of sustainability indicators**, to capture the economic, environmental and social impacts related to DATS use.

In the following chapter the two parts of the Assessment Framework are explained, with the list of indicators included in each part.

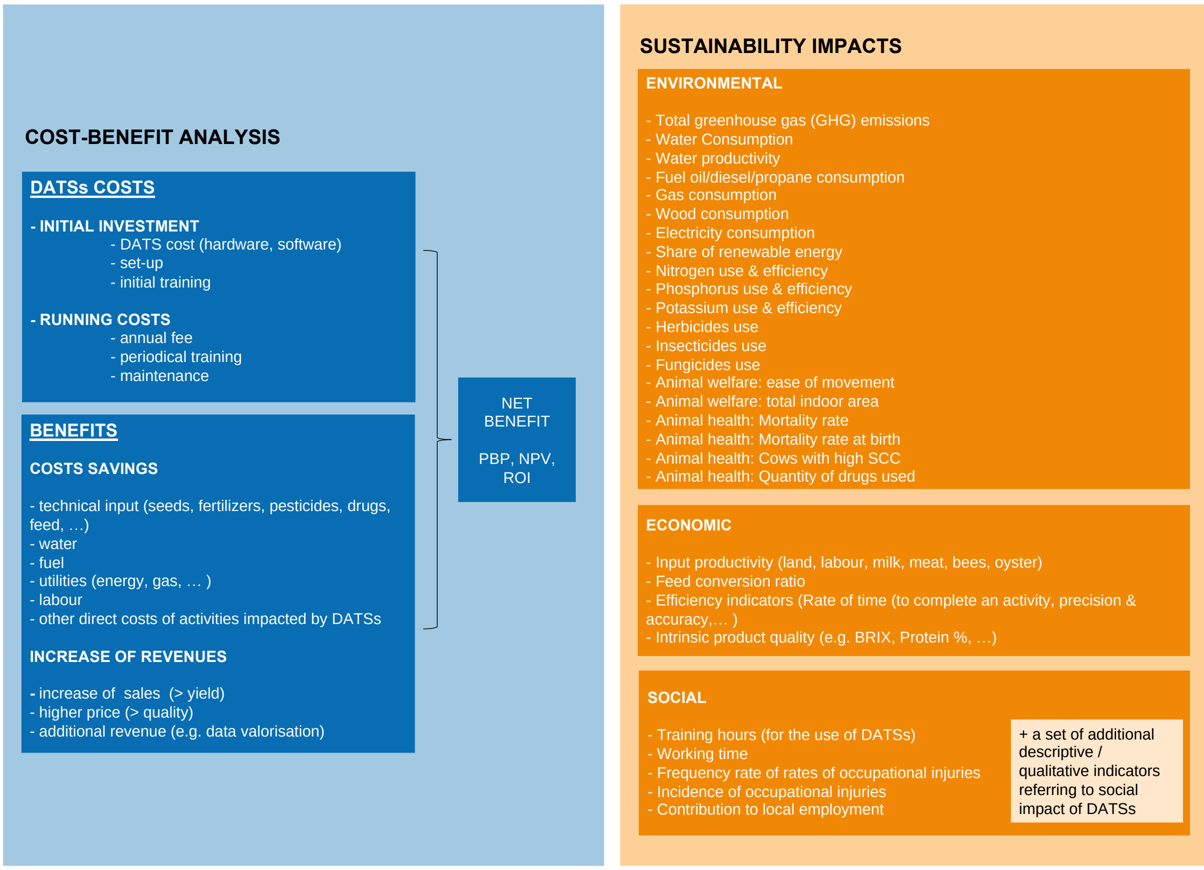


*Figure 3: QuantiFarm Assessment Framework Structure*

## 4.1. Cost-benefit analysis and monetary impact

**The monetary impact is expressed as a measure of the costs and benefits related to the implementation of a DATSs: costs and revenues that can be expressed in monetary value are reported and compared, resulting – at the end of the assessment - in a single monetary value** (net benefit or loss). The methodology for the index is grounded on the methodology of cost-benefit analysis, adapted to the specific purposes of the QuantiFarm project, that is not only to provide an indication of the profitability of the investment, but also to clearly show the activities and processes that are mainly impacted by DATSs application. Additionally, the results of the yearly cost-benefit analysis are used to

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calculate the impacts on the medium-long term, using indicators as Net Present Value (NPV), Return on Investment (ROI) and Pay-back period (PB period). In this cost-benefit analysis only monetary costs and benefits from a financial standpoint at the farm level are considered; whereas costs and benefits not directly quantifiable in monetary values (e.g.: labour conditions, well-being, animal welfare, efficiency, etc.) are included in the "sustainability impacts" of the Framework. A synthetic representation of the cost-benefit analysis implemented in QuantiFarm Assessment Framework is represented in Figure 4.

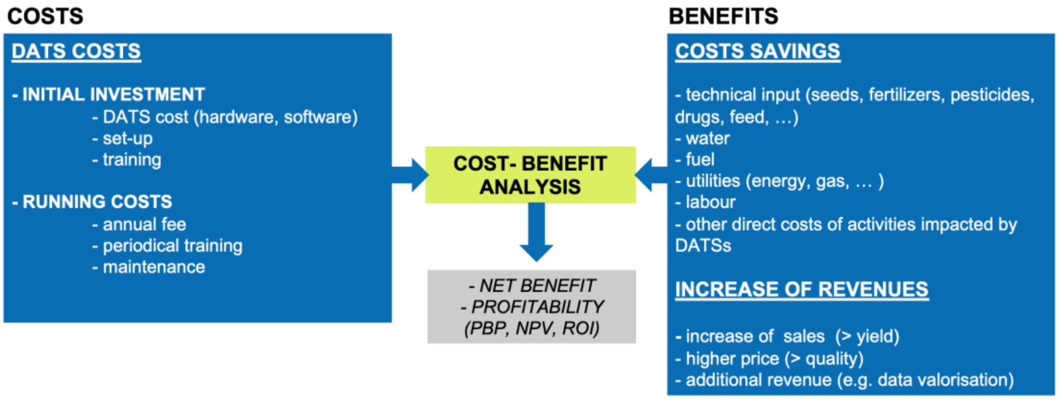


*Figure 4: The cost-benefit analysis implemented in QuantiFarm Assessment Framework*

### 4.1.1. The assessment of costs

Since the Framework aims to analyse the costs and benefits of implementing a DATS, the area of "Costs" in the cost-benefit analysis includes all the costs related to the solution's acquisition[3] and maintenance.

The costs of a DATS are calculated as follows:

- DATS COSTS = INVESTMENT COSTS + RUNNING COSTS (or current expenditures or operational costs) [1]

**Investments costs are related to the first time the farmers are purchasing a solution;** they are mainly related to the initial investment in hardware and software components, set-up costs, and initial training.

- INVESTMENT COSTS = Cost of hardware + cost of software [2]
  - Hardware cost: it is calculated as the sum of the costs of the "physical" part of the DATS. It can include, for example, the cost for sensors, accessories, weather stations, etc.

[3] In some cases the solution is provided free of charge to farmers by the focal company, for example within a supply chain contract.

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- Software cost: calculated as the number of software licenses multiplied for the price of software. It can be calculated as

$$Cost_{software} = N_{softwareunit} * P_{software} \text{ [€]} \quad [3]$$

- Set-up costs: calculated as the sum of the cost for installation (cost of labour for installing the solution) and the cost of training. It is calculated as:

$$Cost_{set-up} = C_{training} + C_{installation} \text{ [€]} \quad [4]$$

where

$$C_{training} = N_{sessions} * P_{employees} * T_{training} \quad [5]$$

$$C_{installation} = P_{employees} * T_{installation} \quad [6]$$

**Running costs refer to the sum of the costs that farmers incur periodically (yearly) for the use of DATSs**, as for example:

- the cost of IT services (e.g. the host of a platform)
- the annual subscription (service) fee for software (e.g. many FMIS and DSS foresee an annual fee)
- the costs for the DATS maintenance (the sum between the cost of services and of equipment)
- a periodical training, if foreseen.

Hence, running costs are calculated as:

- DATS Running Costs = $\sum_{t=1}^{n} Running\ costs$ [7]

where n is the number of years of DATS use.

### 4.1.2. The assessment of benefits

Monetary benefits, in the model, are due mainly to:

- Reduction of costs
- Increase of revenues

that are gained thanks to the implementation of a DATS. In the model, costs and revenues are calculated for both farmers adopting and non-adopting DATSs, and then compared to obtain the benefit (if existing).

A general overview of costs and revenues included in the analysis is presented in Table 3 and Table 4.

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| COSTS CATEGORY | TYPE OF COST | GENERAL FORMULA |
|---|---|---|
| DIRECT COSTS | Cost of production input (except water): e.g. seeds, fertilizers, pesticides, feed, animal drugs, … | $C = Q_{input} * P_{input}$ |
| | Cost of water (for irrigation, fertirrigation, animal drinking, …) | $C = Q_{input} * P_{input}$ |
| | Cost of fuel | $C = Q_{input} * P_{input}$ |
| | Cost of labour (for in-field activities as fertilization, treatments, pruning, etc.; for field visits; for administrative tasks) | *C = ∑ (numbers of hours for an activity * av. hourly salary)* |
| | Other direct costs (related to agricultural production) | *Depends on the type of cost* |
| INDIRECT COSTS | Cost of utilities (energy, gas, …) | $C = Q_{input} * P_{input}$ |

*Table 3: Costs considered in the cost-benefit analysis*

| REVENUES CATEGORY | TYPE OF REVENUE | GENERAL FORMULA |
|---|---|---|
| DIRECT REVENUES | Revenues from product sales | $R = Q_{product} * P_{input}$ |
| INDIRECT REVENUES | Any additional indirect / competitive revenue from, e.g., data valorisation, increase in the market share thanks to better quality, etc[4]. | *Depends on the type of revenue* |

*Table 4: Revenues considered in the cost-benefit analysis*

#### 4.1.2.1. The assessment of costs

Costs are calculated for the productive inputs, for utilities (as energy and gas) and for labour. Beyond the general Assessment Framework, that is designed to be as general as possible, specific formulas are specified to calculate the costs of inputs for the specific sector and referring to specific activities (e.g. fertilisation, phytosanitary treatments, etc.) at the various stages of farming (soil preparation, growing, harvesting, etc.) when this granularity is possible.

Costs are calculated as following:

- COSTS = DIRECT COSTS + INDIRECT COSTS [8]

[4] These typologies of revenues are considered in the calculation when it is possible to assign them a monetary value.

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**Direct costs are the costs that can be directly allocated to specific farming activities, as fertilization, treatments, feeding, animal cleaning**, etc. In this category also the costs of labour are included. They are calculated as follows:

- DIRECT COSTS = Cost of inputs + Cost of labour [9]

where

- Cost of inputs = $\sum_{i=1}^{n}(\text{Q input} \ast \text{P input})$ [10]
- Cost of labour = $\sum(\text{numbers of hours for an activity} \ast \text{av. hourly salary})$ [11] OR $\sum$ (average number of hours for an activity * n. of employees * av. hourly salary) [12]

"Input" are production inputs (as fertilizers, pesticides, drugs, etc.), water (for irrigation, fertigation, animal feeding, etc.), feed, fuel (for machineries, tractors, etc.) and any material or substance directly used in farming activities that are impacted using a DATS.

**Indirect costs are those not directly allocated to a specific activity of function**. Here, the costs for utilities have been considered (e.g. energy for the functioning of a greenhouse). They are calculated as follows:

- INDIRECT COSTS = $\sum(Q\ input \ast P\ input)$ [13]

The typology of cost included in the Assessment Framework specified for the different sectors and activities of the 30 TCs are reported in Table 5. It is important to underline that costs can be calculated for every activity, but – from empirical evidence during the collection of data - farmers often struggle to provide data with the required level of granularity. For this reason, the costs of input can also be included in the framework as "aggregated costs" (for example: cost and quantity of water used during the production according to bills, not specific for each farming activity). Additionally, every kind of production costs that is somehow impacted by the DATSs could be included in the analysis, following the general formulas.

| INPUT | INDICATOR | SECTOR | ACTIVITY | UoMr | FORMULAS |
|---|---|---|---|---|---|
| Water | Cost of water | Arable, Horticulture, Greenhouses | Irrigation | €/ha | ($m^3$ water used for irrigation * water price) / parcel dimension |
| | | | Fertigation | €/ha | ($m^3$ water used for fertigation * water price) / parcel dimension |
| | | | Pesticide dilution | €/ha | ($m^3$ water used for pesticide dilution * water price) / parcel dimension |
| | | Livestock | Cleaning | €/animal | (l water used for cleaning * water price) / number of animals |
| | | | Drinking | €/animal | (l water used for drinking * water price) / number of animals |
| Fuel | Cost of fuel | Arable, Horticulture | Fertilisation | €/ha | (l fuel used for fertilisation * fuel price) / parcel dimension |
| | | | Treatments application | €/ha | (l fuel used for treatments application * fuel price) / parcel dimension |
| | | | Irrigation | €/ha | (l fuel used for irrigation * fuel price) / parcel dimension |
| | | | Sowing / Planting | €/ha | (l fuel used for sowing/planting * fuel price) / parcel dimension |

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| INPUT | INDICATOR | SECTOR | ACTIVITY | UoMr | FORMULAS |
|---|---|---|---|---|---|
| | | Greenhouses | Temperature and Humidity Control | €/ha | (l fuel used for temperature and humidity control * fuel price) / parcel dimension |
| | | Horticulture, Greenhouses | Pruning | €/ha | (l fuel used for pruning * fuel price) / parcel dimension |
| | | Apiculture | Beehives visits | €/beehive | (l fuel used for beehives visits * fuel price) / number beehives |
| | | Aquaculture | Transporting oysters to the laboratory | €/m$^2$ | (l fuel used for beehives visits * fuel price) / underwater area |
| | | Livestock | Milking | €/animal | (l fuel used for milking * fuel price) / number animals |
| | | Livestock | Feeding | €/animal | (l fuel used for feeding * fuel price) / number animals |
| Electricity | Cost of electricity | Arable, Horticulture, Greenhouses | Temperature and Humidity Control | €/ha | (kWh electricity used for temperature and humidity control * electricity price) / parcel dimension |
| | | | Irrigation | €/ha | (kWh electricity used for irrigation * electricity price) / parcel dimension |
| | | Livestock | Milking | €/animal | (kWh electricity used for milking * electricity price) / number animals |
| | | | Heat detection | €/animal | (kWh electricity used for heat detection * electricity price) / number animals |
| | | | Calving detection | €/animal | (kWh electricity used for calving detection * electricity price) / number animals |
| | | | Feeding | €/animal | (kWh electricity used for feeding * electricity price) / number animals |
| Pesticides, Herbicides, Fungicides, Fertilisers | Cost of input | Arable, Horticulture, Greenhouses | Treatments application, fertilisation, soil preparation | €/ha | (kg $treatment_i$ * number of $treatment_i$ * $treatment_i$ price) / ha |
| Feed, drugs | Cost of input | Livestock | Feeding, animal health management | €/animal | (kg $feed_i$ * $feed_i$ price) / number animals |
| Labour | Cost of labour | Arable, Horticulture, Greenhouses | Irrigation | €/ha | (number of hours for irrigation activities * average salary) / parcel dimension |
| | | | Fertilisation | €/ha | (number of hours for fertilisation activities * average salary) / parcel dimension |
| | | | Treatments application | €/ha | (number of hours for treatments application * average salary) / parcel dimension |
| | | | Sowing/planting | €/ha | (number of hours for sowing/planting * average salary) / parcel dimension |
| | | | Pruning | €/ha | (number of hours for pruning * average salary) / parcel dimension |
| | | | Field visits | €/ha | (number of hours for field visits * average salary) / parcel dimension |
| | | Greenhouses | Greenhouse Management | €/ha | (number of hours for greenhouse management * average salary) / parcel dimension |
| | | All | Assessing final product quality | €/ha €/animal €/beehives €/m$^2$ | (number of hours for assessing final product quality * average salary) / parcel dimension (or animals, …) |

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| INPUT | INDICATOR | SECTOR | ACTIVITY | UoMr | FORMULAS |
|---|---|---|---|---|---|
| | | All | Logistics | €/ha<br>€/animal<br>€/beehives<br>€/m$^2$ | (number of hours for logistics * average salary) / parcel dimension (or animals, …) |
| | | Livestock | Cleaning | €/animal | (number of hours for cleaning activities * average salary) / number of animals |
| | | | Stable visits | €/animal | (number of hours for stable visits * average salary) / number of animals |
| | | | Heat detection | €/animal | (number of hours for heat detection activities * average salary) / number of animals |
| | | | Calving detection | €/animal | (number of hours for calving detection activities * average salary) / number of animals |
| | | | Milking | €/animal | (number of hours for milking activities * average salary) / number of animals |
| | | | Feeding | €/animal | (number of hours for feeding activities * average salary) / number of animals |
| | | All | Administrativ e activities | €/ha<br>€/animal<br>€/beehives<br>€/m$^2$ | (number of hours for administrative activities * average salary) / parcel dimension (or animals, …) |

*Table 5: The list of costs included in QuantiFarm Assessment Framework*

Consequently, for each Test Case, the model calculates:

- the costs of farming operation
- the direct and indirect revenues

for farmers both using and not using DATSs.

#### 4.1.2.2. The assessment of revenues

Revenues directly deriving from the use of DATSs are not always easy to quantify, especially in the short term and if they are linked to aspects such as data valorisation (e.g., for traceability or product valorisation vis-à-vis the final consumer). **Anyway, the most relevant increase in revenues using the digital technologies has been seen in the increase of productivity and increase in quality**. In the first case, the increase of revenues is due to the higher quantity sold; in the second case, farmers often can increase the price of the products due to a higher level of quality.

Direct revenues deriving from sales are calculated as

$$Revenues = Q_{sold\ product} * P_{product} \quad [14]$$

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### 4.1.3. Cost-benefit assessment and monetary impact (short and middle-long term)

The comparison between costs and revenues obtained by farmers using and not using DATSs on the single year is defined as the net benefit:

$$\text{Benefit}_{(t)} = \Delta\ \text{Revenues}_{(t)} + \Delta\ \text{Costs}_{(t)} \qquad [15]$$

where:

t = year considered in the analysis

$$\Delta\ \text{Revenues} = \sum R\ (farm\ with\ DATSs) - \sum R\ (farm\ without\ DATSs) \qquad [16]$$

$$\Delta\ \text{Costs} = \sum C\ (farm\ without\ DATSs) - \sum C\ (farm\ with\ DATSs) \qquad [17]$$

This benefit is then compared to the costs of implementing the DATS.

The yearly evaluations and the results of the cost-benefit analysis pose the basis for the mid-long term economic analysis on the profitability of the investment, adopting indicators that are well-grounded in the literature. Particularly, in QuantiFarm Assessment Framework the following indicators are calculated[5]:

- Payback period (PBP)
- Return on the Investment (ROI)
- Net Present Value (NPV)

The **Payback period**, used to evaluate investment projects, calculates the return per year from the start of the project until the returns are equal to the cost of the investment. In other words, benefits are accumulated year by year until the total is sufficient to offset investment costs. The time taken to achieve this payback is called the payback period. Hence, the PBP indicates how quickly the cost of an investment is recovered (but it does not measure profitability). Here it is calculated as a “simple payback period”, i.e., not considering the time value of money (instead considered in Net Present Value) (Lefley, 1996) (Ruegg R.T., 1990) It is then calculated as the following formula:

$$\text{Payback period} = \frac{Cost\ of Investments}{Annual\ cash\ flow} \qquad [18]$$

where the “annual cash flow” in this specific case is calculated as the net benefit previously calculated.

**ROI** is a ratio (percentage) of the net benefit achieved from the DATS to the total investment made in acquiring and operating it. A positive ROI indicates that the benefits or returns from the DATS exceed its cost, implying that the investment is profitable. Conversely, a negative ROI suggests that the costs outweigh the benefits, signalling a loss on the investment. The ROI is calculated as

[5] In the project, whereas the pay-back period is calculated for Test Cases since the first year of data analysis, ROI and NPV are calculated at least from second year for more consistent analysis.

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$$\text{Return on Investment} = \frac{Net\ income}{Cost\ of\ Investments}\ x\ 100\% \qquad [19]$$

**NPV** is one of the most used methods for assessing an investment. It takes into account all the cashflows, actualizing them at the starting point, so it calculates the current value of a future stream of payments (cash flows) from the investment. To calculate it, it is necessary to estimate the timing and amount of future cash flows, discounted at a certain rate that reflect the cost of capital. The acceptance rule is NPV > 0. It is calculated as:

$$\text{NPV} = \sum_{t=0}^{T} Cash\ Flow(t)/(1+r)^{T} \qquad [20]$$

Where

r = discount rate

t = single year

T = total duration

In the QuantiFarm Assessment Framework, the three indicators are considered to give indications about the profitability of the investment in the long term. It is important to note that in the Framework application in the 30 TCs, the Payback Period is calculated since the first year of the project, whereas ROI and NPV will be calculated further, to have more consistent data on the profitability of the investment.

## 4.2. Sustainability impact evaluation

To avoid the risk of drawing simplistic conclusions when relying only on a single value to capture the complexity of multi-dimensional aspects related to sustainability and the impact of DATSs, **the cost-benefit analysis is supported by a set of sustainability indicators that complete the QuantiFarm Assessment Framework.** Following the Triple Bottom Approach, these indicators consider the impacts of DATSs on the economic, environmental, and social domains.

As pointed out in the methodology, to define the set of indicators a deep review of existing sustainability assessment frameworks for the agricultural sector has been conducted, to identify the most relevant KPIs to be included in the QuantiFarm Framework. This list has then been reviewed according to the bottom-up approach, to identify those KPIs suitable for the purpose of understanding the sustainability impact of digital technologies in agriculture.

In the following sections, the indicators selection is described in detail per sustainability dimension, category and sub-category. Compared to the first version of the Framework, the KPIs that have been effectively implemented in the second version of the Framework are indicated in bold and with a star *.

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### 4.2.1. Environmental Domain

Within the Assessment Framework, the following categories are addressed: Atmosphere, Water, Land, Energy & Input, Waste, Biodiversity and Animal Welfare. List of recommended indicators are reported in Table 6.

| CATEGORY | SUB-CATEGORY | INDICATOR |
|---|---|---|
| ATMOSPHERE | Greenhouse Gases | **Total greenhouse gas (GHG) emissions[6]*** |
| | | 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) |
| WATER | 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 |
| LAND | Soil chemical properties | **Soil Organic Carbon*** |
| | | Total Nitrogen |
| | | Available Phosphorus |
| | | Available Potassium |
| | | Soil salinity |
| | Soil biological properties | Soil respiration rate |
| ENERGY & INPUTS[7] | Energy use | **Fuel oil/diesel/propane consumption*** |
| | | **Gas consumption*** |
| | | **Wood consumption*** |
| | | **Electricity consumption*** |
| | Renewable energy | **Share of renewable energy*** |
| | Nutrients use & efficiency | **Nitrogen use & efficiency*** |
| | | **Phosphorus use & efficiency *** |

[6] Mainly GHG Emissions from fuel have been considered in the TCs evaluation for the first year.

[7] In the inputs category water is not considered.

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| CATEGORY | SUB-CATEGORY | INDICATOR |
|---|---|---|
| | | **Potassium use & efficiency *** |
| | Pesticides use | **Herbicides use*** |
| | | **Insecticides use*** |
| | | **Fungicides use*** |
| WASTE | Generated waste | Amount of waste generated |
| | | Amount of hazardous waste generated |
| | | Amount of waste reused and recycled |
| BIODIVERSITY | 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 |
| ANIMAL HEALTH AND WELFARE | 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 6: Recommended indicators to assess the impact of DATSs on environmental sustainability*

### 4.2.2. Economic Domain

The economic dimension in QuantiFarm Assessment Framework includes the following categories: Profitability, Productivity, Efficiency and Food Quality.

| CATEGORY | INDICATOR |
|---|---|
| PROFITABILITY | Net Farm Income |
| | **Production costs*** |
| | Gross profit margin |
| | Net profit margin |
| | Net value added |
| | **Sales revenue*** |
| | Cash flow |
| PRODUCTIVITY | **Land productivity*** |
| | **Labour productivity*** |
| | **Milk productivity*** |
| | **Meat productivity** |
| | **Bees productivity*** |
| | **Oyster productivity*** |
| | **Feed conversion ratio*** |

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| CATEGORY | INDICATOR |
|---|---|
| EFFICIENCY[8] | **Rate of time (to complete an activity) *** |
| | **Precision & Accuracy*** |
| FOOD QUALITY[9] | **"Intrinsic" product quality*** |

*Table 7: Recommended indicators to assess the impact of DATSs on economic sustainability*

### 4.2.3. Social Domain

Within the QuantiFarm 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 DATSs. A subset of recommended indicators is presented in Table 22:

| CATEGORY | SUB-CATEGORY | INDICATOR |
|---|---|---|
| INTERNAL SOCIAL SUSTAINABILITY | Education | **Training hours (for the use of DATSs) *** |
| | | **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) |
| EXTERNAL SOCIAL SUSTAINABILITY | Local community | Contribution to rural economy |
| | | **Contribution to local employment*** |
| | Involvement and participation | Farmers social involvement |
| | | Meetings with stakeholders |
| | Transparency and visibility | Information on labels |
| | | Sustainability certifications and labels |

*Table 8: Recommended indicators to assess the impact of DATSs on social sustainability*

[8] In the context of QuantiFarm, efficiency refers particularity in the ability of DATSs to gain better performances in certain kind of activities (e.g.: reducing errors, reducing the time requested to complete a certain activity, etc.).

[9] 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.

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#### 4.2.3.1. The Social Questionnaire

Despite the thorough review of sustainability impact frameworks conducted for the design of the Assessment Framework, it emerged that the indicators of social sustainability traditionally considered by the literature and already incorporated in the Framework were not completely suitable to clearly explain the impact of DATSs on this sustainability dimension. Additionally, while numerous questionnaires exist in the literature that focus on assessing working conditions in companies, there is a notable scarcity of questionnaires tailored to the primary sector. This idea was confirmed by the interactions with the Test Cases during the development of the Framework; hence, a "Social Questionnaire" has been developed to conduct a more precise and in-depth analysis of the "social" impacts resulting from the adoption of DATSs, as well as to evaluate their qualitative effects. The QuantiFarm questionnaire has been designed not to provide an exhaustive or comprehensive analysis but rather to collect valuable information that can supplement the Assessment Framework.

It is important to consider that while social indicators included in the Framework are assessed for both for DATSs users and non-users, the Questionnaire is addressing mostly the adopters to gain a better understanding of the impact that DATSs can have on social aspects.

The review of the literature has brought to identify four categories of impact:

1. Work-life balance
2. Work-related stress
3. Gender-gap
4. Attractiveness of the agricultural sector for young people

These four dimensions have been included in the questionnaire, with the primary objective to complement the analysis of social impacts of DATSs conducted through the Assessment Framework with descriptive indicators.

- **Work-life balance**. It is important to recognize that work-life balance does not imply an equal distribution of time between work and personal life, but rather entails the ability to effectively manage and harmonize these two domains, ultimately enhancing both the quality of life and work outcomes. When successfully achieved, work-life balance can generate positive spill-over effects, benefiting not only the individuals directly involved but also all other stakeholders. In this regard, the adoption of DATSs has shown promise in facilitating this delicate equilibrium by enabling more efficient task completion and promoting conscious utilization of data (Wolor, 2020); (Esguerra, 2020).
- **Work-related stress**. Work-related stress refers to the physiological, psychological, and behavioural responses that individuals may experience when the demands of their job exceed their ability to cope effectively (Michie, 2002). Nevertheless, the impact of Digital Agricultural Technologies on work-related stress remains uncertain. On one hand, DATSs have the potential to reduce farmers' workload, thereby providing them with more relaxed working schedules. On the other hand, the adoption of new technologies may introduce additional stress and intensify work demands as individuals strive to familiarize themselves with the technology (Smith & Carayon, 1995).
- **Gender gap**. The gender gap in agriculture encompasses the disparities and unequal treatment experienced by men and women within the agricultural sector (OECD, 2018). This gap is apparent in multiple dimensions of agriculture, such as land ownership and tenure, availability of credit and financial services, control over productive assets, involvement in decision-making

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processes, access to education and training, and representation within agricultural organizations and institutions (Fremstad & Paul, 2020). Various social, cultural, economic, and institutional factors contribute to the perpetuation of the gender gap in agriculture. While several studies have examined the impact of gender on technology adoption in agriculture, there remains a dearth of research exploring the influence of DATSs on the gender gap.

- **Attractiveness of the agricultural sector for young people**. Understanding the perceptions of young individuals regarding agriculture as a viable and appealing career choice is essential for addressing the challenges associated with attracting and retaining young talent. Historically, the agricultural sector has struggled to attract young individuals, largely due to perceived factors such as low prestige, manual labour, and limited opportunities for growth and innovation (Kabadzhova, 2022); (Afere, et al., 2019). The questionnaire aims to investigate whether the integration of DATSs, and the resulting increased entrepreneurial opportunities, make the sector more attractive to young people and the children or relatives of farmers.

Copy of the questionnaire is presented in Annex 3.

## 4.3. Assessing the impact of sustainability indicators

To analyse the impacts that DATS could have on the economic, environmental, and social domains, the set of indicators was used to compare, in the same TC, the parcels with DATS and the parcels not implementing the digital solution. For each indicator *i*, the difference between the corresponding value for the parcel with DATS and the value for the parcel without (Δ) was calculated, as following:

$$\Delta \text{ Indicator}_i = \text{Indicator}_{i\ DATS} - \text{Indicator}_{i\ without\ DATS}$$

Since sustainability assessment involves considering indicators related to heterogeneous dimensions, processes, and impacts, it is crucial to find a way to make them comparable, both within the same TC and possibly even among different TCs. Moreover, these indicators are computed for diverse farms characterized by variations in product types, baseline production levels, management practices, and pedo-climatic conditions. It is essential, therefore, to try to normalise the outputs of these indicators to consider the factors mentioned above. Normalization seeks to convert diverse units of measurement into a unified scale, facilitating comparisons among indicators. Various methods, including ranking normalization, distance to target normalization, z-score, min-max normalization, and proportionate normalization, can be employed to normalize farm indicators for sustainability assessment (OECD, 2008) (Talukder, Hipel, & vanLoon, 2017). Considering the heterogeneity of the analysed TCs, it is more informative to assess the impact of the DATS on farms processes and sustainability in percentage terms, rather than focusing solely on absolute values. This is why we opted to normalise the indicators using the percentage variation from the baseline ($\text{Indicator}_i$ without DATS) with the following formula:

$$\Delta \text{ Indicator}_i (\%) = (\Delta \text{ Indicator}_i / \text{Indicator}_{i \text{ without DATS}}) * 100$$

To provide a homogeneous visualization and reporting of the sustainability impacts of each TCs, Δ $\text{Indicator}_i$ (%) are plotted on spider chart, a practical tool often used in literature to assess and visualize agriculture sustainability indicators (Fleur, et al., 2014). As the values of Δ $\text{Indicator}_i$ (%) does not necessarily fall between 1 and 100% and may include negative percentages and/or exceed 100%, each value has been mapped onto a scale of 1 to 10 for standardization and for a more intuitive graphical interpretation of results:

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$$\Delta\ \text{Indicatori}\ (1-10) = \frac{\Delta\ \text{Indicatori}\ (\%) -\ \text{MIN}\ \Delta\ \text{Indicator}_n\ (\%)}{MAX\ \Delta\ \text{Indicator}_n\ (\%) - MIN\ \Delta\ \text{Indicator}_n\ (\%)} * 9 + 1$$

$$\Delta\ \text{Indicator}\ (1-10) = \frac{\Delta\ \text{Indicator}_i (\%) -\ \text{MIN}\ \Delta\ \text{Indicator}_n\ (\%)}{MAX\ \Delta\ \text{Indicator}_n\ (\%) - MIN\ \Delta\ \text{Indicator}_n\ (\%)} * 9 + 1$$

The values obtained for each Indicator in the 1-10 scale were plotted on the spider chart, where each vertex corresponds to a specific Indicator, and the greater proximity of the value to the vertex means a more positive impact of the DATS in that dimension.

The procedure shown above allows the assessment of impacts within the individual TC in terms of percentage variations.

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# 5. Framework application to the 30 Test Cases

This section presents the results of the QuantiFarm Assessment Framework application on the Test Cases.

It is important to underline that obviously not all the Frameworks' indicators have been used in each TC: this is due to the fact, as specified previously, that the Framework aims to be applied to the largest number of cases in Europe, but of course not all the KPIs are suitable for all the cases. Additionally, as explained in the "Methodology", some indicators have been left outside the analysis of the 30 TCs. In particular, the indicators regarding Water Quality, Biodiversity conservation and Land have not been assessed because not evaluable in the short term, and not easily attributable to the impact of DATSs because depending from external factors (out of control of the single farmer). Due to the relevance of these KPIs more at a wide scale, rather on the single farm, in the next phase of data collection and analysis, if feasible, the understanding of the impact of DATSs on these areas could be attempted thought theories as the one related to the Ecosystem Services.

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## 5.1. TC 1 – Arable, Potatoes, SF-DSS, Greece

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | NEUROPUBLIC |
| TC sector | Arable |
| Crop/ Animal | Potatoes |
| Biogeographical Region | Mediterranean |
| Country | Lasithi, Greece |
| Total number of parcels | 8 (4 with DATS and 4 without DATS) |
| Total size of these parcels | 1,19 ha (with DATS: 0,32 ha, 0,2 ha, 0,22 ha, 0,11ha; without DATS: 0,12 ha, 0,05 ha, 0,1 ha, 0,07 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | gaiasense |
| DATS(s) description | The gaiasense platform functions as a comprehensive smart farming system, integrating multiple dimensions to support farmers, agricultural advisors, and research scientists in their work. It continuously records, analyzes, and interprets atmospheric and soil data at specific points within fields during each pass, providing valuable insights. The gaiasense system operates through telemetric autonomous stations known as gaiatrons. These stations gather data from field-installed sensors, monitoring various environmental factors like temperature, humidity, precipitation, soil moisture, and more. The gaiatron serves as an IoT "Deploy-and-Forget" platform. It employs a range of sensors for ongoing surveillance of agricultural conditions in specific areas. Communication between gaiatron stations and cloud-based computer servers utilizes protocols such as GPRS/3G or UHF. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 60 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefit experienced from the implementation of DATS**

Benefits were identified in relation to:

- irrigation management (reduction in water volume and labour costs for this activity)
- increase in yields

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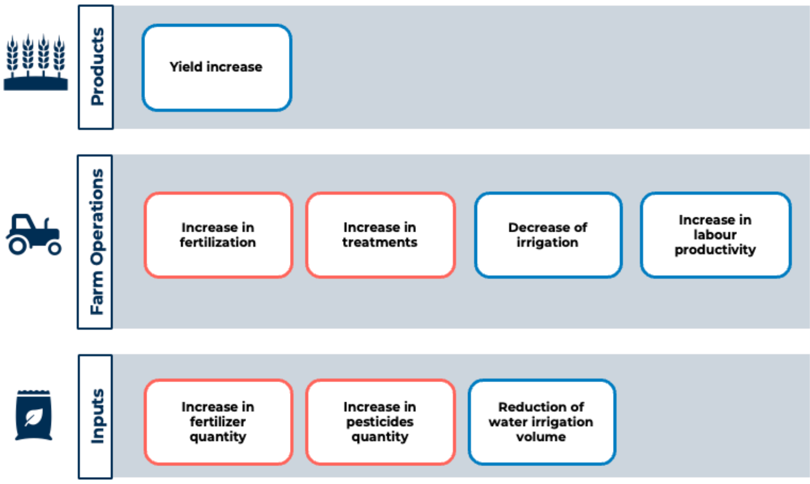


*Figure 5 – Benefit experienced from the implementation of DATS in potatoes cultivation (TC 1).*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

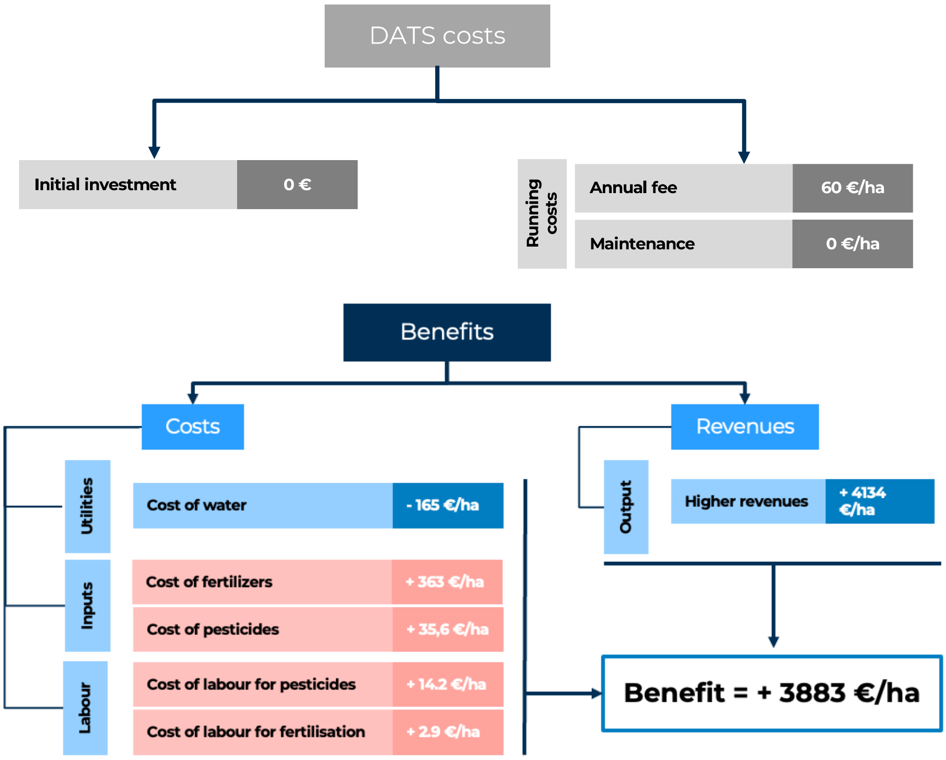


*Figure 6 - Cost-benefit analysis for TC 1*

In Test Case 1, the cost of the digital solution is composed only by an annual fee of €60 per hectare. No costs of initial investments are required, since the solution is provided by NP (technological provider).

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With the implementation of DATS, a benefit of +3883 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **3823 € per hectare** (+ €3883 €/ha – 60€/ha).

Since the farmer made no initial investment, the payback period was not calculated.

**SUSTAINABILITY IMPACT**

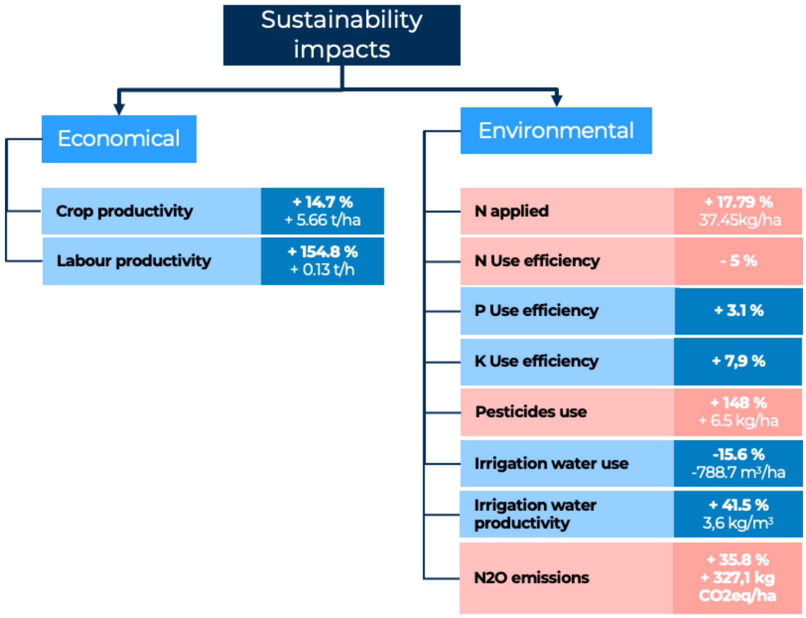


*Figure 7 - Sustainability impacts for TC 1*

**Discussion**

After implementing the DATS, the main benefit is related to yield increase, that has led to a **net benefit of + 3883 €/ha**. Fertilization and treatments activities increased, whereas a reduction in irrigation (hence water volume) has been experienced. Hence, input and labour costs rose overall, but there was a significant decrease in water cost (input and labour). On the revenue side, the selling price of potatoes saw a slight uptick (+ 10€ per ton), coupling with higher yields to boost revenues. Despite increased working hours, the yield growth outpaced the rise in labour hours per hectare, enhancing labour productivity.

This DATS does not entail an initial investment cost, but an annual service fee for having access to the functionalities of the gaiasense platform; so the payback period was not calculated. The benefits considered the yearly fee borne by the farmer.

Regarding the sustainability impacts, there was a moderate enhancement in potassium (K) and phosphorus (P) use efficiency due to a change in the fertilizer practices and increased yields. However, nitrogen (N) use efficiency decreased as more nitrogen fertilizers led to higher $N_2O$ emissions. Irrigation volumes, decreased in line with yield increase, boosted water irrigation productivity.

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From the comparison between farmers adopting and non-adopting DATS (using the Framework), the introduction of the solution had a neutral impact on workers' tasks (as number of hours spent on activities). Nevertheless, based on adopters' answers in the social questionnaire, it seems that the DATS has positively influences the sector's overall attractiveness and intergenerational succession. Additionally, the DSS improved opportunities for acquiring new skills. While acknowledging the time-consuming learning curve, farmers found the process motivating and intellectually stimulating. Notably, the influence of DATS adoption on the gender gap varied among respondents, indicating diverse and multifaceted effects on gender dynamics.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Greece).

The increase in the use of fertilizers and pesticides needs to take into account eventually anomalous climatic conditions, that could have affected the quantity of used products. Further analysis will be conducted in order to isolate the effect of the technology.

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## 5.2. TC 2 – Arable, Corn, Precision Irrigation, Portugal

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Agromais Plus |
| TC sector | Arable |
| Crop / Animal | Corn |
| Biogeographical Region | Continental |
| Country | Quinta da Cholda Azinhaga, Golegã, Portugal |
| Total number of parcels | 4 (2 with DATS and 2 without DATS) |
| Total size of these parcels | 41,17 ha (29,17 ha with DATS and 12 ha without DATS) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Precision Irrigation |
| DATS(s) commercial name | Agromais |
| DATS(s) description | The DATS represents a sophisticated precision irrigation management system that operates within a holistic farm management framework. Sensors gather essential data on individual field water requirements for specific crops, while a data analysis system assesses these needs and generates actionable directives. Additionally, weather stations contribute crucial background data on water availability, which is integrated into the system to regulate irrigation practices. The software consolidates inputs from diverse sensors such as weather, humidity, and leaf moisture index. Initially, refining the data transmission process was imperative, but over time, sensor placement across fields has become more precise, and data interpretation has evolved through experience with the DATS. Moreover, weather stations play a vital role in informing decisions related to chemical applications and monitoring crop cycles. Furthermore, the system assists in pesticide and fertilizer applications by utilizing tracking systems for tractors, among other functionalities. |
| DATS(s) costs | • Initial investment: 31500 €<br>• Set-up: 825 €<br>• Maintenance costs: 97,2 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water. |
| Environmental sustainability | The solution provides support in the implementation of sustainable agronomic practices. |
| Yield increase | Optimizing the use of production inputs helps increase yields. |

**Benefit experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used, although an increase in the use of irrigation water has been observed. A concomitant increase in yields was recorded.

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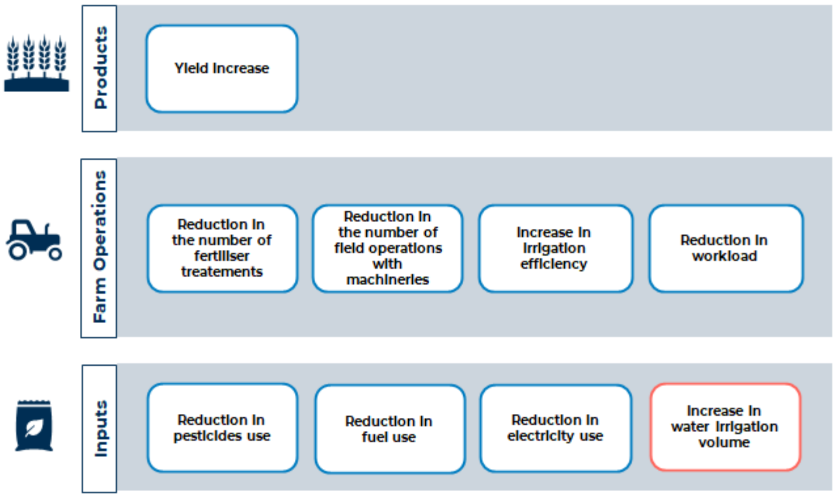


*Figure 8 - Benefits experienced from the implementation of DATS in corn cultivation (TC 2)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below:

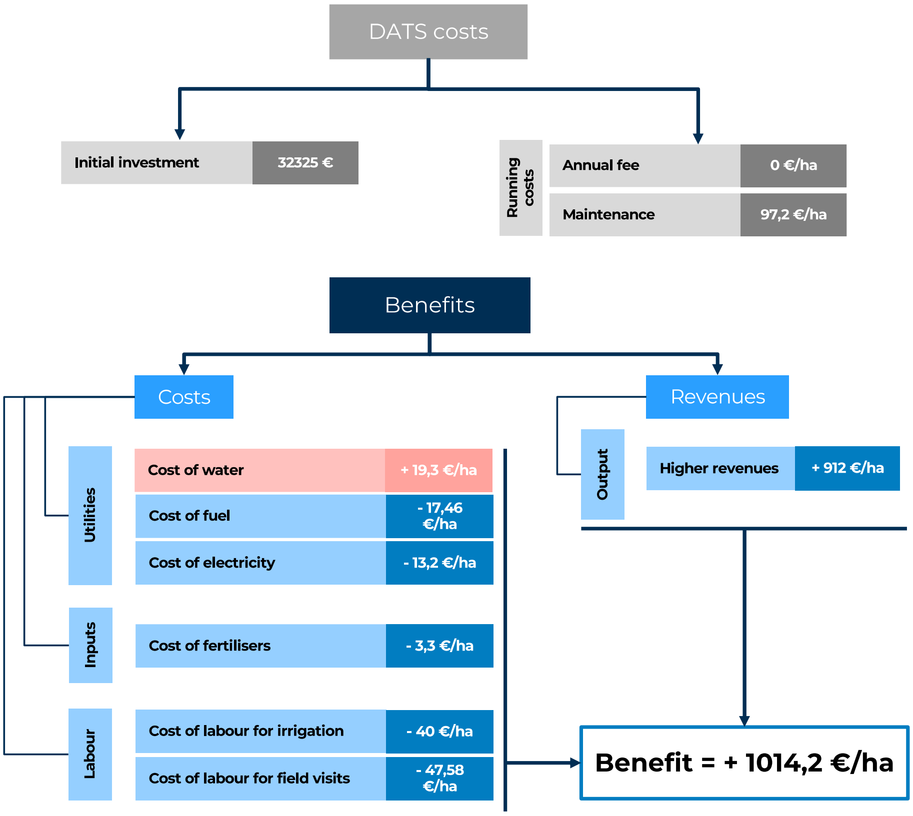


*Figure 9 – Cost–benefit analysis for TC 2*

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In Test Case 2, the cost of the digital solution is composed by an annual maintenance cost of €97,2 per hectare and an initial investment of 32325 € (composed of 31500 € for the purchase of hardware and software and 825 € for the set-up).

With the implementation of DATS, a benefit of +1014,2 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 917 per hectare (**+1014,2 €/ha – 97,2€/ha).

The farmer is expected to payback[10] the initial investment made to acquire the DATS within approximately 14 months (32325/(917*29,17)).

## SUSTAINABILITY IMPACT

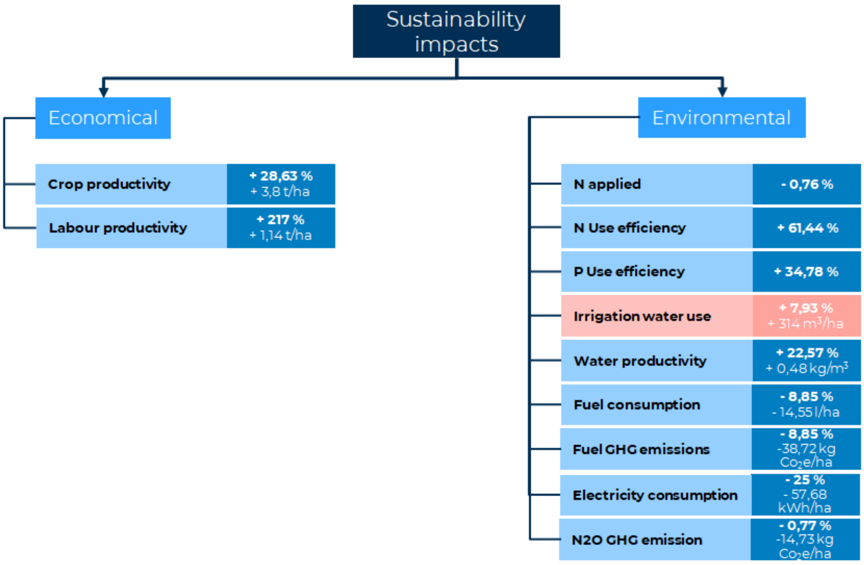


*Figure 10 - Sustainability impacts for TC 2*

### Discussion

Following the implementation of DATS, the farm experienced a **net benefit of + 917 €/ha**, achieved through a combination of reduced costs and increased revenues. The time needed to recover the cost of the investment in DATS (the payback period) is 14 months. Although overall costs decreased, higher water use for irrigation led to increased water cost. Despite unchanged corn sale prices, higher yields resulted in greater overall income. This combination of increased yields and reduced working hours per hectare boosted labour productivity.

Regarding the sustainability impacts, there was a modest reduction in nitrogen (N) use per hectare. This resulted in a slight decrease in $N_2O$ GHG emissions. The precision irrigation system notably enhanced irrigation and fertigation management, improving productivity and water efficiency. Although the DATS has led to an increase in water consumption, it also has significantly boosted production.

[10] Please note that payback period is closely associated with the size of each farm.

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Reduced field visits and optimized irrigation system usage led to decreased electricity and fuel consumption, thus lowering GHG emissions. Considering the results of social questionnaire, implementing DATS notably improved farm operations by addressing unforeseen issues, enhancing task scheduling flexibility, and allowing farmers to allocate time to other tasks. However, it did not significantly simplify the complexity of work. Moreover, the adoption of DATS generated interest among younger generations in farming and agriculture, promising a smooth transition and ensuring the farm's future succession.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Portugal).

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## 5.3. TC 3 – Arable, Wheat, SF DSS / Agri-environmental Monitoring, Spain

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ITACyL |
| TC sector | Arable |
| Crop/Animal | Wheat |
| Biogeographical Region | Mediterranean |
| Country | Spain |
| Total number of parcels | 2 (1 with DATSs and 1 without DATSs) |
| Total size of these parcels | 38,73 ha (with DATS: 30,58 ha; without DATS: 8,15 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | DSS/Agri-environmental Monitoring |
| DATS(s) commercial name | SATIVUM |
| DATS(s) description | SATIVUM sis a Farm Advisory Tool (FAST) for Nutrients aiding farmers and advisors in optimizing fertilizer application to meet crop nutrient requirements. This solution facilitates a structured decision-making process by integrating anticipated yield and nutrient needs with information on soil, manure, and water. Users can make informed choices regarding the most suitable fertilizer type and application rate. The application process can be conducted for groups of parcels with the same crop in a specific area, individual parcels, or designated management areas within a parcel.<br>Beyond recommending the appropriate fertilizer, SATIVUM also provides the required application rate (kg fertilizer/ha). This recommendation is based on a comprehensive assessment that considers factors such as the specific crop's nutrient requirements, soil conditions, past yield of the crop, tillage practices, residues on the terrain, target yield, previous manure applications, and nitrogen supplied. To streamline the fertilization process, the FAST tool preloads all necessary data for fertilizer calculations. This data, sourced from official databases, encompasses essential information relevant to the specific farm. Additionally, SATIVUM offers farmers insights into the phenological evolution of their crops using Sentinel-2 satellite images. It enables parcel zoning based on the Vegetation Vigour Index (NDVI). |
| DATS(s) costs | The tool is a software provided for free to all the Spanish farmers.<br>• Initial investment: 0 €<br>• Set-up: 0 €<br>• Annual fee: 0 €/ha<br>• Maintenance costs: 0 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of agrochemicals. |
| Yield increase | Optimizing the use of production inputs helps increase yields. |

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**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used.

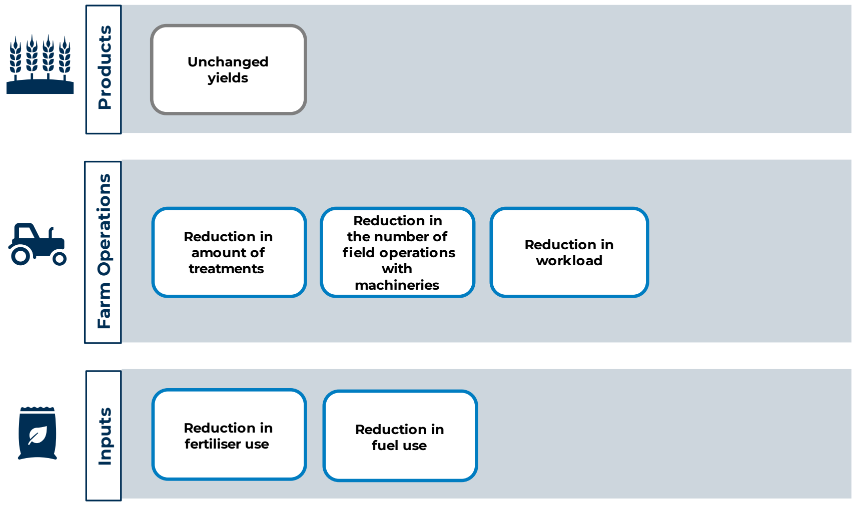


*Figure 11 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 3)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below. There are no costs for this software, since it is provided for free to all Spanish farmers simply registering on the web-site.

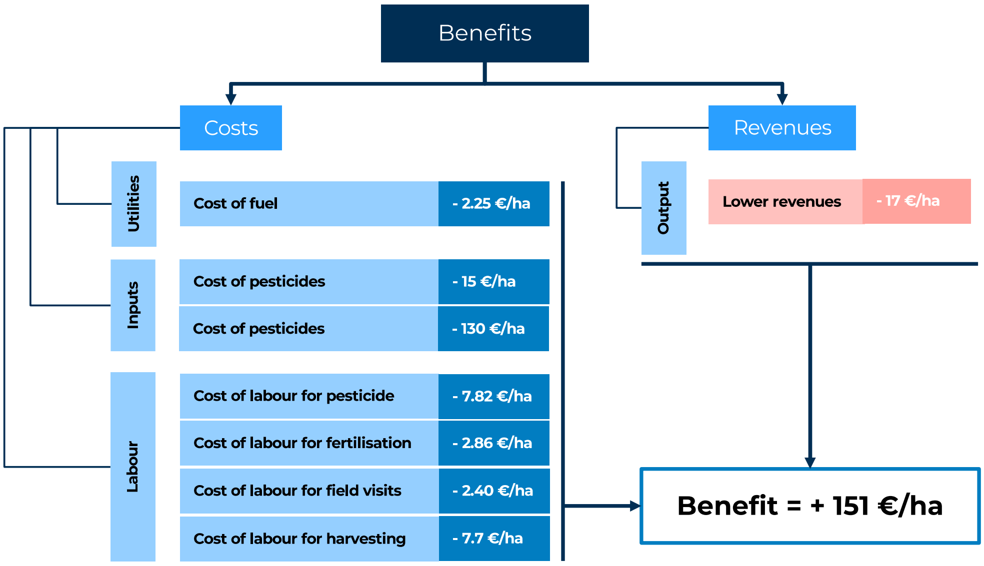


*Figure 12 – Cost-benefit analysis for TC 3*

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

SATIVUM is a free public tool for farmers, which is why the initial investment, maintenance costs and annual fees are zero. With the implementation of DATS, a **benefit of +151 €/ha** was recorded.

Since the farmer made no initial investment, the payback period was not calculated.

## SUSTAINABILITY IMPACT

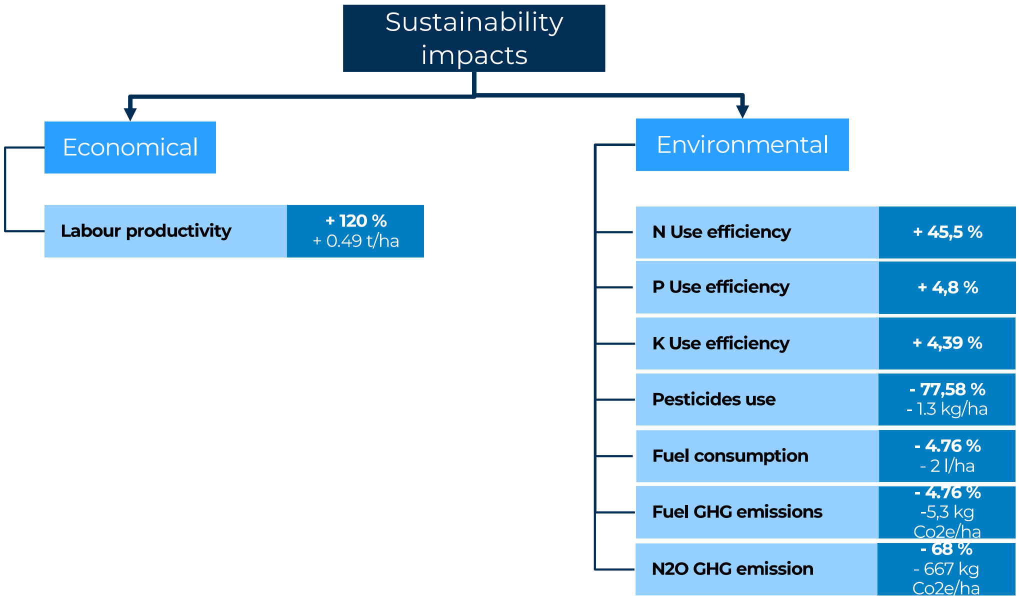


*Figure 13 - Sustainability impacts for TC 3*

### Discussion

Following the implementation of DATS, the farm has seen a **net benefit of +151 €/ha**, achieved through a reduction in utility, input, and labour costs. Despite an overall decrease in revenue attributed solely to a variance in the selling price of wheat (unrelated to DATS), the decline in revenue is specifically tied to a difference in the selling price of wheat, as the yield has remained unchanged. This variation cannot be ascribed to DATS but rather to a disparity in the bargaining power of farmers, as the yield has remained constant. The benefits have primarily increased due to an overall reduction in costs resulting from more efficient agricultural management. Even though yields remained constant, the reduction in working hours per hectare has enhanced labour productivity.

In terms of sustainability impacts, the reduction in the number of treatments has led to a decrease in nitrogen (N) usage per hectare, leading to a slight reduction in nitrous oxide ($N_2O$) emissions—a greenhouse gas derived from nitrogen. For other analysed active ingredients (P and K), there has been a decrease in usage along with an increase in their effectiveness. In addition, a reduction in fuel consumption has been recorded, which has contributed to a decrease in greenhouse gas emissions.

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

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Spain).

It's worth noting that this analysis excludes considerations related to barley. This omission is due to adverse weather conditions in the spring of 2023 (specifically, drought), as reported by the same TCs. Consequently, all fertilization plans were modified, deviating from Sativum's recommendations.

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

## 5.4. TC 4 – Arable, Cotton, VRA, Greece

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Augmenta |
| TC sector | Arable |
| Crop/ Animal | Cotton |
| Biogeographical Region | Mediterranean |
| Country | Larissa, Thessaly Greece & Magnesia, Central Greece |
| Total number of parcels | 4 (2 with DATS and 2 without DATS) |
| Total size of these parcels | 10,07 ha (with DATS: 2,85 ha, 2,28 ha; without DATS: 2,95 ha, 1,99 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | VRA |
| DATS(s) commercial name | Augmenta HA VRA |
| DATS(s) description | The DATS utilizes the correlation between OBPC and NDVI values, leveraging its own vegetation index to execute Augmenta Harvest Aid (HA) VRA operations. Using camera-based vision and dynamic algorithms, the Augmenta field analyser generates the AUG-Index, detecting plant aging and the necessity for HA. Through an on-the-go prescription map, it controls sprayers, applying precise amounts of HA Defoliant in real-time with a single pass.<br>Conveniently adaptable, the unobtrusive Augmenta field analyser mounts onto typical tractors or sprayers and interfaces with various machinery protocols via ISOBUS or OEM-specific connections. With integrated GPS and cloud connectivity, it offers real-time monitoring through the Augmenta Tablet and Web Portal for operational insights, financial records, and analytics.<br>Versatile across major crop types, Augmenta field analyser remains adaptable, incorporating new functionalities via software updates rather than hardware modifications. Presently offering Harvest Aid Defoliant and PGR-VRA operations, its capabilities continue to expand, encompassing upcoming features like Green on Brown selective spot spraying, reflecting ongoing development efforts. |
| DATS(s) cost | • Initial investment: 24000€<br>• Maintenance costs: 1,97 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | The smart application of agrochemical reduces waste and input costs. |
| Yield increase | Optimising the use of production inputs helps increase yields. |

**Benefits experienced from the implementation of DATS**

Augmenta field analyses plays a pivotal role in optimizing crop management, especially considering the vulnerability of cotton to changing weather patterns, leading to a restricted harvest period.

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

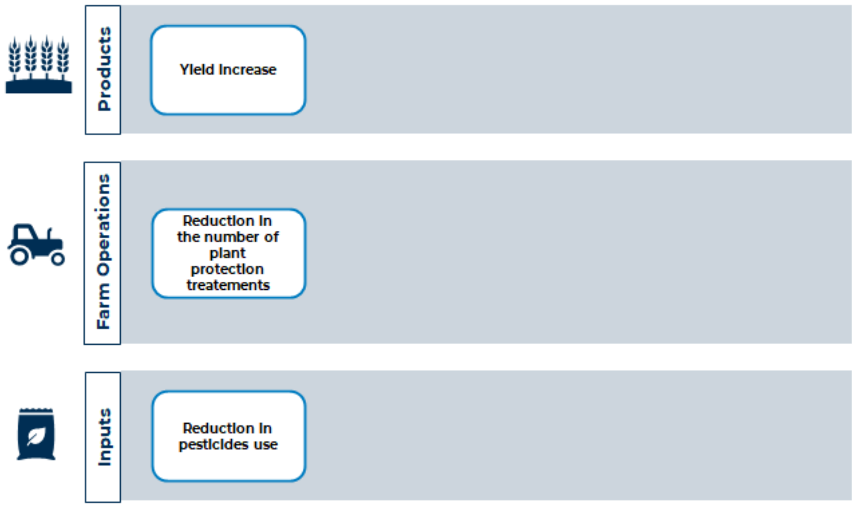


*Figure 14 - Benefits experienced from the implementation of DATS in cotton cultivation (TC 4)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

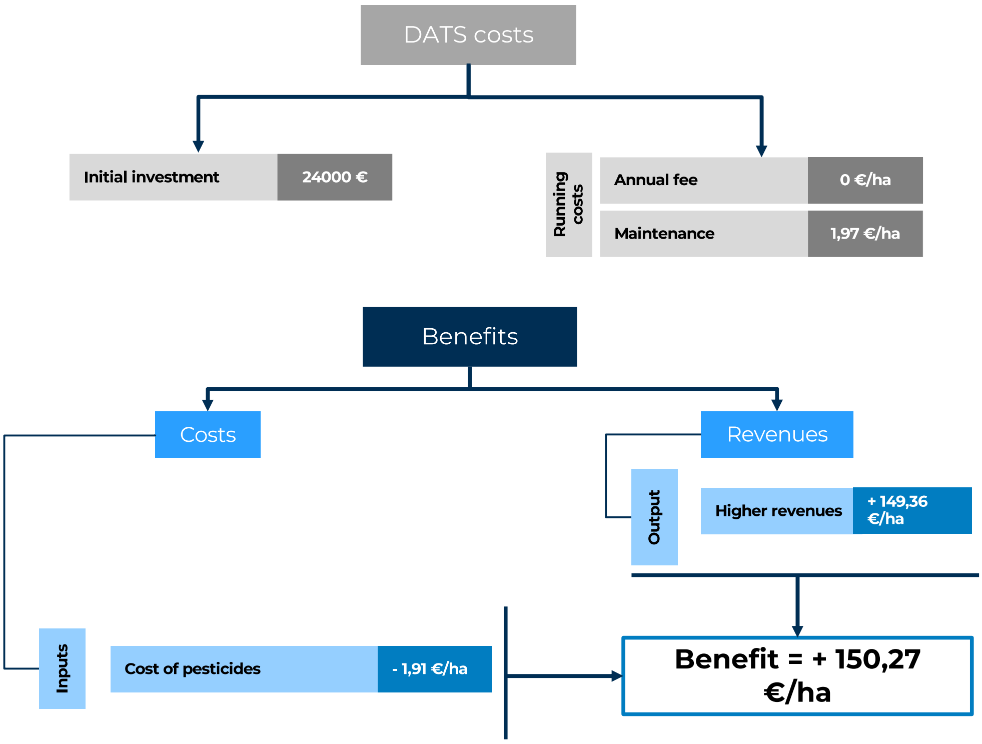


*Figure 15 - Cost-benefit analysis for TC 4*

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

In Test Case 4, the cost of the digital solution is composed by an initial investment of 24000 € for the purchase of hardware and software and an annual maintenance cost of €1,97 per hectare.

With the implementation of DATS, a benefit of +150,27 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 148,3 per hectare** (+150,27 €/ha – 1,97 €/ha).

Due to the extreme weather conditions (floods) that affected the TCs and the reduced data provided, the calculation of the payback period was not carried out because it would lead to incorrect conclusions.

## SUSTAINABILITY IMPACT

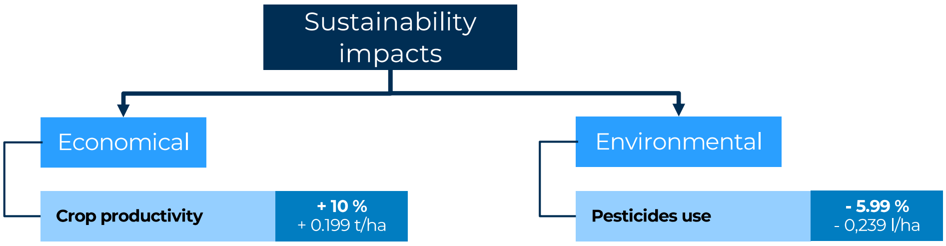


*Figure 16 - Sustainability impacts for TC 4*

### Discussion

In this case, the implementation of DATS has led to a more efficient use of pesticides, thus reducing the costs and the burden on the environment. Additionally, higher revenues have neem recorded: this is the factor mainly impacting on the **net benefit of + 148,3 €/ha**. Indeed, despite an unchanged cotton selling price, a boost in yields translated to enhanced final receipts. At the moment, no significant increase in product quality has been recorded, but in the long term, farmers expect that the solution may have an impact on this KPI, favouring an increase in the selling price. The benefits presented for this first year of data collection is relatively small as the test case suffered a flood that compromised data collection and DATS potential. For this reason, the calculation of the payback period has not been conducted as it would lead to incorrect conclusions.

In terms of sustainability impacts, there was a modest improvement in pesticide use efficiency. In fact, the management of plant protection products benefited significantly from the support of the VRA, leading to a reduction in the use of agrochemicals.

Regarding the impact on workers and society, according to the social questionnaire positive social impacts have been noted following the adoption of DATS. Specifically, the VRA significantly improved work operations, enabling the farmer to adeptly address unforeseen challenges, handle intricate tasks, make more deliberate and effective decisions, and manage the impacts of climate change. Moreover, the farmer noticed heightened interest among the younger generation in the agricultural sector and in working on his farm, fostering a positive succession on the farm. Finally, the farmer highlighted that the learning curve for utilizing the solution was not burdensome; rather, it proved to be motivating and engaging.

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

**Data and analysis issues**

The test case suffered a flood that compromised data collection and DATS potential. For this reason, the calculation of the payback period has not been conducted as it would lead to incorrect conclusions.

The cost estimates for the pesticides were carried out using the information coming from the provider:

- Price of Kabuki 2.5EC: https://agrogru.com/products/kabuki-2-5-ec-piraflufen-etil-26-5g-l
- Price Plant Growth Regulators applied PIX 5SL: https://www.agricenter.gr/κατάστημα/ρυθμιστές/pix-5-sl-1lit/

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

## 5.5. TC 5 – Arable, Wheat, SF DSS, Turkey

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | HORTA |
| TC sector | Arable |
| Crop/ Animal | Wheat |
| Biogeographical Region | Anatolian |
| Country | Turkey |
| Total number of parcels | 20 (10 with DATSs and 10 without DATSs) |
| Total size of these parcels | 148,8 ha (with DATS: 7,5 ha, 10 ha, 20 ha, 13 ha, 13 ha, 9,5 ha, 10 ha, 4 ha, 3 ha; without DATS: 1 ha, 1ha, 19 ha, 6,5 ha, 4,1 ha, 3 ha, 6,2 ha, 3 ha, 10 ha, 15 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | granoduro.net® |
| DATS(s) description | The DATS provides support in the implementation of sustainable agronomic practices. It is a web accessible service that integrates in mathematical models and returns clear and effective advice and quick alarms related to the field management. It can provide farmers with advises about sowing, fertilization, alarms about the risk of main diseases, and plant protection products. The DATS is implemented throughout the durum wheat growing season, spanning from sowing to harvest.<br>granoduro.net operates as web-accessible service that integrates different information on the characteristics of each parcel - as weather patterns, soil properties, and crop characteristics like growth rate, phenology, nutritional and water requirements - into mathematical models. These models generate actionable insights and prompt alerts to field management. |
| DATS(s) cost | • Initial investment: 0 €<br>• Annual fee: 4€/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefits expected from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of pesticides used. A concomitant increase in yields was recorded.

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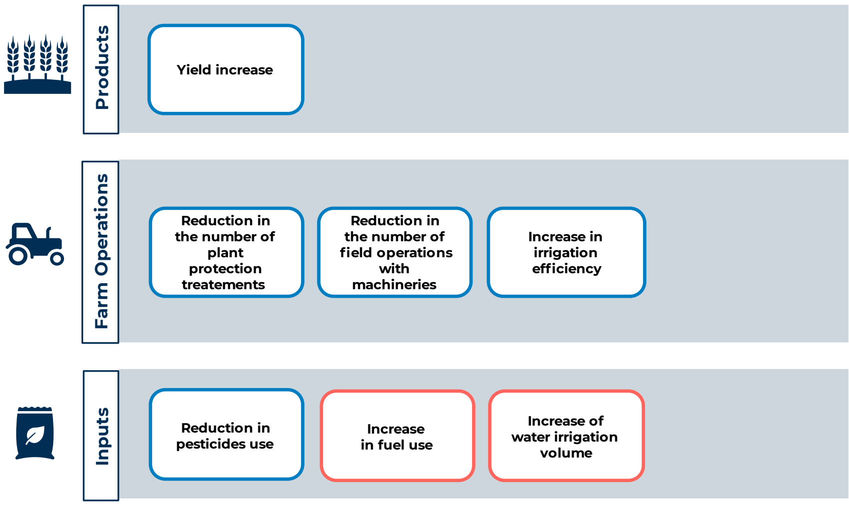
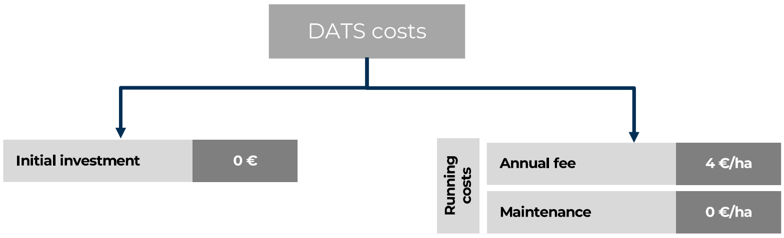



*Figure 17 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 5)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

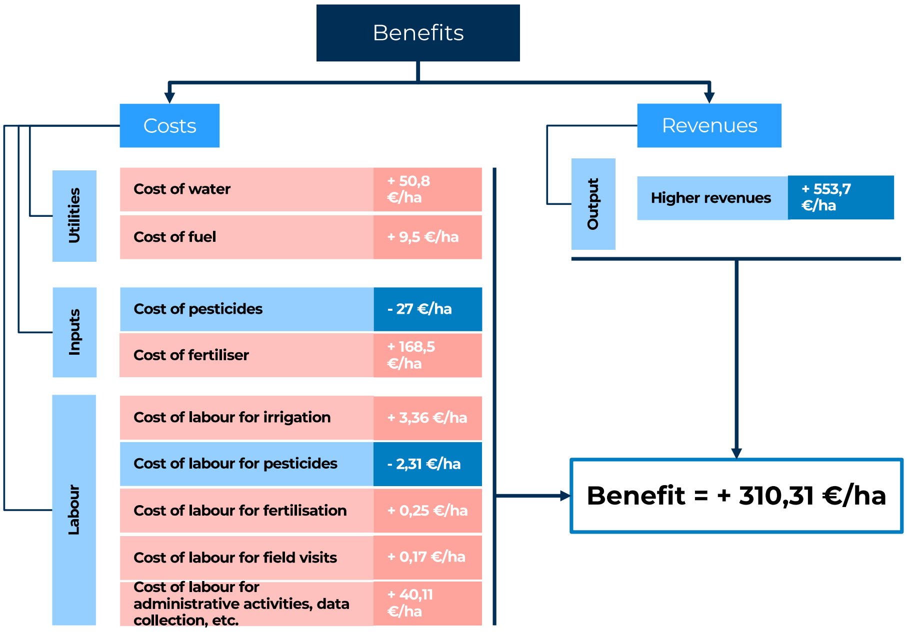



*Figure 18 - Cost-benefit analysis for TC 5*

In this Test Case, the cost of the digital solution is composed only by an annual fee of €4 per hectare. No costs of initial investments are required.

With the implementation of DATS, a benefit of +310,31 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 306,31 per hectare** (+ 310,31 €/ha – 4 €/ha).

Since the farmer made no initial investment, the payback period was not calculated.

**SUSTAINABILITY IMPACT**

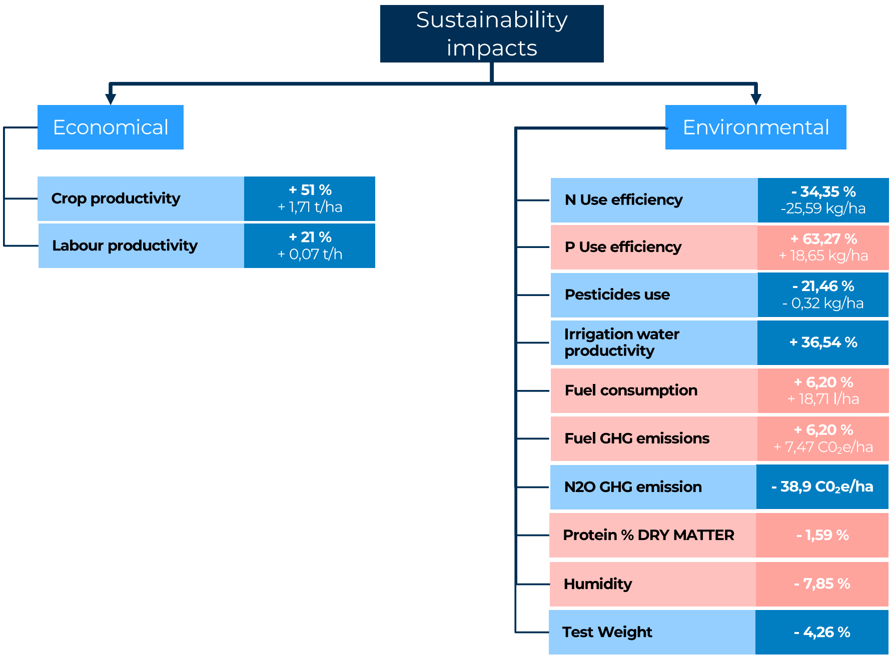



*Figure 19 - Sustainability impacts for TC 5*

**Discussion**

In this specific test case, there is a notable variation in wheat yields not only among different agricultural enterprises but also within individual plots of the same farm. Consequently, attributing fluctuations in productivity and revenue solely to the adopted technology proves exceedingly challenging. Across the ten scrutinized agricultural companies, the mean observed profits are positive, totalling € 306.31 per hectare.

The average indicates that costs have generally increased (except for the cost of pesticides and pesticide labour). As mentioned earlier, on the revenue side, there is no uniform impact among all the analysed farmers, and the costs of selling the grain remain unchanged (due to variations in grain quality). However, it can be said that the increase in yields has translated into higher final receipts. Although, on average, the hours worked per hectare increased, the yields increased more than proportionally, allowing for an increase in labor productivity.

Regarding environmental impact, there was a consistent effect among the parcels, as agronomic management varied between farms. On average, there was a decrease in nitrogen (N) use and a consequent decrease in nitrous oxide ($N_2O$) emissions. Simultaneously, there was an increase in phosphorus (P) use. Pest management and irrigation significantly benefited from Decision Support System (DSS) support, leading to a substantial reduction in the use of agrochemicals (fungicides and pesticides). Similarly, there was a parallel decrease in irrigation volumes, aligning with the increase in yields and contributing to an increase in water irrigation productivity. On average, there was an increase in fuel consumption and a consequent rise in emissions. In terms of product quality, results varied significantly among different parcels, with a noted reduction in protein percentage on dry matter, and humidity, but an increase in test weight.

When comparing farmers who adopted Decision Support Systems (DATS) with those who did not (using the Framework), the introduction of the solution had a neutral impact on workers' tasks, measured by the number of hours spent on activities. However, responses from adopters in the "social questionnaire" indicated positive outcomes. In general, a positive impact was recorded from the implementation of DATS on work activities. While not unanimous, the solution favored the majority of respondents in recording an increase in the ease of performing complex tasks and making decisions more efficiently and consciously. Additionally, the ten farmers stated that the implementation of DATS has fostered the interest of the younger generation to work in their farms or in the agriculture sector, helping to ensure succession on the farm. Regarding learning to use DATS, it did not generate particular stress and was not particularly time-consuming; instead, learning to use the solution was stimulating and interesting for most respondents. Finally, the implementation of the solution has fostered women's interest in working on the farm.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Turkey).

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

## 5.6. TC 6 – Arable, Wheat, Machinery with VRA / data analytics, The Netherlands

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Delphy |
| TC sector | Arable |
| Crop/ Animal | Wheat |
| Biogeographical Region | Continental |
| Country | Colijnsplaat, The Netherlands |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total size of these parcels | 7 ha (with DATS: 3,5 ha; without DATS: 3,5ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Machinery with VRA, data analytics |
| DATS(s) commercial name | - Soil moisture sensors > Agro exact / sencrop - supplier<br>- Weather poles > Agro exact / sencrop - supplier<br>- GPS > Raven – supplier<br>- Drone flights and elevation maps > Aurea Imaging – supplier<br>- QMS Water > Delphy Development<br>- BOS-system > Agrovision – supplier |
| DATS(s) description | TCs implemented a combination of different DATS:<br>Sensors and Weather Stations. Soil moisture sensors and weather stations collect real-time data about soil conditions and atmospheric factors. They measure soil moisture, temperature, humidity, atmospheric pressure, wind speed, and other relevant metrics.<br>Drone Flights and Elevation Maps. Drones equipped with imaging technology capture aerial data and create elevation maps of the agricultural land. These maps provide detailed information about the topography, soil variability, and potentially stressed areas of the fields.<br>GPS Integration. GPS technology, such as the Raven system, provides accurate positioning and navigation data, aiding in precise location-specific actions and data collection.<br>Variable Rate Application (VRA) Software. Utilizing the data from sensors, weather stations, and drone-generated maps, the VRA software processes this information. It segments the land into management zones based on specific soil properties, crop requirements, and other factors. This segmentation allows for targeted application of materials like fertilizers or pesticides at varying rates across different zones.<br>QMS Water Software. This software integrates data from various sources—humidity sensors, weather stations, and the compiled drone-generated map. It uses this information to determine irrigation needs on a per-plot basis. It calculates moisture deficits or surpluses, considering soil characteristics, crop parameters, and weather forecasts. This data-driven approach helps optimize water usage by providing insights into when and where irrigation is needed.<br>BOS (DSS) System. The DSS system integrates data from various treatments. It likely uses historical and real-time data to recommend optimal treatment plans based on crop conditions, weather forecasts, and other relevant factors.<br>Overall Workflow:<br>- Data from soil sensors and weather stations provide real-time information about soil moisture and atmospheric conditions.<br>- Drone flights generate detailed maps of the field, which are integrated with sensor data and fed into the QMS Water system. |

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

| | |
|---|---|
| | - QMS Water, using this integrated data, calculates precise irrigation needs for different areas of the field.<br>- VRA software then implements these irrigation recommendations, ensuring variable rate application of water and other materials based on the specific requirements of different zones. |
| DATS(s) costs | • Initial investment: 125 €/ha (437,5 €)<br>• Set-up: n.a. €<br>• Maintenance costs: n.a. €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes possible to optimise the use of water. |
| Yield increase | Optimising the use of production inputs helps the increase of yields. |

**Benefits experienced from the implementation of DATS**

While there was an increase in yields and an optimisation of fertiliser use efficiency, there was a decrease in labour productivity and an increase in hours worked.

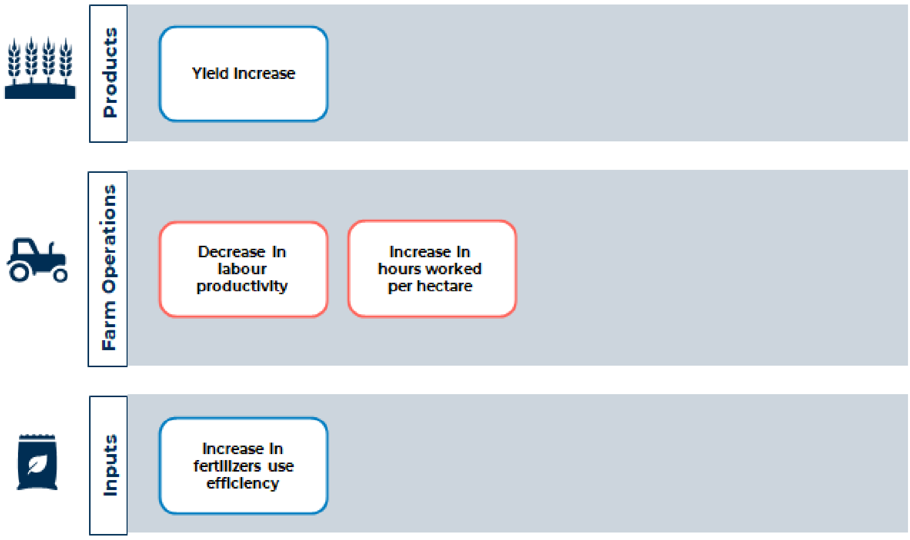



*Figure 20 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 6)*

**COST-BENEFIT ANALYSIS (MONETARY IMPACT)**

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

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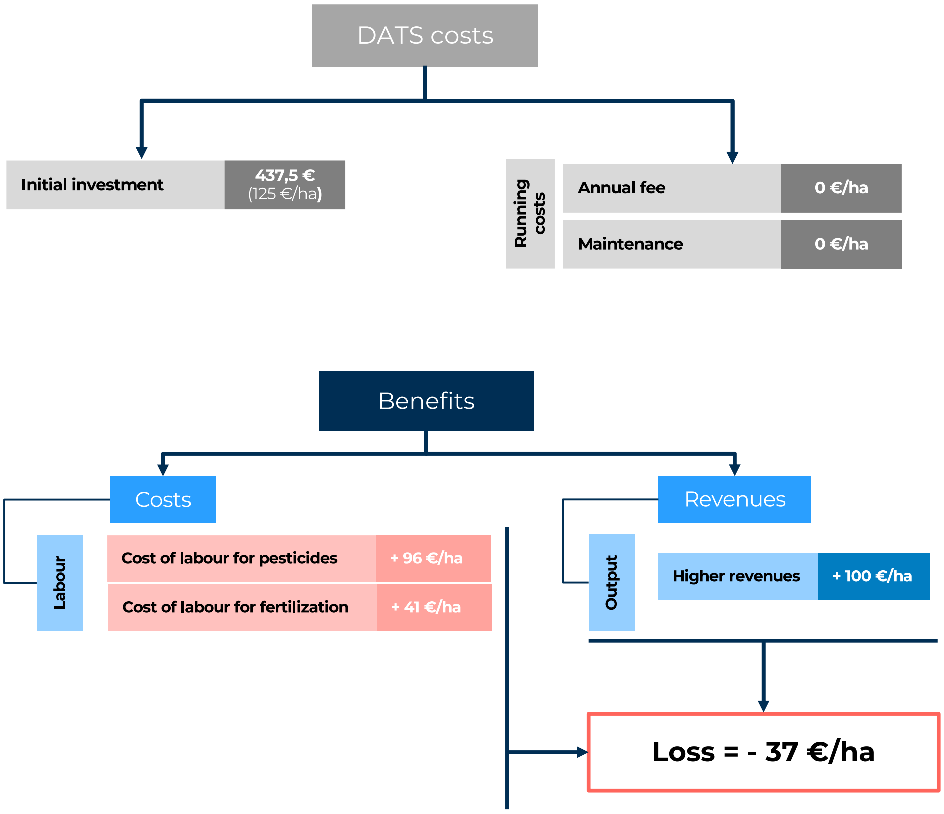


*Figure 21 - Cost-benefit analysis for TC 6*

In Test Case 6, the cost of the digital solution is composed by an initial investment of 437,5 € (125€/ha).

## SUSTAINABILITY IMPACT

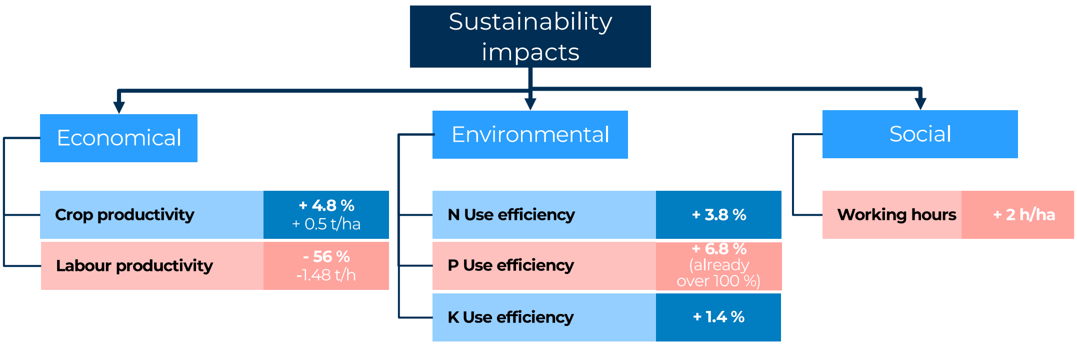


*Figure 22 – Sustainability impacts for TC 6*

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

**Discussion**

After the implementation of DATS, the company recorded a **net loss of - 37 €/ha**. Although the DATS has brought to significant increase in revenues, the negative result is primarily caused by an increase in labour costs (related to treatments) that exceeded the increase in revenues. Despite wheat selling prices remaining unchanged, the increase in yields led to an overall income increase of +100 €/ha. Although there was a recorded yield increase (+4.8%), the hours worked per hectare increased disproportionately, resulting in a reduction in labour productivity and an increase in costs.

Regarding sustainability impacts, DATS has enabled the efficient use of fertilizers (N, P, and K). From the point of view of social sustainability, the solution allowed solving unforeseen problems and making decisions more consciously and efficiently; but learning to use the solution, while not stressful, was complicated and time-consuming.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (The Netherlands).

It is necessary to note that the increase in yields cannot be solely attributed to the adoption of DATS, as it may be influenced by pedoclimatic variables. Therefore, to ensure more robust results, additional data collection periods will be necessary.

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## 5.7. TC 7 – Arable, Potatoes, SF DSS, Poland

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | FFP2 |
| TC sector | Arable |
| Crop / Animal | Potatoes |
| Biogeographical Region | Continental |
| Country | Poland |
| Total number of parcels | 6 (3 with DATS and 3 without DATS) |
| Total size of these parcels | 255 ha (with DATS: 34 ha, 30 ha, 34 ha; without DATS: 16 ha, 96 ha, 45 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | gaiasense |
| DATS(s) description | The gaiasense platform functions as a comprehensive smart farming system, integrating multiple dimensions to support farmers, agricultural advisors, and research scientists in their work. It continuously records, analyzes, and interprets atmospheric and soil data at specific points within fields during each pass, providing valuable insights. The gaiasense system operates through telemetric autonomous stations known as gaiatrons. These stations gather data from field-installed sensors, monitoring various environmental factors like temperature, humidity, precipitation, soil moisture, and more. The gaiatron serves as an IoT "Deploy-and-Forget" platform. It employs a range of sensors for ongoing surveillance of agricultural conditions in specific areas. Communication between gaiatron stations and cloud-based computer servers utilizes protocols such as GPRS/3G or UHF. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 50 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefits experienced from the implementation of DATS**

Although there was a general increase in costs, this was accompanied by an increase in yields, this leading to an increase in the labour productivity and the efficiency of nutrients.

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

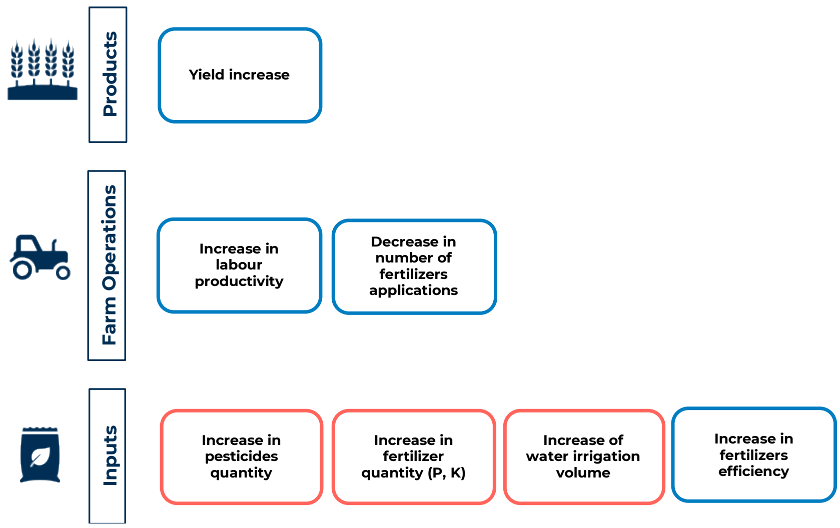


*Figure 23 - Benefits experienced from the implementation of DATS in corn cultivation (TC 7)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

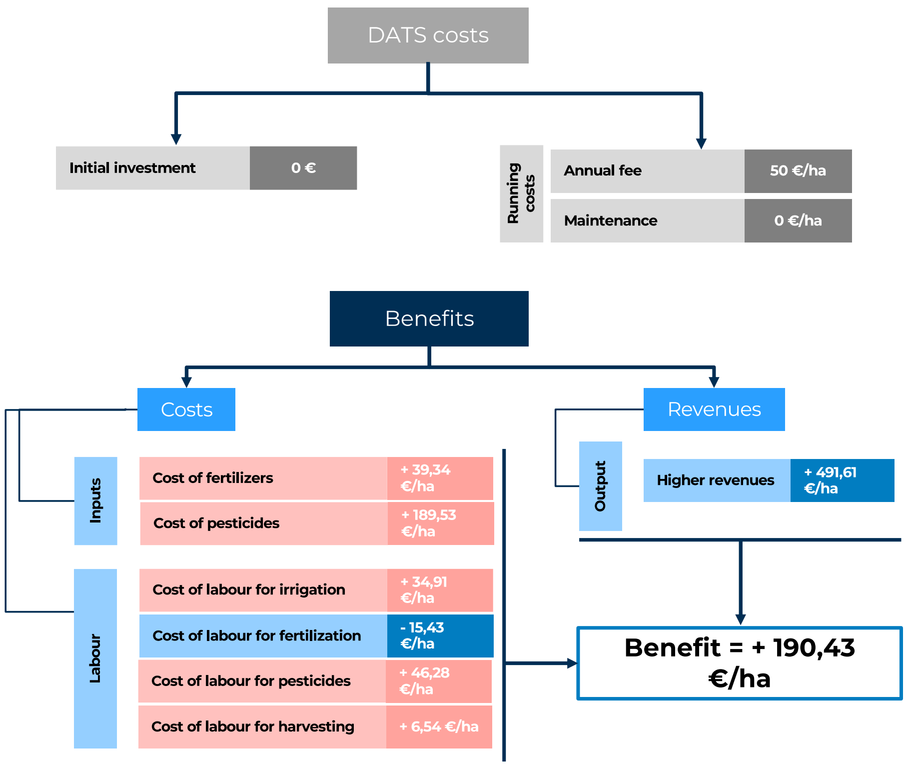


*Figure 24 - Cost-benefit analysis for TC 7*

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

In this Test Case, the cost of the digital solution is composed only by an annual fee of €50 per hectare. This DATS does not entail an initial investment cost, but an annual service fee for having access to the functionalities of the gaiasense platform.

With the implementation of DATS, a benefit of +190,43 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 140,43 per hectare** (+ 190,43 €/ha – 50€/ha).

Since the farmer made no initial investment, the payback period was not calculated.

## SUSTAINABILITY IMPACT

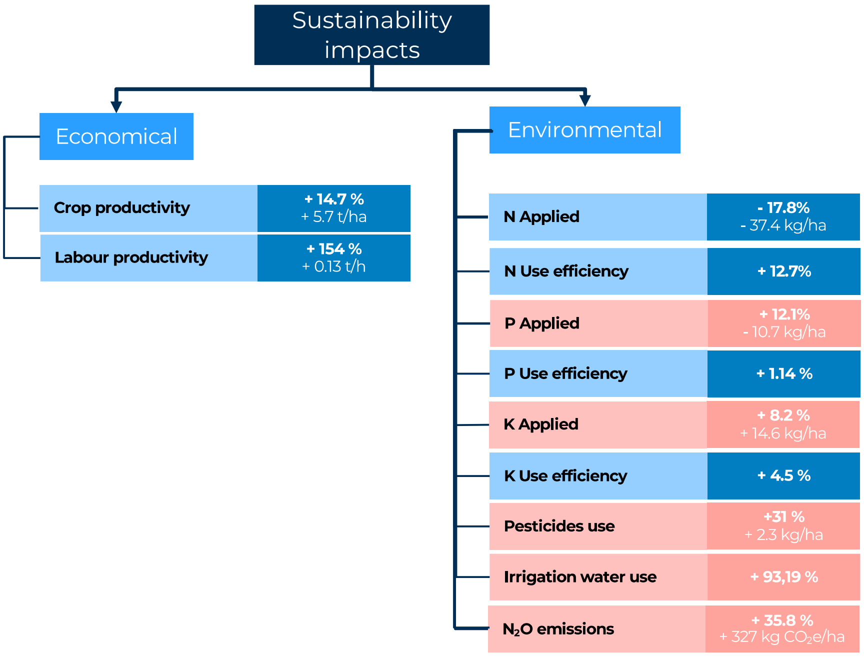


*Figure 25 - Sustainability impacts for TC 7*

### Discussion

Following the implementation of DATS, the farm experienced a **net benefit of +140,43 €/ha**, credited to a more balanced increase in revenue vis-à-vis costs. Overall, the farm using DATS experienced an increase of treatments and irrigations. Fertilizers increase only for K and P applications, whereas decrease for N; additionally, the farm adopting the technology was able to reduce fertilizers application from 4 to 3, this leading to a reduction in the cost of fertilization even if there was an increase of products for K and P. This broad cost escalation stemmed from DATS adeptness in understanding and addressing crop needs, leading to a yield surge and subsequently augmented income. Despite a documented rise in work hours, the substantial yield increases bolstered labour productivity significantly. There was also an increase in the water use; but this incrementation did not carry a monetary implication, as the farm sources water from a well, resulting in a cost of 0 for water supply.

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

In terms of sustainability, there was a reduction in nitrogen use per hectare, resulting in a slight drop in nitrous oxide ($N_2O$) greenhouse gas emissions. Moreover, it has been observed an increase of the efficiency of nitrogen, potassium, and phosphorus usage due to the increase in yields.

Regarding work dynamics, according to the social questionnaire DATS positively influenced complex task execution, fostered informed and efficient decision-making, and offered flexibility in the pace of work. Its impact on farm succession and sector attractiveness was neutral, while respondents found the learning curve for DATS usage challenging yet compelling and motivating.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Poland).

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

## 5.8. TC 8 – Silos Management, Grains, Silo management, Latvia

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Agrosmart SIA |
| TC sector | Silos Management |
| Crop/ Animal | Wheat, Rapeseed, Rye, Barley |
| Biogeographical Region | Boreal |
| Country | Latvia |
| Total number of parcels | 2 (1 with DATSs and 1 without DATSs) |
| Total size of these parcels | 12 silos (with DATS: 1 silo; without DATS: 11 silos) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Silo management |
| DATS(s) commercial name | Agrosmart for silos |
| DATS(s) description | The DATS is a ground-breaking system designed for agricultural storage and trade businesses. It offers a comprehensive solution by merging various operational aspects, allowing users to boost productivity through efficient and precise processes. It handles automated acceptance, lab procedures, storage, and unloading operations. It seamlessly integrates with scales, lab equipment, and facilitates document management, logistics planning, and contract/order handling. The software keeps farmers informed about their deliveries, monitors contract execution, generates grain quality reports, and operates on the cloud, accessible via various devices through web browsers. Specialized installations enable communication with scales and lab equipment, with options for additional integrations like card scanners or accounting systems. |
| DATS(s) cost | • Initial investment: 20000 €<br>• Maintenance cost: 0,024 €/t |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to save time (and labour costs) as many tasks are automated. |
| Increase the effectiveness of processes | The solution promotes efficiency of processes through automation, tracking and analysis. |
| Reduce the risk of human error | Through automation, logging and alerts, DATS reduces the risk of human error. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations mainly related to workload and reduced fuel consumption. In contrast, an important increase in electricity consumption was recorded.

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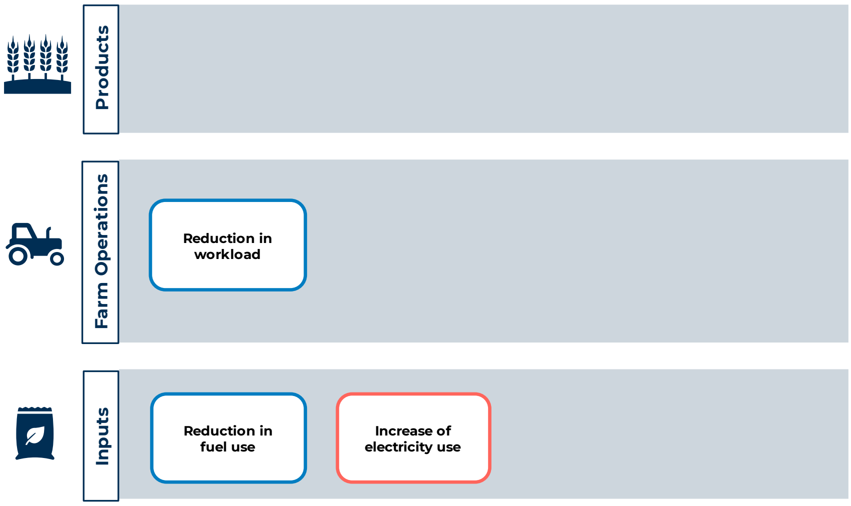
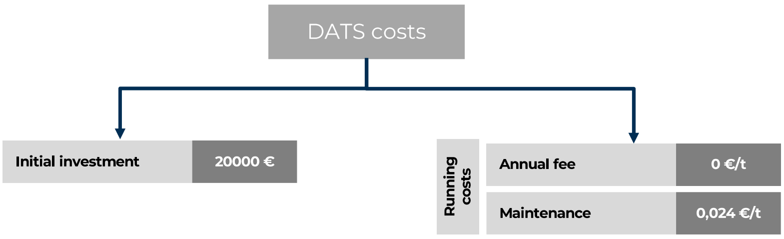



*Figure 26 - Benefits experienced from the implementation of DATS in silos management (TC 8)*

### COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

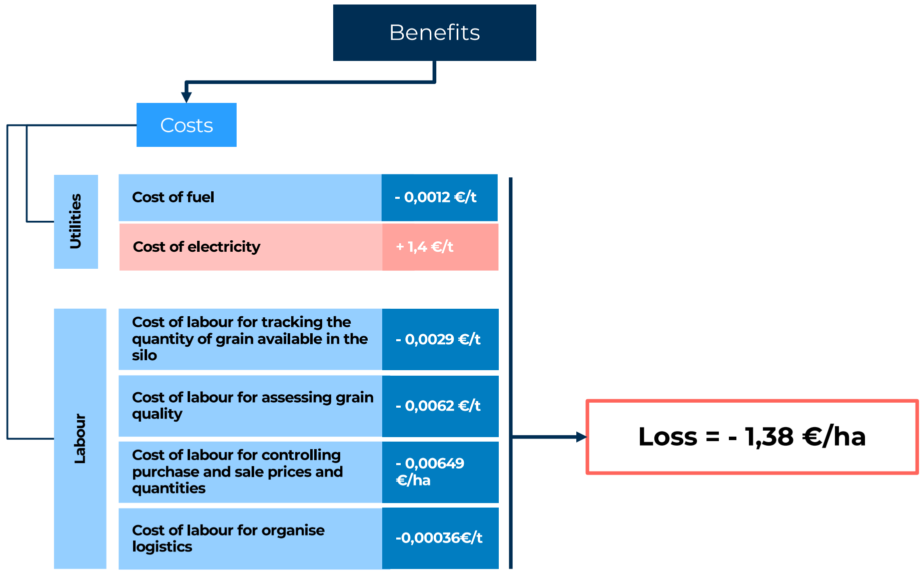



*Figure 27 - Cost-benefit analysis for TC 8*

In this Test Case, the cost of the digital solution is composed by an initial investment of 2000 € and annual maintenance cost of 0,024€/t.

With the implementation of DATS, a loss of – 1,38 €/t was recorded. Consequently, the net loss deriving from the cost-benefit analysis is **- € 1,40 per tons (**– 1,38 €/t – 0,024€/y).

## SUSTAINABILITY IMPACT

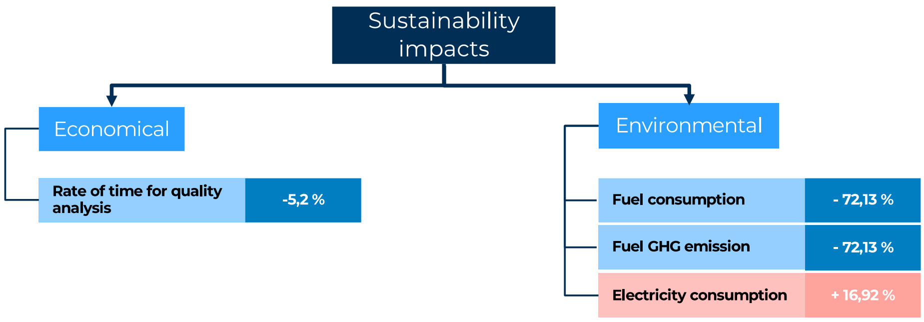



*Figure 28 - Sustainability impacts for TC 8*

### Discussion

Following the implementation of DATS, the farm experienced a net loss of -1.40 € per ton. Despite a general reduction in labour costs across all activities and a decrease in fuel expenses, the surge in electricity costs resulted in a recorded loss for the TC. It is essential to note that, in this context, only changes in utility and labour costs were considered for benefit calculation. As explicitly stated by the TC, DATS has no impact on the production or selling price of the product. As previously emphasized,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DATS facilitates efficient monitoring of silos, product quality, and logistics activities. The workload associated with the analysed activities has indeed diminished post-DATS implementation. If we were to solely focus on the impact observed in labour costs, a positive benefit would be evident.

Regarding sustainability impacts, although an increase in electricity consumption was noted, it cannot be exclusively attributed to DATS implementation, as factors such as silo type and energy class can play a significant role. However, there was a reduction in fuel consumption, leading to a consequent decrease in greenhouse gas emissions. Furthermore, although not quantified in this assessment, the digital solution is believed to positively influence the time required for quality assessment and may contribute to theft reduction.

When comparing farmers who adopted DATS with those who did not (utilizing the Framework), the introduction of the solution had a neutral impact on workers' tasks, measured by the number of hours spent on activities. Nevertheless, responses from adopters in the "social questionnaire" indicated positive outcomes. DATS significantly improved work efficiency, reduced workload, and enhanced the industry's appeal to younger individuals, contributing to farm succession. Additionally, the solution aided in addressing complex standards and regulations. Finally, the implementation process was neither stressful nor time-consuming.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Latvia).

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## 5.9. TC 9 – Arable, Corn for silage and wheat, FMIS/ Financial Modelling, Slovenia

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | KGZS |
| TC sector | Arable |
| Crop/ Animal | Corn for silage and wheat |
| Biogeographical Region | Alpine |
| Country | Slovenia |
| Total number of parcels | 4 (2 with DATS and 2 without DATS) |
| Total size of these parcels | 41,57 ha (16,8 ha with DATS and 24,77 ha without DATS) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | FMIS/ Financial Modelling |
| DATS(s) commercial name | Farm Manager |
| DATS(s) description | Farm Manager is a system designed to support decision-making in agricultural operations by integrating various databases. Serving as a business planning and data aggregation platform, it caters to the needs of farmers and food producers. This advanced e-service empowers users to formulate holistic production plans for their farms, employing diverse farming methods and technologies.<br>The DATS seamlessly integrates information from satellites (Earth Observation), drones, in-situ sensors (IoT), weather stations, and external sources like soil test databases, public records (Farm register), and weather forecasts.<br>Farm Manager facilitates meticulous planning and business modelling for all facets of agricultural production, encompassing both crops and animal husbandry. The platform is versatile, serving purposes such as advising farms on production redirection, business modelling, planning, and data aggregation. Adopting a modular approach, users can opt for a single module or a combination thereof for their analyses, allowing modelling for specific production aspects or the entire farm. |
| DATS(s) costs | • Initial investment: 0 €<br>• Set-up: 0 €<br>• Annual fee: 0 €/ha<br>• Maintenance costs: 0 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise fuels for driving machinery. |
| Environmental sustainability | The solution allows a rationalisation of the use of machinery at company level and a consequent reduction in fuel consumption. |

### Benefits experienced from the implementation of DATS

The main benefit experienced by the use of the DATS was in the reduction of fuel. Uneven impacts on yield and on-farm operations were identified.

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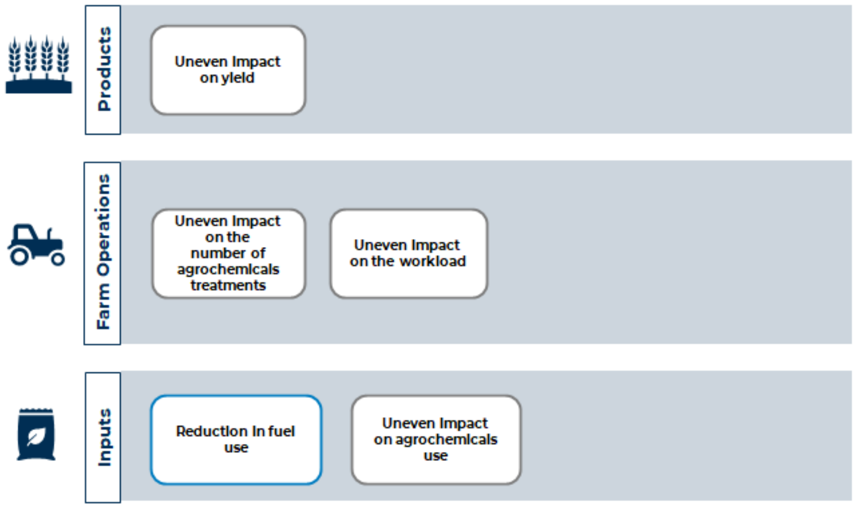


*Figure 29 - Benefits experienced from the implementation of DATS in corn for silage and wheat cultivation (TC 9)*

**COST-BENEFIT ANALYSIS (MONETARY IMPACT) AND SUSTAINABILITY IMPACT (Corn for silage)**

Farm Manager is a free public tool for farmers, which is why the initial investment, maintenance costs and annual fees are zero. The impact of DATS varies between the two crops under analysis. Specifically, a net loss of – 23.09 €/ha was observed for corn for silage. The monetary impact deriving from the cost-benefit analysis resulting from the application of the Assessment Framework are outlined below.

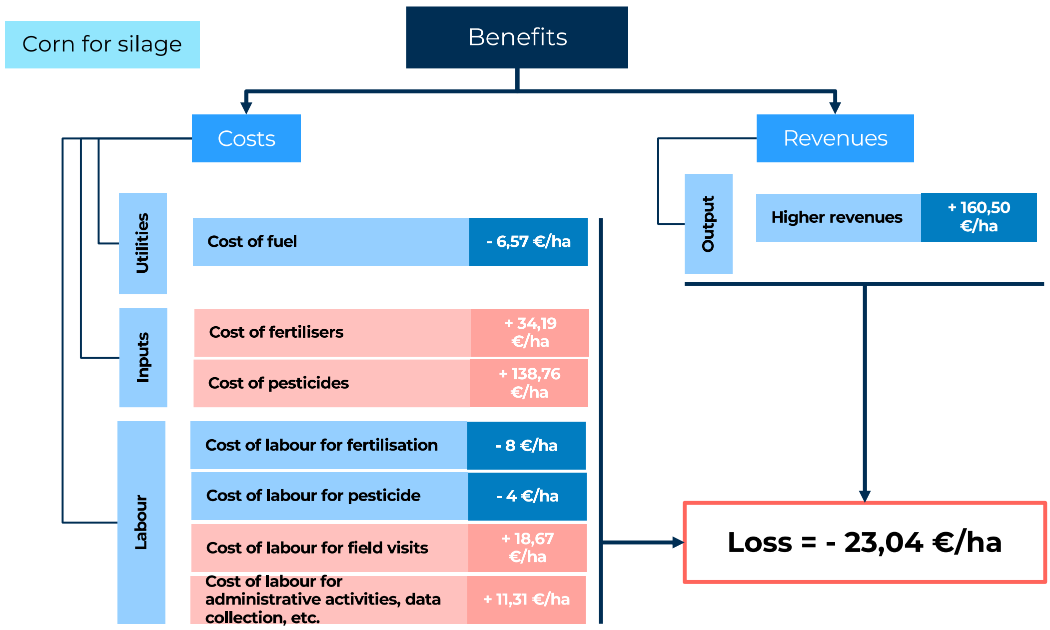


*Figure 30 - Cost-benefit analysis for TC 9 (Corn for silage)*

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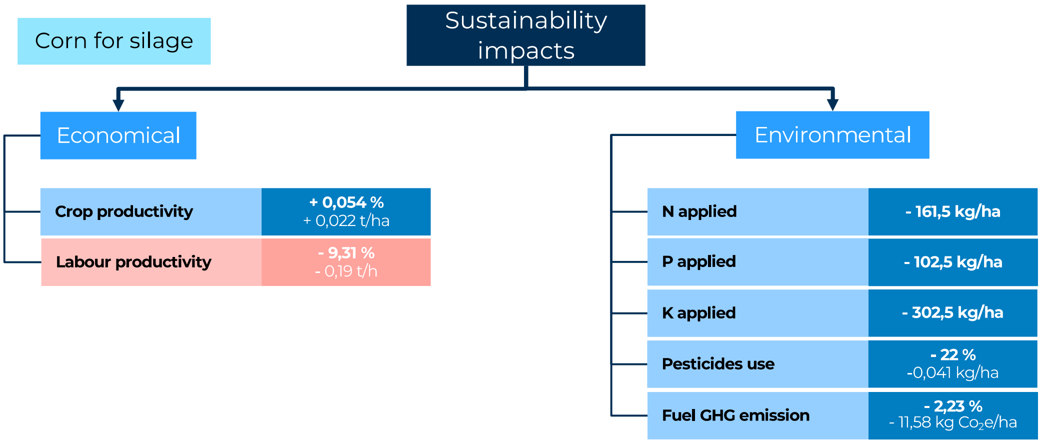


*Figure 31 - Sustainability impacts for TC 9 (Corn for silage)*

### COST-BENEFIT ANALYSIS (MONETARY IMPACT) AND SUSTAINABILITY IMPACT (Wheat)

Farm Manager is a free public tool for farmers, which is why the initial investment, maintenance costs and annual fees are zero. A net loss of - 312.42 €/ha was noted for wheat. The monetary impact deriving from the cost-benefit analysis resulting from the application of the Assessment Framework are outlined below.

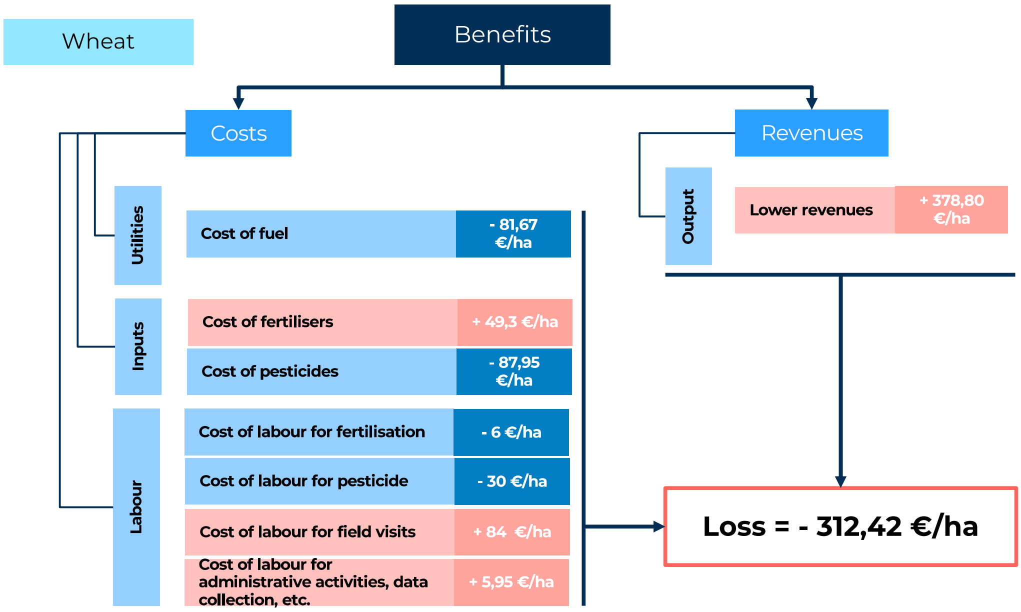


*Figure 32 - Cost-benefit analysis for TC 9 (Wheat)*

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

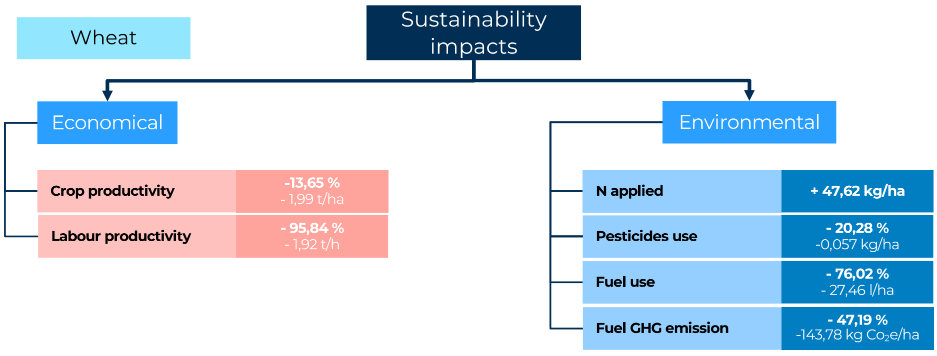


*Figure 33 - Sustainability impacts for TC 9 (Wheat)*

Since the farmer made no initial investment, the payback period was not calculated.

**Discussion**

After implementing DATS, the farm producing corn for silage experienced a net loss of -23.04 €/ha, primarily due to increased costs (except for fuel costs, which decreased for the farm using DATS). Agrochemicals, fertilizers, and labour costs were higher in the parcel with DATS compared to the one without. Despite a slight increase in yields, the rise in revenue was mainly due to the higher selling price of the product. A 6.25% increase in the selling price was recorded. While land productivity improved with DATS, the increase in working hours per hectare led to a decrease in labour productivity.

In terms of sustainability impacts, pest management benefited from DATS, resulting in reduced use of fungicides and pesticides (kg/ha) and increased fertilizer utilization efficiencies. DATS may have caused a reduction in Fuel GHG and $N_2O$ GHG emissions.

Turning to the wheat-producing farm, significant variations in yields were observed among different agricultural enterprises, making it challenging to attribute productivity and revenue fluctuations solely to the adopted technology. The farm experienced a net loss of -312.42 €/ha. Despite a general decrease in costs, there was a substantial reduction in yield. Additionally, the implementation of DATS increased fertilizer and labour costs for field visits, administrative, and data collection activities. Productivity analysis revealed smaller land and labour productivity in the parcel with DATS, attributed to reduced output yields.

The sustainability analysis results were influenced by fertilizer application differences, particularly in the parcel without DATS, where only N-fertilizer was applied. Consequently, fertilizer utilization efficiency calculations were not entirely relevant. In general, there was an increase in fertilizer application, including N, P, and K elements, with a simultaneous reduction in agrochemical use (kg/ha). DATS usage led to a decrease in fuel GHG emissions, primarily due to reduced fuel consumption, but an increase in $N_2O$ GHG emissions in the parcel with DATS, linked to higher N-fertilizer use.

In comparing farmers who adopted DATS with those who did not (using the Framework), the introduction of the solution had a neutral impact on workers' tasks, measured in the number of hours spent on activities. According to the respondent, the implementation of DATS had no impact on the categories analysed within the social questionnaire.

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**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Slovenia).

Due to missing data regarding water consumed for irrigation, the analysis could not compute results in terms of costs for water and irrigation productivity.


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## 5.10. TC 10 – Arable, Wheat, SF DSS, Romania

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ANAMOB |
| TC sector | Arable |
| Crop/ Animal | Wheat |
| Biogeographical Region | Steppe |
| Country | Coslogeni, Calarasi, Romania |
| Total number of parcels | 2 (1 with DATSs and 1 without DATSs) |
| Total size of these parcels | 795,77 ha (552,67 ha with DATSs and 243,1 without DATSs) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | DSS |
| DATS(s) commercial name | |
| DATS(s) description | A comprehensive software maintains records of all field operations and enables monitoring of equipment fleet.<br>The solution also uses a combination of other DATSs (hardware and software):<br>- Harvest Combines generate yield maps and gather crucial data for adapting technology and making informed decisions.<br>- Meteo stations. Recording meteorological data aids in result analysis and timely decision-making, offering daily assistance in making informed choices.<br>- Satellite-derived NDVI images are instrumental in preventing issues, exercising control, and facilitating decision-making processes.<br>- Efficient scheduling of agricultural tasks for each plot, precise distribution of product consumption among parcels, and management of resources. |
| DATS(s) cost | • Initial investments: 70000 €<br>• Set-up (training): 395,6 €<br>• Maintenance: 5,43 €/a |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used. A concomitant increase in yields was recorded.

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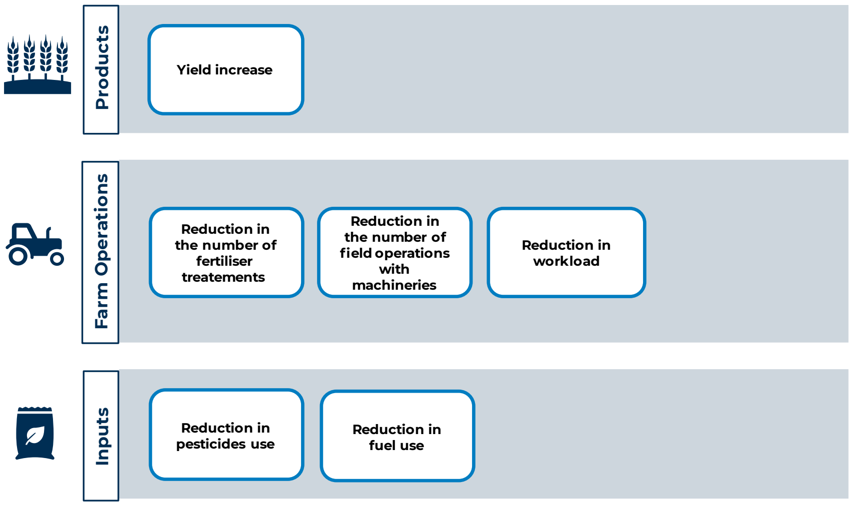


*Figure 34 - Benefits experienced from the implementation of DATS in wheat cultivation (TC 10)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

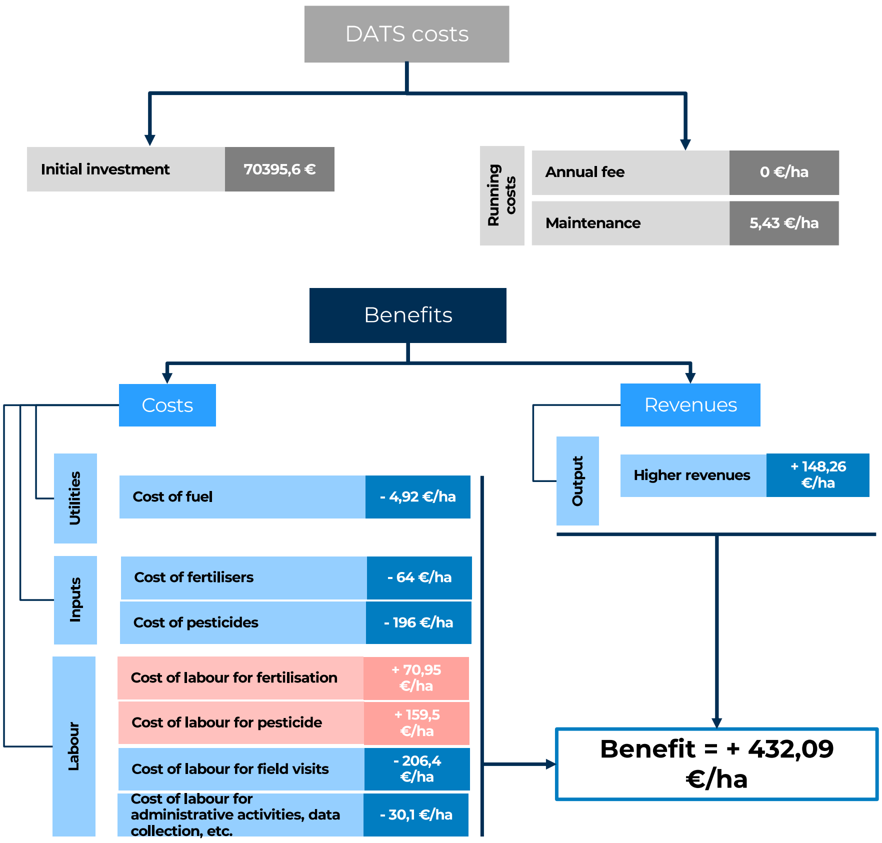


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*Figure 35 - Cost-benefit analysis for TC 10*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €5,43 per hectare and an initial investment of 70395,6 € (composed of 70000 € for the purchase of hardware and software and 395,6 € for the set-up).

With the implementation of DATS, a benefit of + 432,09 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 426,66 per hectare** (+432,09 €/ha – 5,43 €/ha).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 3 months (70395,6/(426,66*552,67)).

## SUSTAINABILITY IMPACT

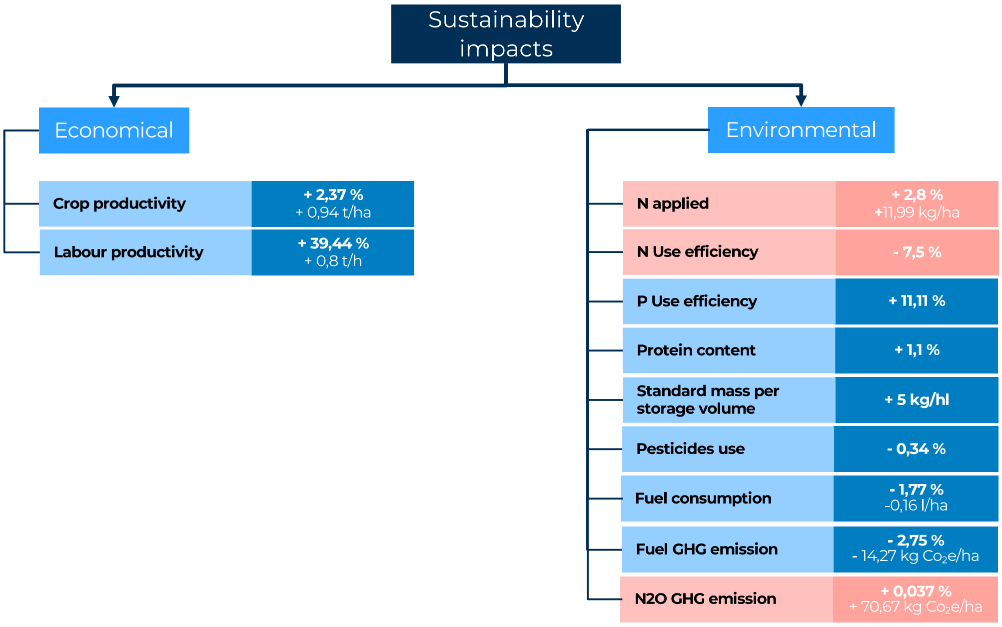


*Figure 36 - Sustainability impacts for TC 10*

### Discussion

Following the implementation of DATS, the farm experienced a **net benefit of + €426.66 per hectare**. This gain resulted from a combination of cost reduction and increased revenue. The payback period for the investment in DATS is 3 months. While overall costs have decreased, there has been a rise in labour costs associated with treatments such as pesticides and fertilisation.

Despite variations in wheat selling prices between user and non-user, the disparity cannot be attributed to the adoption of DATS but rather to differences in bargaining power or contract types of non-using farmer. Non-user is selling their products at a price +0.04%. Although user farmer applies a slightly lower price, the boost in yields has led to an overall revenue increase. The combination of increased yields and reduced working hours per hectare has enhanced labour productivity.

DATS has facilitated the more efficient application of agrochemicals, leading to an overall reduction in their use. Positive impacts on phosphorus (P) efficiency have been observed following the

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implementation of the solution, although a modest increase in nitrogen (N) use per hectare has resulted in elevated $N_2O$ greenhouse gas emissions. The reduction in the use of agrochemicals has also led to a decline in fuel usage and, consequently, reduced fuel emissions.

The direct impact of DATS on product quality is unclear; however, there is an interesting observation of an increase in protein content and standard mass per storage volume.

In comparing farmers who adopted DATS with those who did not (using the Framework), the introduction of the solution had a neutral impact on workers' tasks, measured in the number of hours spent on activities. Nonetheless, responses from adopters in the "social questionnaire" indicated positive outcomes, including enhanced flexibility in planning and executing work activities, a more conscientious and efficient decision-making process, and improved decision-making regarding the pace or speed of work. This implementation did not adversely affect the physical and emotional well-being of individuals. Finally, the execution of the solution was not only devoid of complexity and time-consuming challenges but was, in fact, engaging and motivating.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Romania).

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## 5.11. TC 11 – Fruit, Olives, SF DSS, Greece

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Neuropublic |
| TC sector | Fruit |
| Crop/ Animal | Olives |
| Biogeographical Region | Mediterranean |
| Country | Greece |
| Total number of parcels | 10 (5 with DATs and 5 without DATs) |
| Total size of these parcels | 14.09 (with DATs: 8.6 ha and without DATs: 5.5ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | gaiasense |
| DATS(s) description | The gaiasense platform functions as a comprehensive smart farming system, integrating multiple dimensions to support farmers, agricultural advisors, and research scientists in their work. It continuously records, analyzes, and interprets atmospheric and soil data at specific points within fields during each pass, providing valuable insights. The gaiasense system operates through telemetric autonomous stations known as gaiatrons. These stations gather data from field-installed sensors, monitoring various environmental factors like temperature, humidity, precipitation, soil moisture, and more. The gaiatron serves as an IoT "Deploy-and-Forget" platform. It employs a range of sensors for ongoing surveillance of agricultural conditions in specific areas. Communication between gaiatron stations and cloud-based computer servers utilizes protocols such as GPRS/3G or UHF. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 272 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

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**Benefits experienced from the implementation of DATS**

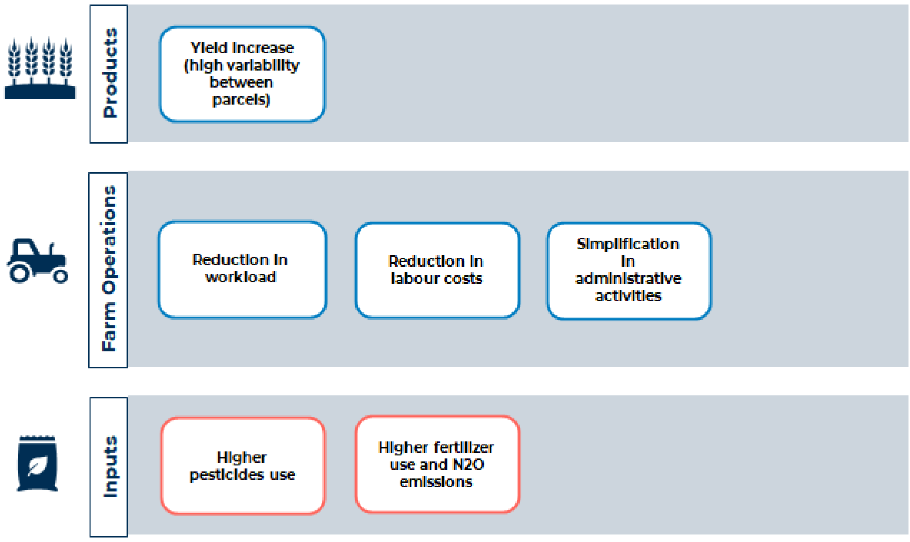
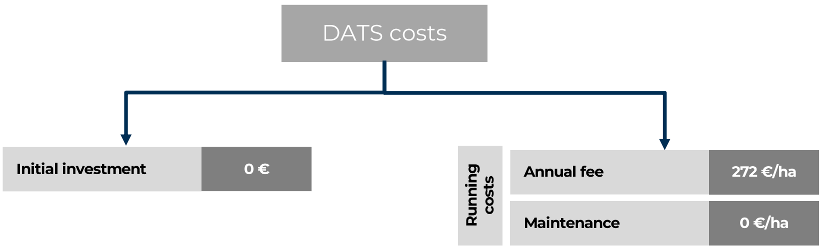



*Figure 37 - Benefits experienced from the implementation of DATS in olives cultivation (TC 11)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

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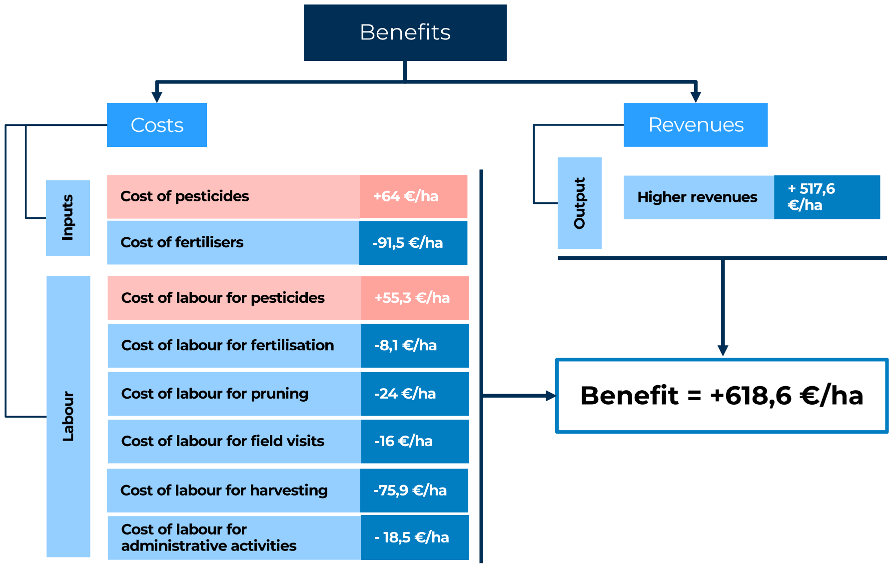


*Figure 38 - Cost-benefit analysis for TC 11*

In this Test Case, the cost of the digital solution is composed only by an annual fee of €272 per hectare. This DATS does not entail an initial investment cost, but an annual service fee for having access to the functionalities of the gaiasense platform.

With the implementation of DATS, a benefit of +618,6 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 346,6 per hectare** (+ 618,6 €/ha – 272€/ha).

Since the farmer made no initial investment, the payback period was not calculated.

## SUSTAINABILITY IMPACT

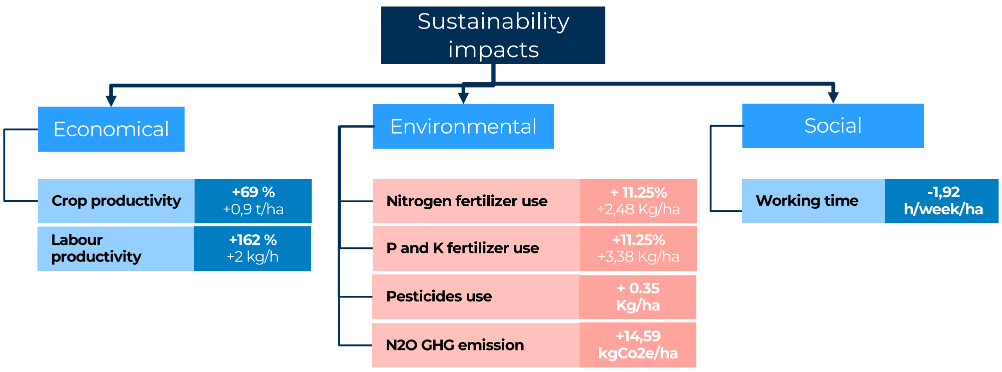


*Figure 39- Sustainability impact for TC 11*

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**Discussion**

In this Test Case we observe a substantial variability in olive yields, not only among different farms but also within individual parcels of the same farm. It is therefore extremely difficult to attribute a variation in productivity and revenue to the technology adopted. For the 4 Farms analysed, the average of the **net benefits** observed is + € **346,6 per hectare**. This gain resulted not only from higher revenues (+ € 517.6 per hectare), but also from a significant drop in some costs: among these, the cost of fertilization activities, pruning, field visits, harvesting and administrative activities.

The observed increase in productivity is estimated at around +0.9 t/ha. Fuel consumption and fuel costs decreased in plots with DATS, but the significance of this reduction is not significant. The main benefits of the technology, at the moment, seem to be related to the simplification of agronomic management and monitoring of olive orchards. The DATS is helping farmers to reduce field visits and to record agronomical and management data more easily. Farmers, thanks to the application of DATS had to work, on average, 1.5 hours less per week per hectare. Overall, there is a notably positive trend observed concerning the influence of DATS on work-related tasks. This trend is conducive to resolving intricate problems, making well-informed decisions, and broadening the spectrum of tasks by enabling individuals to concentrate on different or novel activities. Furthermore, DATS contributes to increased leisure time, which is predominantly spent with family members or friends. According to the respondent, the implementation of the solution was not complex or time-consuming; instead, it was engaging and motivating.

**Data and analysis issues**

Average salary data and average professional salary partly calculated on the basis of the "Eurostat data on average wages for the Country".

Missing updated data for FARM3.

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## 5.12. TC12 – Fruit, Apple, Drones and soil sensors, Poland

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Delphy |
| TC sector | Fruit |
| Crop/ Animal | Apple |
| Biogeographical Region | Continental |
| Country | Poland |
| Total number of parcels | 2 parcels (1 with DATS and 1 without DATS) |
| Total size of these parcels | 2 ha (with DATS: 1 ha; without DATS: 1 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Drones and soil sensors |
| DATS(s) commercial name | Water sensors – Estede;<br>QMS Water – Delphy;<br>Digital vigour map - Aurea Imaging;<br>Digital blossom map - Aurea Imaging;<br>QMS Root pruning – Delphy;<br>Digital pest control – Trapview;<br>RIMpr – Rimpro. |
| DATS(s) description | TCs implemented a combination of different DATSs:<br>Water sensors monitor soil moisture content, enabling precise water management by calculating the required water for crops based on sensor data and climatic conditions. This not only increases efficiency but also contributes to environmental sustainability by reducing water usage.<br>Digital vigour maps facilitate decision-making in orchards by visualizing growth differences between trees. This aids in tasks like root pruning and fertilizer application, ensuring targeted actions to enhance production and orchard homogenization.<br>Digital blossom maps provide information on the density of flowers per tree during blossoming, enabling growers to make informed decisions on blossom and fruit thinning. This targeted approach reduces labor, the use of chemical thinning agents, and increases overall production.<br>QMS Root pruning assists growers in creating task maps for machines and gaining an overview of growth vigour in the field over time. This supports decision-making related to root pruning and contributes to yield increase and orchard homogenization.<br>Digital pest control and RIMpro aid in effective and efficient management of pests and diseases. These technologies predict development over time, helping growers determine the optimal timing for crop protection product applications. This not only reduces costs but also promotes environmental sustainability by minimizing unnecessary chemical use. |
| DATS(s) costs | • Initial investment: 2250 €<br>• Set-up: 0 €/ha<br>• Maintenance costs: 350 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Yield increase | Optimising the use of production inputs helps increase yields. |

### Discussion

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It seems like the implementation of DATSs didn't yield noticeable changes in agronomic management between user and non-user parcels. The reasons behind this lack of impact could be attributed to several factors:

- Early Implementation: Since this was the first year of implementing the solution, it's common not to immediately observe significant changes. New technologies often require time for users to adapt and integrate them effectively into their practices.
- Operational Issues: Problems with the moisture sensors, compounded by the distance between the farmer in Poland and the TCL in the Netherlands, hindered timely interventions. This likely impacted the functionality and effectiveness of the system.
- Cultural and Communication Barriers: Language and cultural differences between the technology provider and the farmer may have impeded effective communication or understanding of the technology's full potential or use.

Due to these challenges, the farmer maintained the same approach for both parcels, making it impossible to quantify sustainability impacts for the first year. The parcel using the solution will incur some additional operational costs related to hardware maintenance and software fee costs, which are not borne by the non-user parcel.

However, the implementation of DATS has made it possible to notice some qualitative impacts on the social level. Indeed, the farmer experienced a positive impact on social sustainability, as the technology reduced stress and facilitated certain work activities. DATS contributed positively to the attractiveness of the agricultural sector and supported intergenerational succession. Finally, it's noted that the technology had a negative impact on the physical and emotional wellbeing of the farmer.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Poland).

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## 5.13. TC 13 – Fruit, Grapevine, SF DSS, Italy

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | HORTA |
| TC sector | Fruit |
| Crop/ Animal | Grapevine |
| Biogeographical Region | Continental |
| Country | Italy |
| Total number of parcels | 3 (2 with DATSs and 1 without DATSs) |
| Total size of these parcels | 2,93 ha (with DATS: 1,55 ha & 0.54 ha; without DATS: 0,84 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | vite.net® |
| DATS(s) description | The DATS provides support in the implementation of sustainable agronomic practices. It is a web accessible service that integrates mathematical models and expert knowledge to provide clear and effective advice and quick alarms related to field management. The DATS is implemented throughout the grapevine's growth phases, spanning from bud break to pre-harvest. The DSS hinges on weather data obtained from a weather station positioned near the field. This weather station includes sensors for temperature, rainfall, relative humidity, and leaf moisture.<br>Vite.net operates as a web-accessible service that integrates different information on the characteristics of each parcel - as weather patterns, soil properties, and crop characteristics like growth rate, phenology, nutritional and water requirements - into mathematical models. These models generate actionable insights and prompt alerts to field management. Enhancements to crop management are achievable by incorporating additional solutions:<br>i) Remote sensing imagery: Horta accesses external image providers to acquire data, leveraging this information to offer tailored guidance to farmers.<br>ii) Drones: collaborating with an external drone company, Horta utilizes gathered data to advise farmers effectively. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 63 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advice about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used. A concomitant increase in yields was recorded.

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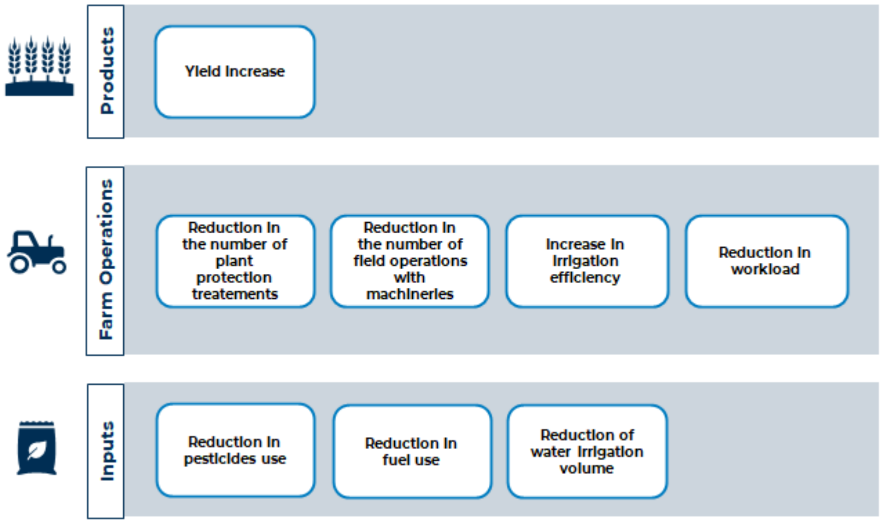
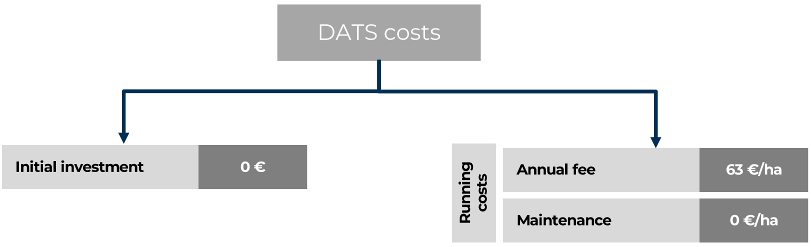



*Figure 40 – Benefits experienced from the implementation of DATS in grapevine cultivation (TC 13)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

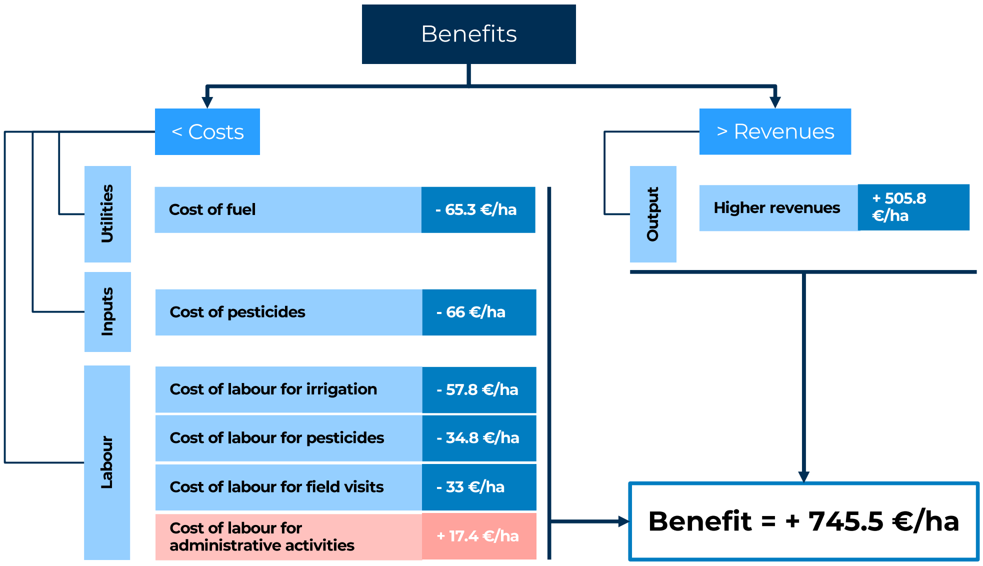



*Figure 41 - Cost-benefit analysis for TC 13*

In this Test Case, the cost of the digital solution is composed only by an annual fee of €63 per hectare. No costs of initial investments are required, as the farmer already had a weather station available.

With the implementation of DATS, a benefit of +745.5 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 682,5 per hectare (**+ 745.5 €/ha – 63 €/ha).

Since the farmer made no initial investment, the payback period was not calculated.

## SUSTAINABILITY IMPACT

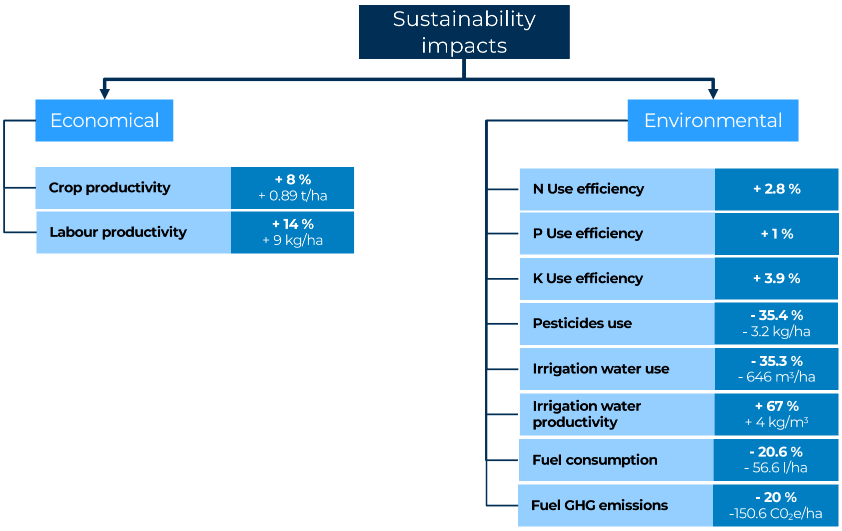



*Figure 42 - Sustainability impacts for TC 13*

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

**Discussion**

Following the implementation of DATS, the farm experienced a **net benefit of + 682.45 €/ha**, resulting from an interplay of reduced costs and increased revenues. it is important to highlight that the sole cost that experienced an increase was the labour cost associated with administrative activities. This rise can be attributed to the fact that these activities are not carried out in the non-user farm. On the revenue front, despite an unchanged grape selling price, increased yields translated to enhanced final receipts. The combination of higher yields and diminished working hours (per hectare) paved the way for a rise in labour productivity.

In terms of environmental impact, there was a modest enhancement in fertilizer (N, P, K) utilization efficiency, not stemming from changes in fertilizer management practices but rather from the yield increment. Notably, pest management benefitted significantly from DSS support, facilitating a substantial reduction in agrochemicals use (fungicides and pesticides). Similarly, a parallel decline in irrigation volumes was observed, aligning with increased yields and contributing to heightened water irrigation productivity. It's worth mentioning, though, that this improvement does not carry a monetary implication, as the farm sources water from a well, resulting in a cost of 0 for water supply.

The analysis performed on the organic farm has not been considered in this evaluation. This decision stems from the increased difficulty in isolating the impact of DATS within the two organic parcels. This strong divergence in results (both in terms of costs and yields, and in terms of sustainability) would have led to an inaccurate overview. Subsequent data collection endeavours will enable a more precise 'isolation' of the DATS influence on the various key performance indicators (KPIs).

The farmer expressed positive social outcomes subsequent the implementation of the DSS. Specifically, the DATS significantly improved work operations, enabling the farmer to adeptly address unforeseen challenges, handle intricate tasks, make more deliberate and effective decisions, and manage the impacts of climate change. Moreover, the farmer noticed heightened interest among the younger generation in the agricultural sector and in working on his farm, fostering a positive succession on the farm. Finally, the farmer highlighted that the learning curve for utilizing the solution was not burdensome; rather, it proved to be motivating and engaging.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Italy).

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

## 5.14. TC 14 – Fruit, Blueberries and strawberries, Precision fertigation/ Variable root pruning, Serbia

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | TERRA |
| TC sector | Fruit |
| Crop/ Animal | Blueberries and strawberries |
| Biogeographical Region | Pannonian |
| Country | Serbia |
| Total number of parcels | 4 (2 with DATSs and 2 without DATSs) |
| Total size of these parcels | 7,45 ha (with DATSs: 3,2 ha, 0,25 ha; without DATSs: 3,7 ha, 0,3 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Precision fertigation/ Variable root pruning |
| DATS(s) commercial name | Netafim "NETAJET" and Netafim NMC pro system for irrigation and fertigation with light sensors |
| DATS(s) description | Blueberries: the NetaJetTM 4G blends various fertilizers seamlessly within its distinctive HidroMix static mixing chamber, creating a homogeneous solution that is then injected into the main irrigation water line. The collection of data involves a combination of information from a mobile app and the DATS interface. Farmers utilize handheld sensors for measuring the pH and EC of water drainage from plastic containers. This data serves as the basis for making informed decisions about the subsequent fertilization plan.<br>Strawberries: the DATS blends various fertilizers seamlessly within its distinctive HidroMix static mixing chamber, creating a homogeneous solution that is then injected into the main irrigation water line. A sensor within the greenhouse monitors temperature and sunlight exposure, and this data is utilized by software to regulate misting, thereby managing the ambient temperature. Data collection involves merging information from a mobile app and the DAT interface, with the data being directly extracted from DAT. |
| DATSs costs | Blueberries<br>• Initial investment: 60000 €<br>• Set-up: 1038 €<br>• Maintenance: 109,37 €/ha<br>Strawberries<br>• Initial investment: 60000 €<br>• Maintenance: 4000 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and fertilisers. |
| Environmental sustainability | The DSS provides the optimization of resource use, so it has a positive impact on the environment. |
| Yield increase | Precise application of water and fertilisers promotes higher yields. |

**Benefits expected from the implementation of DATS**

DATS did not have a homogenous impact on the two different crops (blueberries and strawberries), also considering the diversity of cultivation systems.

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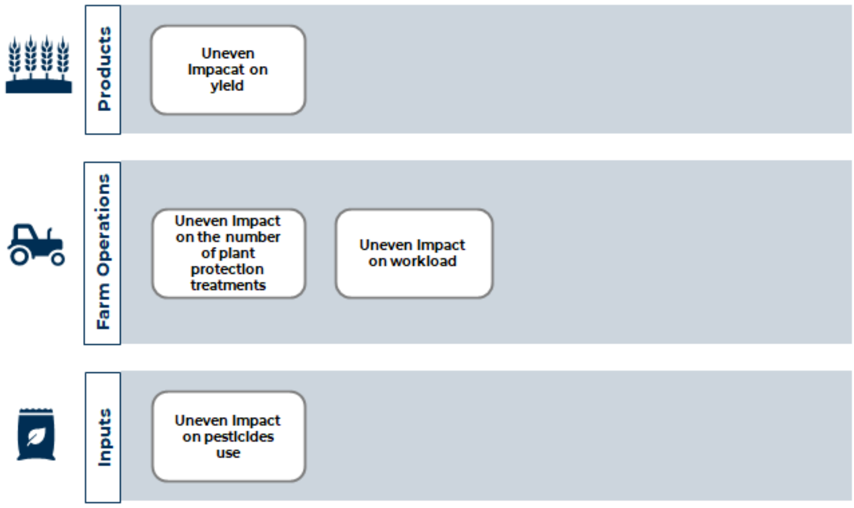



*Figure 43 - Benefits experienced from the implementation of DATS in blueberries and strawberries cultivation (TC 14)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT) AND SUSTAINABILITY IMPACT (blueberries)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

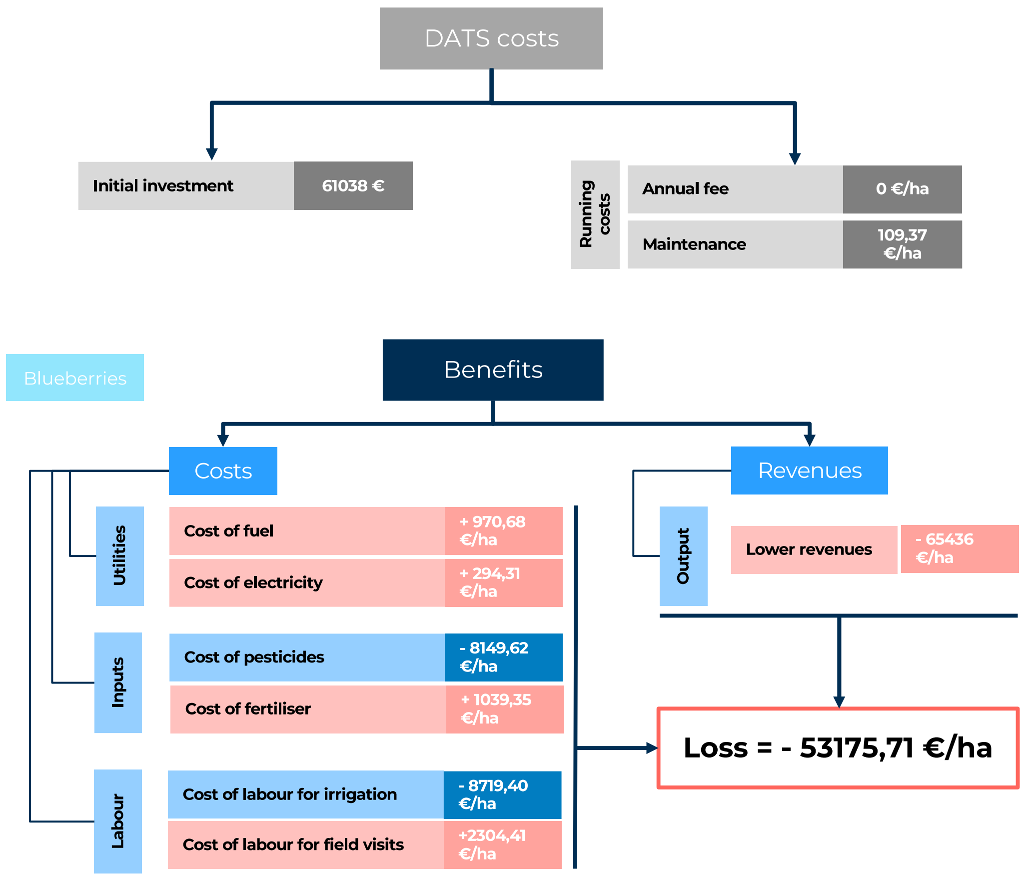



*Figure 44 - Cost-benefit analysis for TC 14 (blueberries)*

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

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €109,37 per hectare and an initial investment of 61038 € (composed of 60000 € for the purchase of hardware and software and 1038 € for the set-up).

With the implementation of DATS, a loss of – 53175,71 €/ha was recorded. Consequently, the cost-benefit analysis shows a net loss of **€ 53285,09 per hectare** (– 53175,71– 109,37 €/ha).

The payback period has not been calculated as the farmer has recorded negative benefits.

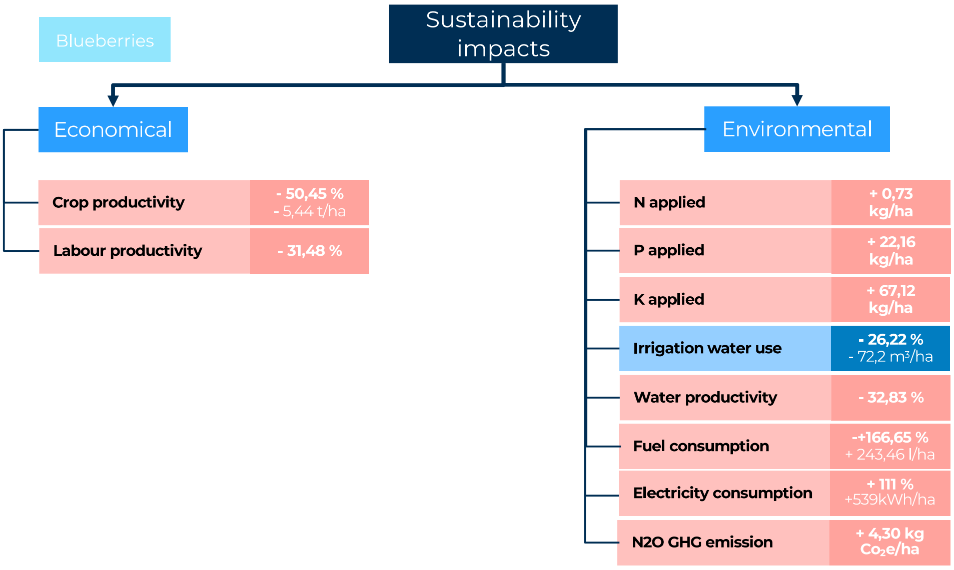
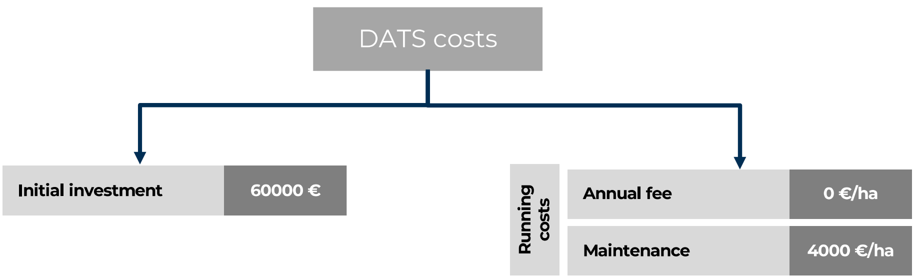



*Figure 45 - Sustainability impacts for TC 14 (blueberries)*

**COST-BENEFIT ANALYSIS (MONETARY IMPACT) AND SUSTAINABILITY IMPACT (strawberries)**




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

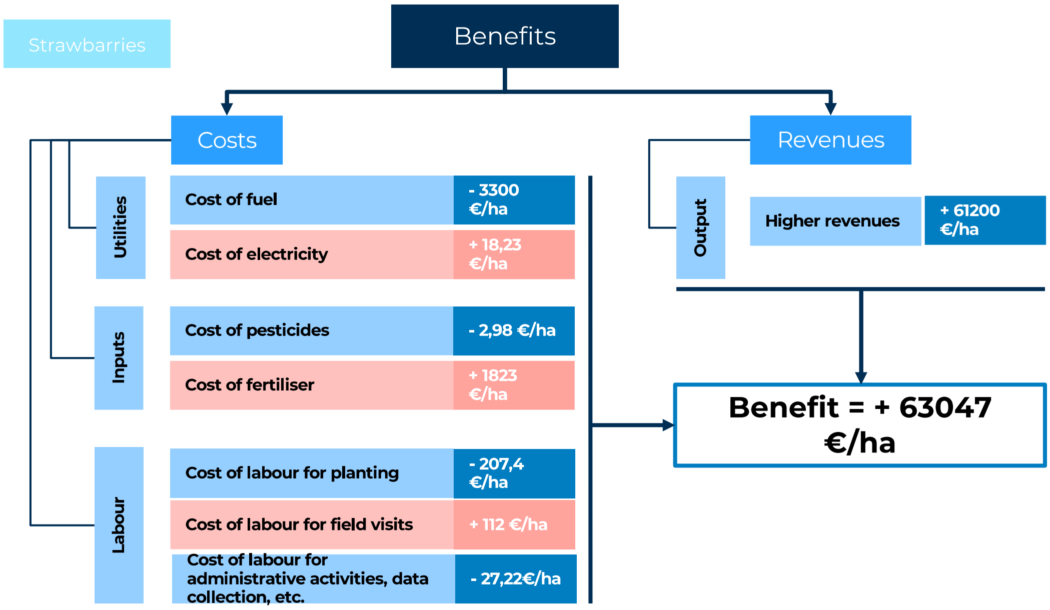



*Figure 46 - Cost-benefit analysis for TC 14 (strawberries)*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €4000 per hectare and an initial investment of 60000 €.

With the implementation of DATS, a benefit of + 63047,37 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ + 59047,37 per hectare (**+ 63047,37 – 4000 €/ha).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 4 years (60000/(59047,37*0,25)).

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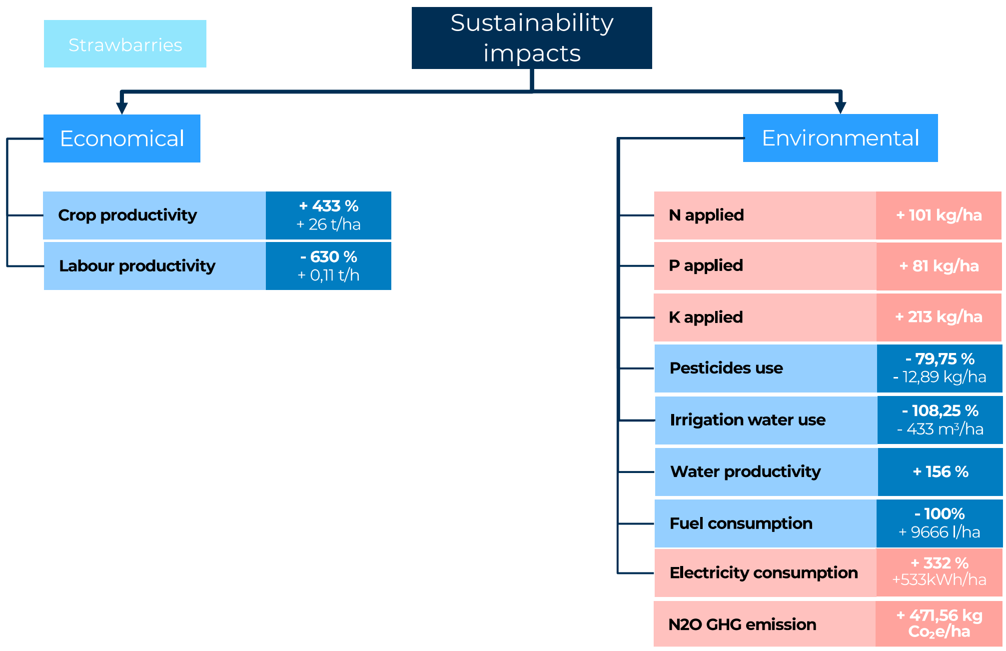


*Figure 47 - Sustainability impacts for TC 14 (strawberries)*

**Discussion**

Identifying a distinct impact of implementing DATS on the two crops proves challenging. For example, blueberries suffered a decrease in yield, while the opposite was observed for strawberries. In the case of blueberries, the yield of the parcel without DATS was more than double that of the parcel with DATS. However, attributing this difference in yields solely to the implementation of DATS is difficult, as various factors such as distinct agronomic practices and variations in soil and climate conditions must be considered.

This trend extended to utility, input, and labour costs. Despite an overall cost reduction for blueberries driven by lower pesticide and irrigation labour expenses, reduced yields resulted in decreased revenue, even though the DATS user set a higher price compared to the non-DATS user. Conversely, for strawberries, cost reduction coincided with increased yields and revenue, despite the DATS user setting a lower price than the non-DATS user. This combination led to a net benefit of + €59047.37/ha for the user.

In terms of sustainability impacts, DATS had a varied effect on the two crops. Labour productivity decreased for blueberries but increased for strawberries. DATS slightly adjusted fertilizer and agrochemical management for both crops, allowing farmers to better meet actual crop needs. This justified the general increase in fertilizers and reduction in pesticides. The rise in nitrogen use, however, resulted in increased $N_2O$ emissions. The solution also contributed to reduced water consumption and improved water efficiency for strawberries, along with increased yield.

Comparing DATS adopters to non-adopters using the Framework, the solution had a neutral impact on workers' tasks, measured by hours spent on activities. However, adopters, as indicated in the "social questionnaire," reported positive outcomes. Overall, DATS had a predominantly positive impact on work activities and the sector's appeal to younger generations. The solution aided in addressing unforeseen problems, making more informed and efficient decisions, focusing on new tasks, and

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enhancing flexibility. Importantly, its implementation did not adversely affect physical or emotional well-being. Furthermore, DATS allowed for more free time, predominantly spent with family or friends. Respondents noted that implementing the solution was not complicated or time-consuming but rather interesting and motivating.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Serbia).

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## 5.15. TC 15 – Fruit, Olives, SF DSS, Cyprus

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Filagro |
| TC sector | Fruit |
| Crop/ Animal | Olives |
| Biogeographical Region | Mediterranean |
| Country | Cyprus |
| Total number of parcels | 8 (4 with DATS and 4 without) |
| Total size of these parcels | 8,13 ha (with DATS: 0,7 ha, 3,5ha, 0,18 ha, 1,25 ha; without DATS: 0,2 ha, 1,5 ha, 0,35 ha, 0,45 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | gaiasense |
| DATS(s) description | The gaiasense platform functions as a comprehensive smart farming system, integrating multiple dimensions to support farmers, agricultural advisors, and research scientists in their work. It continuously records, analyzes, and interprets atmospheric and soil data at specific points within fields during each pass, providing valuable insights. The gaiasense system operates through telemetric autonomous stations known as gaiatrons. These stations gather data from field-installed sensors, monitoring various environmental factors like temperature, humidity, precipitation, soil moisture, and more. The gaiatron serves as an IoT "Deploy-and-Forget" platform. It employs a range of sensors for ongoing surveillance of agricultural conditions in specific areas. Communication between gaiatron stations and cloud-based computer servers utilizes protocols such as GPRS/3G or UHF. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 213 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advice about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefits experienced from the implementation of DATS**

In general, benefits have been experienced in a lower use of fertilizers, this resulting in a reduction of $N_2O$ emissions. Additionally, a simplification of administrative activities was gained. On the other hand, a higher use of pesticides and water consumption have been recorded. Within the TC, a great variability between different parcels was found in terms of both yield and cost.

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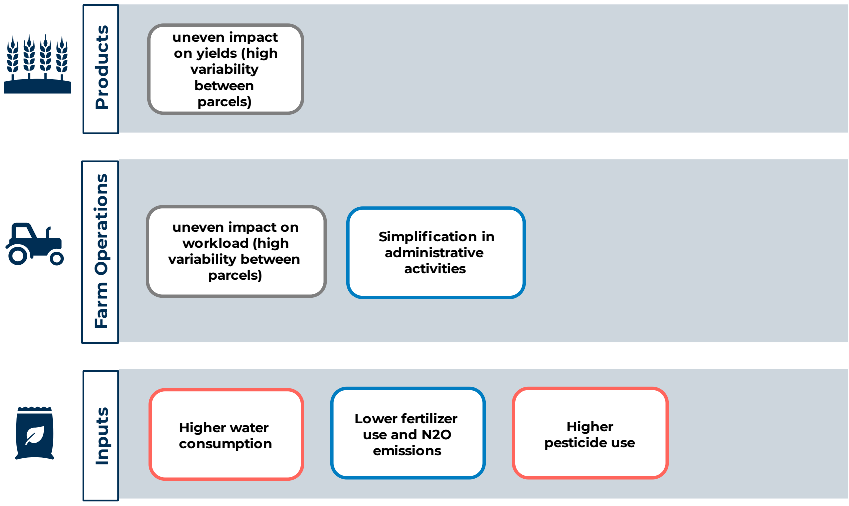
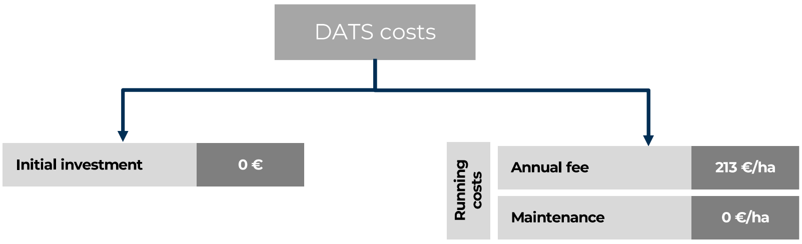



*Figure 48 - Benefits experienced from the implementation of DATS in olives cultivation (TC 15)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

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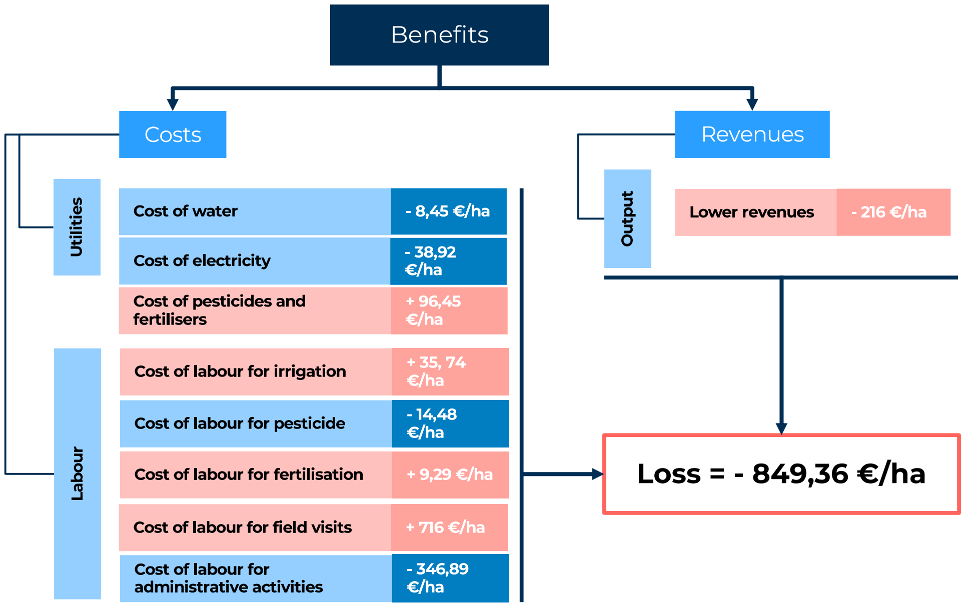


*Figure 49 - Cost-benefit analysis for TC 15*

In this Test Case, the cost of the digital solution is composed only by an annual fee of €213 per hectare. This DATS does not entail an initial investment cost, but an annual service fee for having access to the functionalities of the gaiasense platform.

With the implementation of DATS, a loss of -849,36 €/ha was recorded. Consequently, the cost-benefit analysis shows a net loss of **€ - 1062,36 per hectare (**-849,36 €/ha – 213 €/ha).

Since the farmer made no initial investment, the payback period was not calculated.

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**SUSTAINABILITY IMPACT**

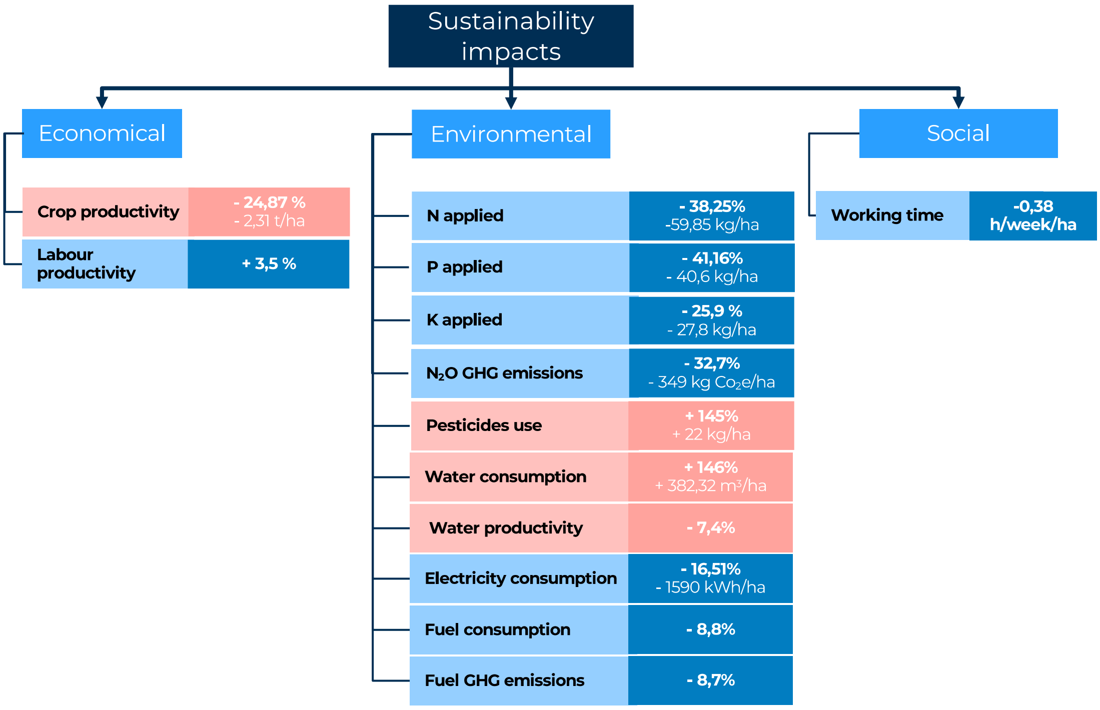


*Figure 50 - Sustainability impacts for TC 15*

**Discussion**

In this particular test case, a significant variation in olive yields is evident not only among distinct agricultural enterprises but also within individual plots of the same company. Consequently, attributing fluctuations in productivity and revenue solely to the adopted technology proves exceedingly challenging. Across the four scrutinized agricultural companies, the mean observed profits are negative, totalling a net loss of **– 1062,36 € per hectare**. This deficit stems not only from a decline in revenues—varying significantly among the analysed plots, with two cases exhibiting an increase and the remaining two experiencing a decrease – but also from escalating costs. These costs include expenditures on fertilizers and pesticides, labour for irrigation, and field visits. On the other hand, there is a general reduction in the cost of water and electricity.

One of the most positive impact is on the time spent in administrative activities: the implementation of the DATS has facilitated the recording of agronomic and managerial data for farmers. Thanks to DATS, farmers have, on average, worked 0.38 hours less per week per hectare.

The combined effect of reduced yields and diminished working hours per hectare has marginally increased labour productivity.

In terms of sustainability impacts, although DATS has had a minimal effect on fuel costs, it has enabled a reduction in fuel consumption, subsequently mitigating greenhouse gas emissions. There has been a decrease in the use of nitrogen (N), phosphorus (P), and potassium (K) per hectare. The reduction in

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nitrogen use has resulted in a decline in nitrous oxide ($N_2O$) emissions. DATS has led to an increase in water consumption, and the variability of yields has contributed to a reduction in average water efficiency. Overall, a positive impact has been noted from the implementation of DATS in agricultural activities.

While not universally agreed upon, the solution has predominantly favoured farmers by enhancing the ease of performing complex tasks and facilitating more efficient and conscious decision-making. Additionally, all farmers have asserted that the adoption of DATS has stimulated the interest of the younger generation in working on their farms or within the agriculture sector, ensuring succession on the farm. Furthermore, DATS provides farmers with more leisure time, primarily spent with family or friends. Finally, women on the farm have actively encouraged the adoption of DATS.

**Data and analysis issues**

Average salary data and average professional salary partly calculated on the basis of the “Eurostat data on average wages for the Country” (Cyprus).

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## 5.16. TC16 – Fruit, Apple, Drones and soil sensors, The Netherlands

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Delphy |
| TC sector | Fruit |
| Crop/ Animal | Apple |
| Biogeographical Region | Continental |
| Country | The Netherlands |
| Total number of parcels | 2 parcels (1 with DATS and 1 without DATS) |
| Total size of these parcels | 4 ha (1 ha with DATS and 3 ha without DATS) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Drones and soil sensors |
| DATS(s) commercial name | Water sensors – Estede;<br>QMS Water – Delphy;<br>Digital vigour map – Aurea Imaging ;<br>Digital blossom map – Aurea Imaging;<br>QMS Root pruning – Delphy;<br>Digital pest control – Trapview;<br>RIMpr – Rimpro. |
| DATS(s) description | TCs implemented a combination of different DATSs:<br>Water sensors monitor soil moisture content, enabling precise water management by calculating the required water for crops based on sensor data and climatic conditions. This not only increases efficiency but also contributes to environmental sustainability by reducing water usage.<br>Digital vigour maps facilitate decision-making in orchards by visualizing growth differences between trees. This aids in tasks like root pruning and fertilizer application, ensuring targeted actions to enhance production and orchard homogenization.<br>Digital blossom maps provide information on the density of flowers per tree during blossoming, enabling growers to make informed decisions on blossom and fruit thinning. This targeted approach reduces labor, the use of chemical thinning agents, and increases overall production.<br>QMS Root pruning assists growers in creating task maps for machines and gaining an overview of growth vigour in the field over time. This supports decision-making related to root pruning and contributes to yield increase and orchard homogenization.<br>Digital pest control and RIMpro aid in effective and efficient management of pests and diseases. These technologies predict development over time, helping growers determine the optimal timing for crop protection product applications. This not only reduces costs but also promotes environmental sustainability by minimizing unnecessary chemical use. |
| DATS(s) cost | • Initial investments: 4850 €<br>• Set-up (training): 192 €<br>• Maintenance costs: 500 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Yield increase | Optimising the use of production inputs helps increase yields. |

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**Benefits experienced from the implementation of DATS**

DATS seems to have led to an increase in yields. Although there has been an increase in the time spent on file visits, labour productivity has increased thanks to DATS. Positive impacts are also observed in the decrease of growth regulators used and an increase in irrigation water use efficiency.

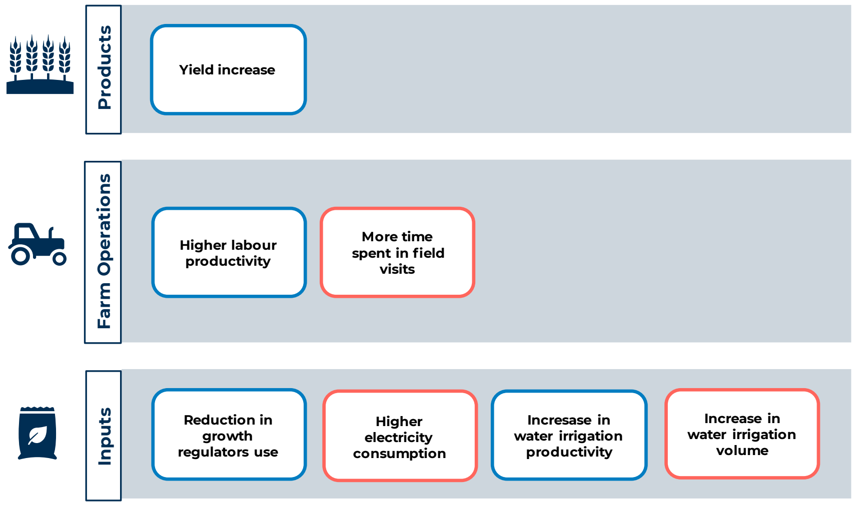
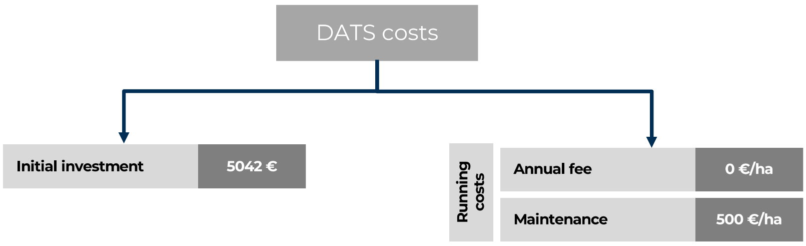



*Figure 51 – Benefits experienced from the implementation of DATS in apple cultivation (TC 16)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

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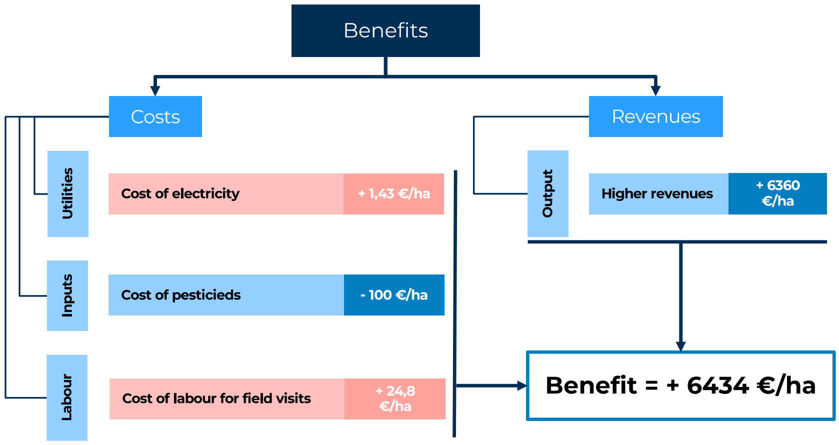


*Figure 52 – Cost-benefit analysis for TC 16*

In this Test Case, the cost of the digital solution is composed by an initial investment of 5042 € (composed of € 4850 for the purchase of hardware and software and 192 € for the set-up) and an annual maintenance cost of € 500/ha.

With the implementation of DATS, a benefit of + 6434 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 5934 per hectare** (+6434 €/ha – 500€/ha).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 10 months.

## SUSTAINABILITY IMPACT

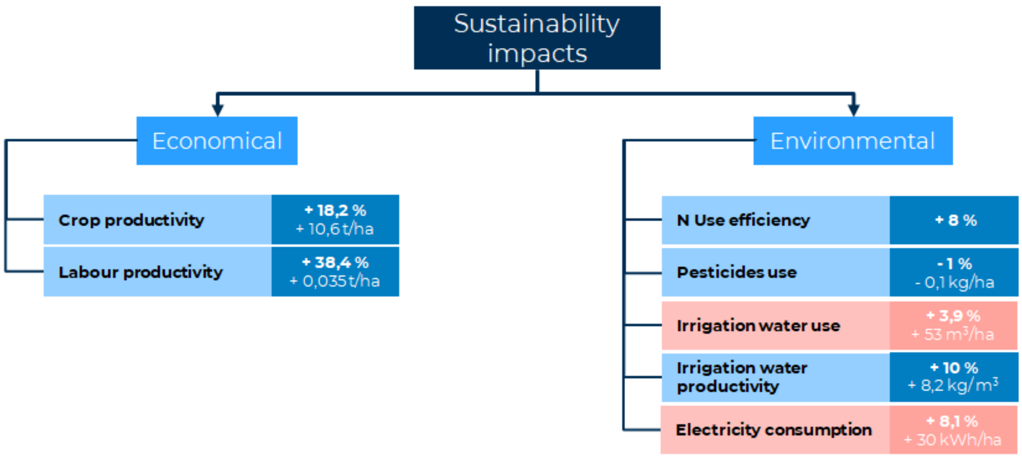


*Figure 53 – Sustainability impacts for TC 1*

### Discussion

Following the implementation of DATS, the farm experienced a +€5934 per hectare. This gain was achieved through a combination of the reduction of some costs (pesticides) and particularly increased revenue for the increase of yields. The payback period for the investment in DATS is just under a year.

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While the costs of inputs (pesticides) decreased, there was a slight uptick in electricity expenses due to increased usage of relevant utilities. Conversely, a rise in field visits resulted in increased labour costs. The most relevant benefit of this solution has been seen on yields: despite unchanged apple selling prices, the higher yields led to an overall income increase. The combination of increased yields and reduced labour hours per hectare has significantly boosted labour productivity.

In terms of sustainability impacts, there was a modest improvement in nitrogen (N) efficiency and a slight reduction in the use of phytosanitary products. Although water consumption increased, water productivity rose primarily due to the increase in yield.

While a generally positive impact was observed following the DATS implementation, it cannot be conclusively stated that the yield increase is solely attributable to the implemented solution. It is essential to note that various favourable soil and climatic conditions may have contributed to the observed results. The implementation of DATS has positively influenced i) the execution of complex tasks; ii) the ability to make more conscious and efficient decisions; and iii) the focus on other/new tasks. On one hand, the solution has positively impacted the complexity of the work; on the other hand, it has not diminished the intensity of the work. Regarding the learning curve for DATS usage, it has not induced significant stress and has not been overly time-consuming. Conversely, learning to use the solution has proven to be stimulating and interesting for the majority of respondents.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (The Nederland).

## 5.17. TC 17 – Fruit, Vineyard, FMIS, Romania

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ANAMOB |
| TC sector | Fruit |
| Crop/ Animal | Vineyard |
| Biogeographical Region | Black Sea |
| Country | Cogealac, Constanta County, Romania |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total size of these parcels | 26 ha (with DATS: 14 ha; without DATS: 12 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | FMIS |
| DATS(s) commercial name | fms.agricloud.ro |
| DATS(s) description | AgriCloud utilizes IoT technology to oversee the conditions of vineyards. The DATS is implemented across all processes in the vineyard, incorporating humidity sensors for both soil and air, wind speed and direction monitors, as well as a comprehensive weather station.<br>In addition to real-time monitoring, AgriCloud offers a high-resolution satellite imagery feature, allowing users to observe and assess activities in the fields. |
| DATS(s) cost | • Initial investments: 4400 €<br>• Set-up (training): 774 € |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water and agrochemicals. |
| Environmental sustainability | The DSS provides support in the implementation of sustainable agronomic practices. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used. A concomitant increase in yields was recorded.

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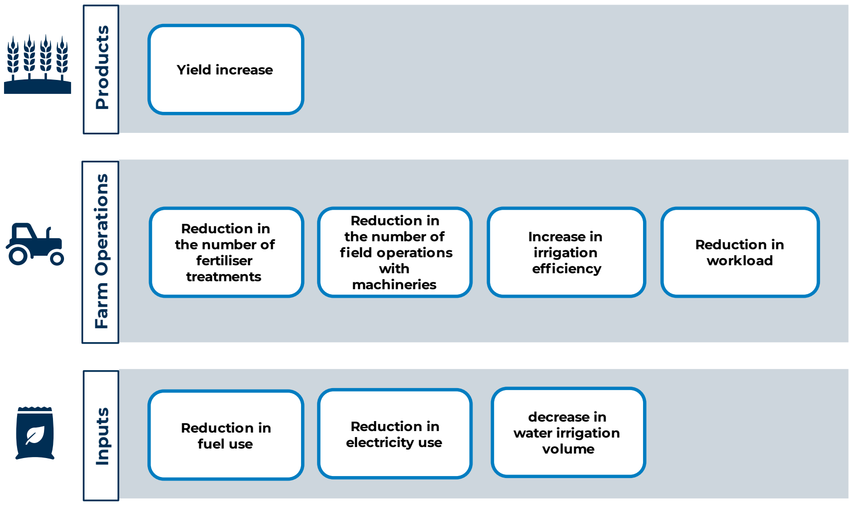


*Figure 54 - Benefits experienced from the implementation of DATS in vineyard (TC 17)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

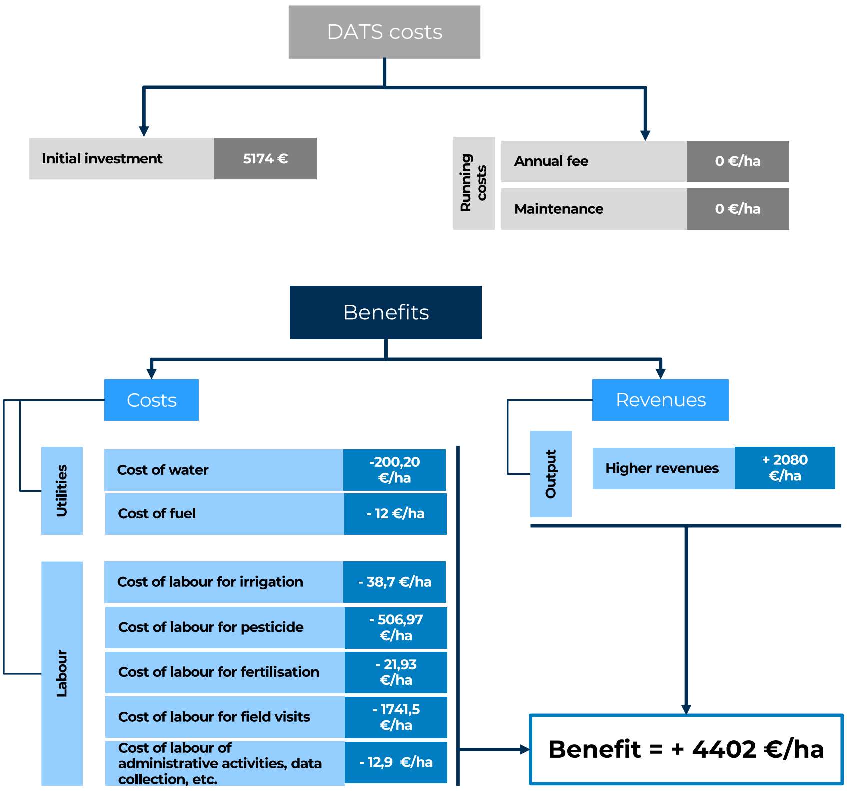


*Figure 55 - Cost-benefit analysis for TC 17*

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

In this Test Case, the cost of the digital solution is composed by an initial investment of 5174 € (composed of 4400 € for the purchase of hardware and software and 774 € for the set-up).

The net benefit deriving from the cost-benefit analysis is **€ 4402 per hectare.**

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 1 months.

## SUSTAINABILITY IMPACT

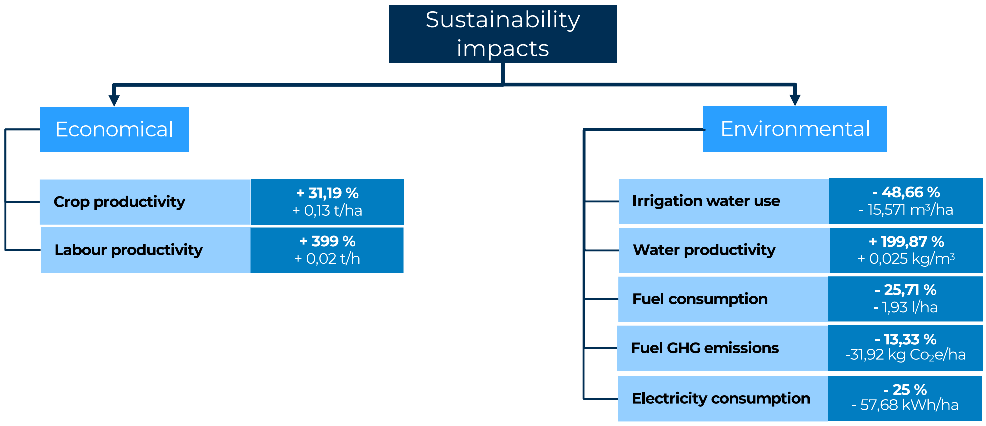


*Figure 56 - Sustainability impacts for TC 17*

### Discussion

After the implementation of DATS, the company experienced a net benefit of +€4402 per hectare, attributed to a combination of cost reduction and increased revenue. This gain translated into a payback period for the investment in DATS is 1 months. Despite the unchanged grape sale prices, higher yields contributed to a substantial increase in overall income. This synergy of elevated yields and reduced working hours per hectare significantly enhanced labour productivity.

In terms of sustainability, DATS facilitated more efficient and precise irrigation, resulting in a noteworthy reduction in water consumption. The combination of higher yields and decreased water usage led to an improvement in water productivity. Furthermore, a reduction in fuel usage was observed due to enhanced treatment application efficiency and a decrease in field operations, resulting in lower fuel emissions.

Comparing farmers who adopted DATS with those who did not (utilizing the Framework), the introduction of the solution had a neutral impact on workers' tasks, measured by the number of hours spent on activities. However, responses from adopters in the "social questionnaire" indicated positive outcomes. The implementation of the DATS solution had an overall positive impact on work activities, offering greater flexibility in organizing tasks and managing work speed. The solution positively affected farmers by providing a sense of security about the future and better equipping them to manage climate changes. Concerning the learning curve associated with using DATS, it did not induce

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significant stress and was not excessively time-consuming. On the contrary, learning to use the solution proved stimulating and interesting for the majority of respondents.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Romania).

In the analysis report, the costs and quantities of fertilisers and agrochemicals were not presented, as the provided data is not entirely clear. Further clarification and in-depth information are needed.

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## 5.18. TC 18 – Vegetables, Tomatoes, SF DSS, Italy

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | HORTA |
| TC sector | Vegetables |
| Crop/ Animal | Tomatoes |
| Biogeographical Region | Continental |
| Country | Italy |
| Total number of parcels | 10 (5 with DATSs and 5 without DATSs) |
| Total size of these parcels | 108,1 ha (with DATS: 6,1 ha, 6 ha,2 ha, 4,34 ha, 4,5 ha, 3,2 ha, 10,5 ha, 1,5 ha, 9,13 ha, 14,3 ha; without DATS: 2,1 ha, 6 ha, 1,7 ha, 4,34 ha, 5,2 ha, 6,6 ha, 10,5 ha, 2 ha, 5,3 ha, 7,3 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | SF DSS |
| DATS(s) commercial name | pomodoro.net® |
| DATS(s) description | The DATS provides support in the implementation of sustainable agronomic practices. It is a web accessible service that integrates mathematical models for the main tomato diseases, weather data and soil physical-chemical characteristics, to return clear and effective advice and quick alarms related to the field management. It can provide farmers with advises about fertilization, alarms about the risk of main diseases, and plant protection products complying with the 'zero residue' protocol. Main goals for using the technology: input/cost reduction; environmental sustainability. The DATS addresses the plant protection in tomato cropping. The DATS proved to be helpful in decreasing direct costs for plant protection (less treatments, different product), and increasing the net farmer income (premium price for zero residue product). The DATS also support the farmer in the choice of the right kind of product for applying treatment in a particular growth stage, based on the guidelines of the zero-residue protocol. |
| DATS(s) cost | • Initial investment: 0 €<br>• Annual fee: 45€/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of agrochemicals. |
| Product quality increase | The DSS can provide farmers with advises about fertilization, alarms about the risk of main diseases, and data about weather, water balance and crop growth. |
| DAT influence on worker-power and labour time | A reduction of workload can be expected by using the DAT by easing the complying with the zero-residue protocol. It is not expected, however, that this will lead to a reduction in the number of farm workers. A reduction in treatments performed can also be expected. The user needs to consider some time for using the DAT (consulting it and filling in information), it can be quantified as 1-2 hours per year. A reduction of workload can be expected in the use of the DAT by a possible reduction of field operation (i.e., less plant protection product applications). |

**Benefits expected from the implementation of DATS**

Benefits were identified in relation to on-farm operations. A concomitant increase in yields was recorded.

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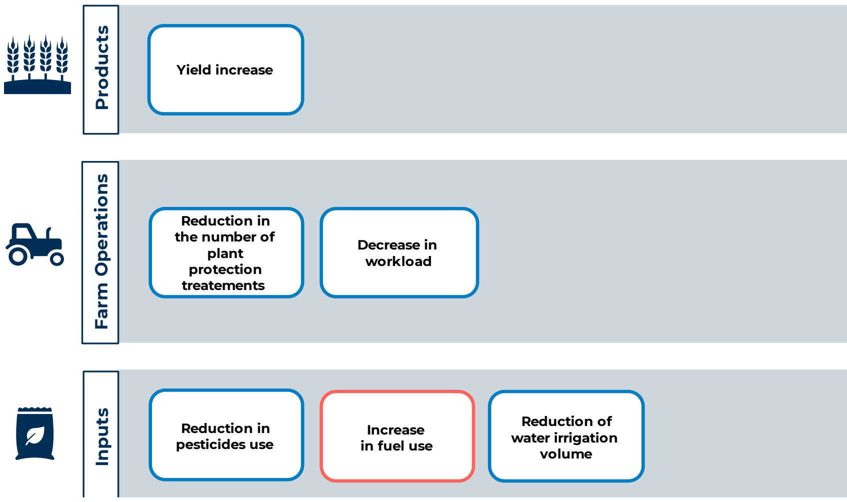


*Figure 57 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 18)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

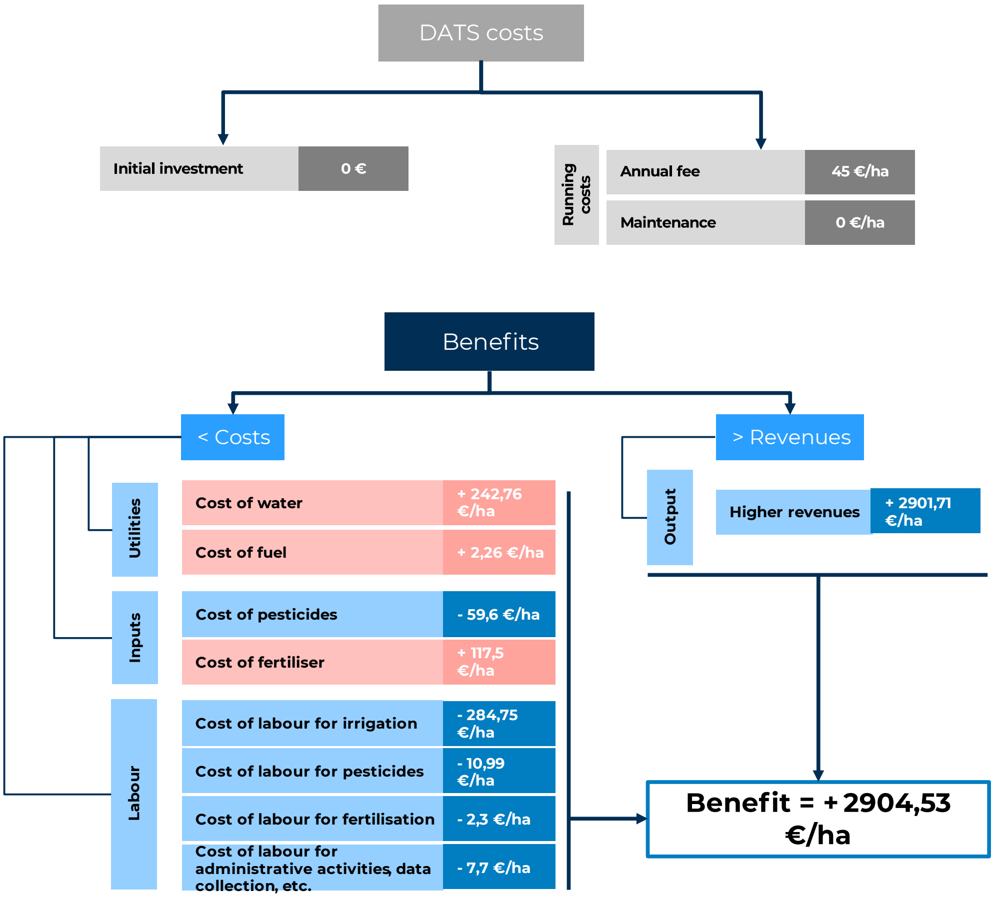


*Figure 58 - Cost-benefit analysis for TC 18*

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In this Test Case, the cost of the digital solution is composed only by an annual fee of €45 per hectare. No costs of initial investments are required, due to the fact that the solution is provided by Horta (technological provider). With the implementation of DATS, a benefit of +2904,53 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 2859,53 per hectare (**+ 3207,52 €/ha – 45 €/ha).

Since the farmer made no initial investment, the payback period was not calculated.

## SUSTAINABILITY IMPACT

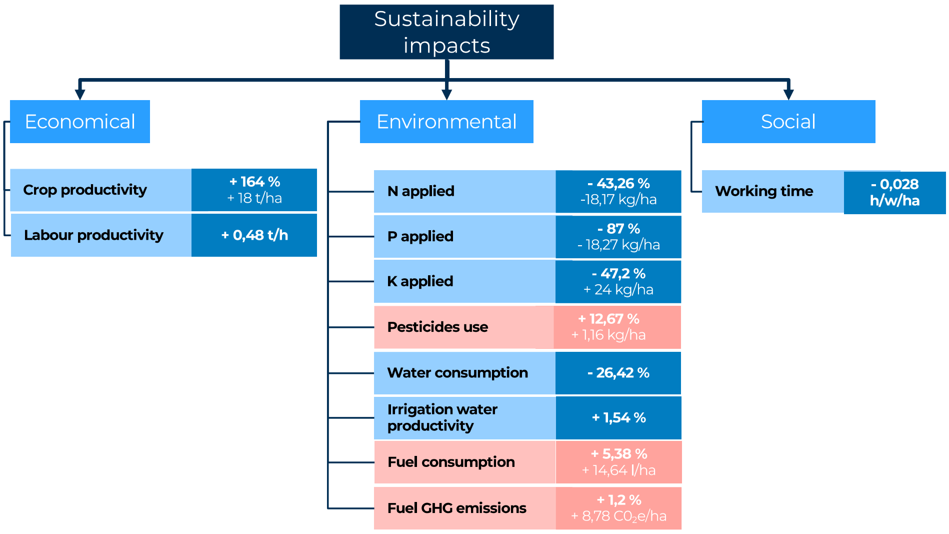


*Figure 59 - Sustainability impacts for TC 18*

### Discussion

In this specific test case, there is a significant variation in tomato yields not only among different agricultural enterprises but also within individual parcel of the same farm. As a result, attributing fluctuations in productivity and revenue solely to the adopted technology proves exceedingly challenging. Across the ten scrutinized agricultural companies, the mean observed profits are positive, totalling € 3162,52 per hectare. This volatility of results is also reflected in the values indicated for the analysed Key Performance Indicators (KPIs). In fact, for some KPIs (e.g., water), an increase (or reduction) in costs is recorded in conflict with the reduction (or increase) in consumption. This can be justified by different agronomic management practices and varying prices of utilities and inputs.

Concerning sustainability impacts, there is a recorded reduction in fertilizers (N, P, and K) and an increase in their efficiency. The application of the Decision Support System (DSS) has improved irrigation management, leading to a reduction in water consumption and an increase in efficiency. Additionally, in terms of fuel and pesticides, the usage of these varies significantly depending on the analysed agricultural company and individual parcels. On average, an increase in fuel (and consequently greenhouse gas emissions) and an increase in phytosanitary products used have been recorded.

When comparing farmers who adopted Decision Support Systems (DSS) with those who did not (using the Framework), the introduction of the solution had a positive impact on working hours. Moreover,

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responses from adopters in the "social questionnaire" indicated positive outcomes. Generally, a positive impact from the implementation of DSS on work activity was recorded. Though not unanimous, the solution favoured the majority of respondents, reflecting an increase in the ease of performing complex tasks and making decisions more efficiently and consciously. Additionally, the 10 farmers stated that the implementation of DSS has fostered the interest of the younger generation to work on their farm or in the agriculture sector, contributing to succession planning on the farm.

Concerning learning to use DSS, despite generating stress and being time-consuming, the process was stimulating and interesting for the majority of respondents. Finally, the implementation of the solution had a positive impact on the gender gap, fostering women's interest in working on the farm. Women on the farm also encouraged the purchase and adoption of DSS.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Italy).

## 5.19. TC 19 – Vegetables, Tomatoes, Automated greenhouse, The Netherlands

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | Delphy |
| TC sector | Vegetables |
| Crop/ Animal | Tomatoes |
| Biogeographical Region | Continental |
| Country | The Netherlands |
| Total number of parcels | 2 (1 with DATSs and 1 without DATSs) |
| Total size of these parcels | 8,5 ha (with DATS: 6 ha; without DATS: 2,5 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Automated greenhouse |
| DATS(s) commercial name | QMS Tomatos |
| DATS(s) description | The QMS tomatoes (Quality Management System) is a computer program designed for greenhouse cultivation, allowing users to set a cultivation plan based on specific company information, such as greenhouse properties, varieties, and start/end dates. It calculates crop development, production, and light demand, managing light availability for optimal scenarios. The software consists of three main components: Delphy dashboard (centralizing farm data), Climate profiler (machine learning model suggesting optimal climate), and Climate controller (translating recommendations into set points).<br>Sensors inside the greenhouse include a Load cell (measuring plant weight gain), Phytosense (measuring sap flow and stem diameter variation), and pointed micro-climate sensors (capturing microclimate for better heating decisions). The Climate computer integrates data, and a Weather station outside captures external climate conditions.<br>The technology works by establishing a cultivation strategy in QMS, considering location, greenhouse specs, etc. It calculates crop development and light requirements weekly, adjusting scenarios based on light availability. The adaptive strategy updates with real-time climate and crop data weekly. The Delphy dashboard centralizes data for analysis. When configured correctly, the system enables autonomous climate and irrigation management in the greenhouse. |
| DATS(s) Costs | • Initial investment: 8000 €<br>• Maintenance: 500 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of in0utes and utilities. |
| Environmental sustainability | The DSS provides the optimization of resource use, so it has a positive impact on the environment. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations and the reduction of inputs used. A concomitant increase in yields was recorded.

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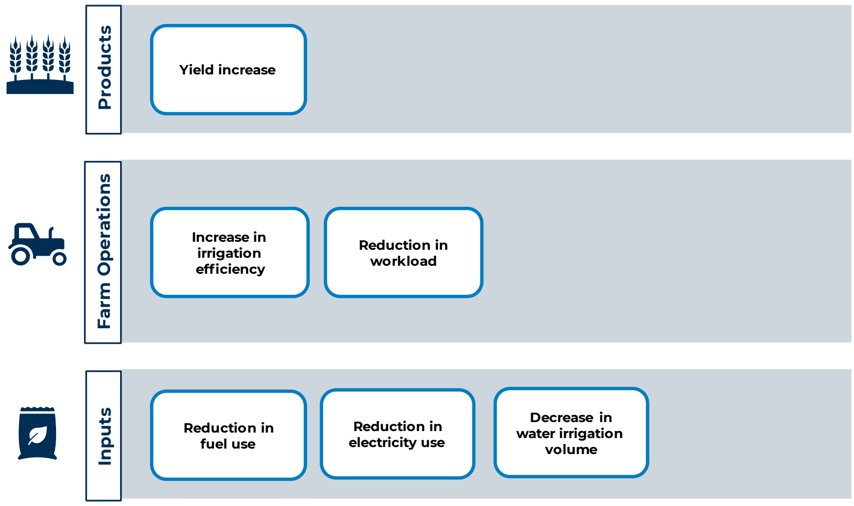


*Figure 60 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 19)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

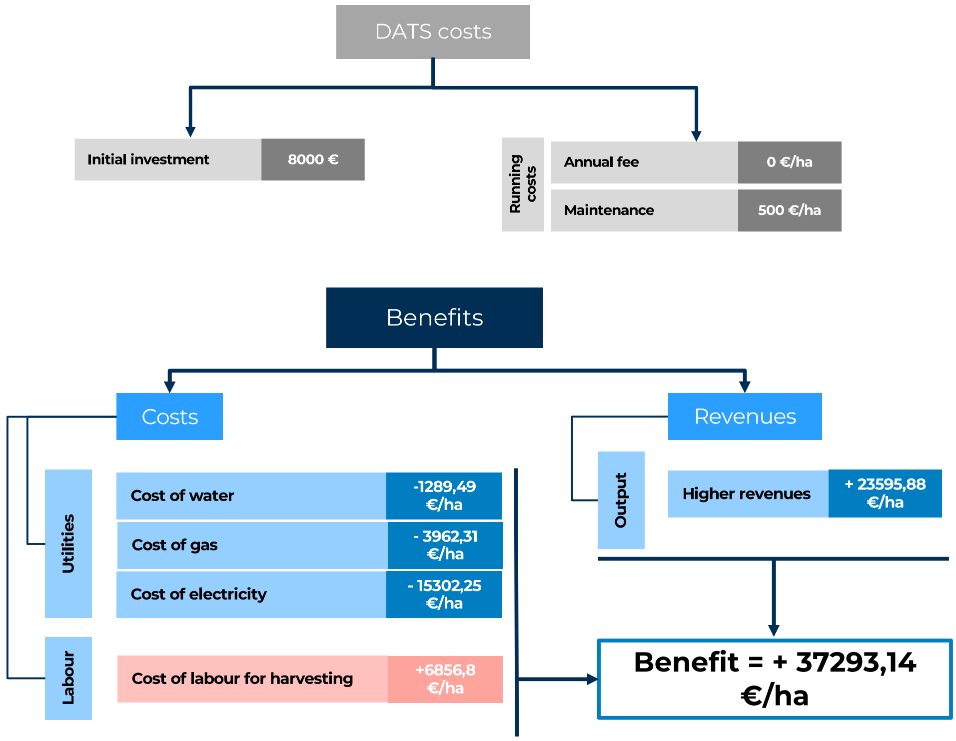


*Figure 61 - Cost-benefit analysis for TC 19*

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In this Test Case, the cost of the digital solution is composed by a maintenance cost of 500 €/ha and an initial investment of 8000 €. With the implementation of DATS, a benefit of + 37293,14 €/ha was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **+ 36793,14 €/ha (**+ 37293,14 €/ha – 500 €/ha).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 1 months (8000/(36793,14*6)).

### SUSTAINABILITY IMPACT

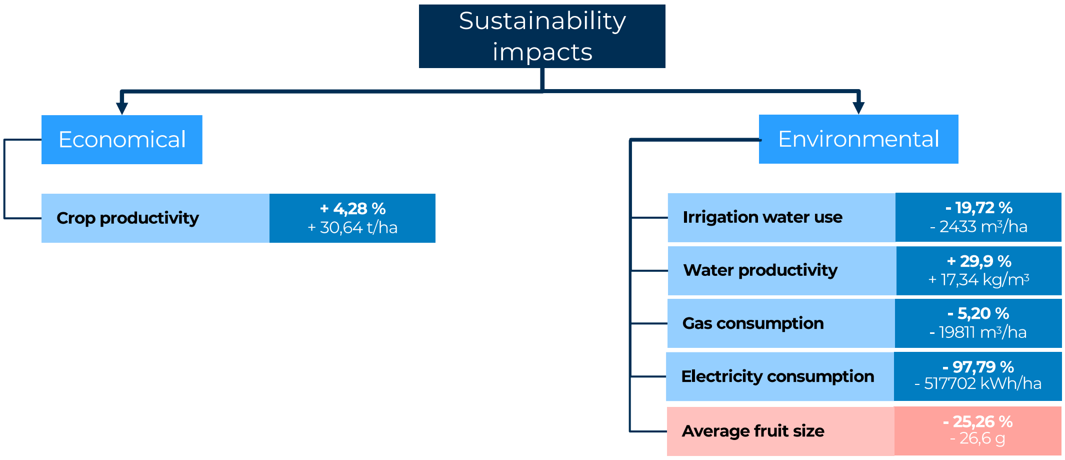


*Figure 62 - Sustainability impacts for TC 19*

### Discussion

While the analysis results are highly favourable, validating the representativeness of the presented findings proves challenging. Consequently, we deem it essential to engage in discussions with the TCL to evaluate the acquired inputs. Subsequent analyses will incorporate missing data related to work and inputs. It is crucial to acknowledge that, in this TC, farmers refrained from disclosing actual incurred costs due to competitiveness concerns. Instead, they provided average market prices for various inputs and utilities. This absence of information impeded a secondary truth check.

Derived from responses to the Social Questionnaire, it can be asserted that the implementation of the DATS solution has generally yielded positive impacts on work activities. Specifically, the DATS has afforded greater flexibility in organizing activities, managing work pace, and decision-making. Furthermore, the solution has positively influenced the farmer's confidence in the future and enhanced their ability to cope with climate changes.

### Data and analysis issues

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (The Nederland).

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## 5.20. TC 20 – Fruit, Bananas, Precision irrigation, Spain

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ANYSOLUTION SL (AnySol) |
| TC sector | Fruit |
| Crop/ Animal | Bananas |
| Biogeographical Region | Macaronesia |
| Country | (Spain, Canary Islands) |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total size of these parcels | 2,46 ha (2,24 ha with DATS and 0,22 ha without DATS= |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Precision Irrigation |
| DATS(s) commercial name | NADIA |
| DATS(s) description | NADIA is a platform that brings together a set of applications for the integration of the Internet of Things (IoT). It receives information from all connected sensors in real time. It stores and analyses this information and allows interaction with these sensors. |
| DATS(s) costs | • Initial investment: 15000 €<br>• Annual fee: 0 €/ha<br>• Maintenance costs: 0 €/ha |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of water. |
| Environmental sustainability | The DATS provides support in the implementation of sustainable agronomic practices. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations, although an increase in the use of irrigation water has been observed. A concomitant increase in yields was recorded.


*Figure 63 - Benefits experienced from the implementation of DATS in bananas cultivation (TC 20)*

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**COST-BENEFIT ANALYSIS (MONETARY IMPACT)**

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

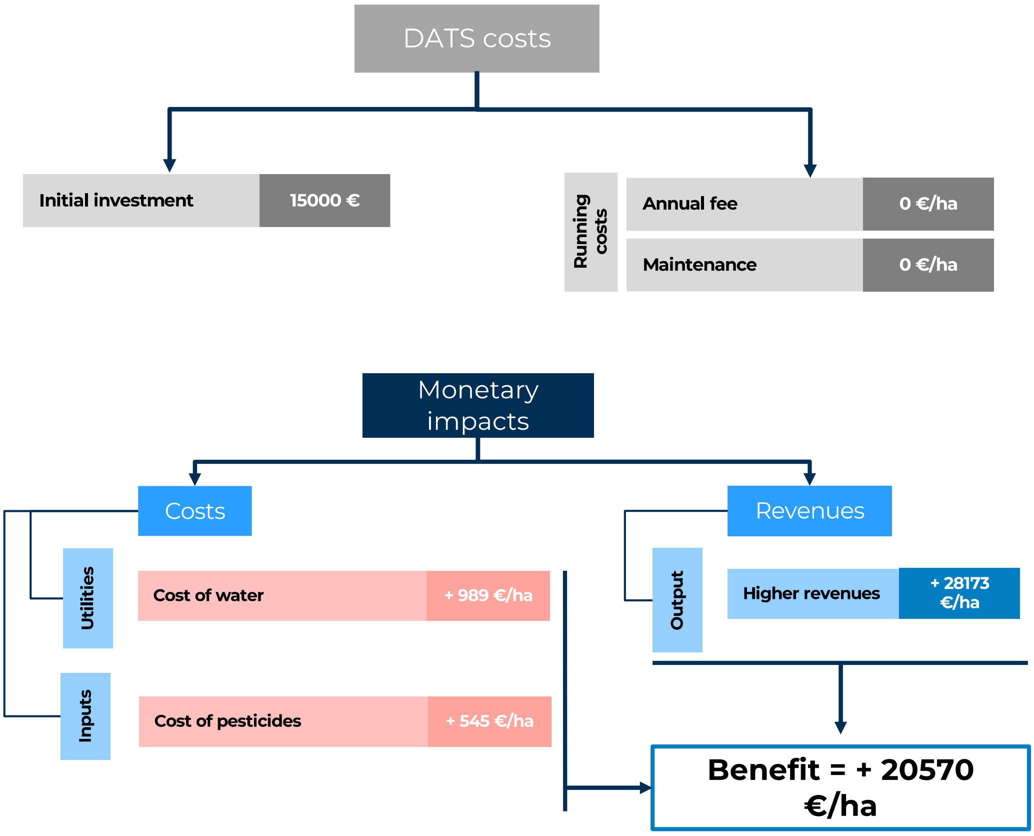


*Figure 64 - Cost-benefit analysis for TC 20*

In this Test Case, the cost of the digital solution is composed by an initial investment of 15000 €. With the implementation of DATS, a benefit of + 20570 €/ha was recorded.

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 4 months (15000/(20570*2,24)).

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## SUSTAINABILITY IMPACT

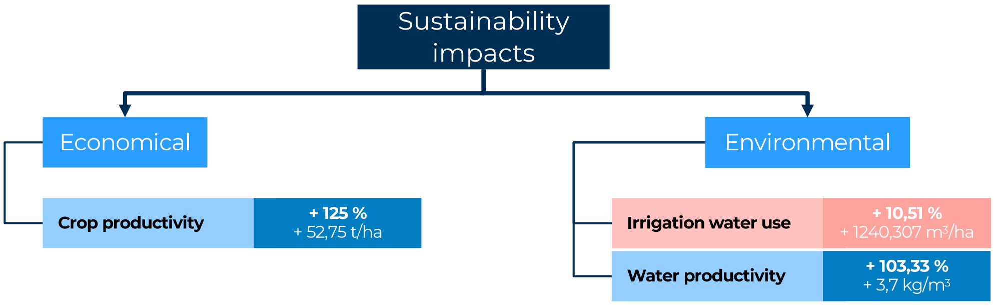


*Figure 65 - Sustainability impacts for TC 20*

### Discussion

Following the implementation of DATS, the farm experienced a **net benefit of + €20,570/ha**, attributed to a substantial increase in revenue. The analysis of benefits excluded the cost of DATS, as it is entirely free for farmers. Despite the rise in revenue, there was a general increase in all costs, including utilities and inputs. Although not factored into the analysis due to incomplete information, labour costs are anticipated to rise post-implementation of the solution. Farmers achieved higher revenue due to increased yields and a 6.25% uptick in the selling price of bananas. This surge is credited to the enhanced product quality produced by farmers utilising DATS compared to non-users. Concerning sustainability impacts, the solution primarily influenced irrigation. While there was a rise in water consumption, it was proportionally less than the increase in production, leading to improved water productivity.

In terms of the social questionnaire, the respondent conveyed that the implementation of DATS had a generally positive impact on work activities. Specifically, the solution aided in resolving unforeseen problems, streamlined the execution of complex tasks, reduced work complexity, and enhanced the balance between work and leisure time. The solution positively affected farmers' confidence in the future and their ability to manage climate changes. Regarding the learning curve for using DATS, it did not induce significant stress and was not excessively time-consuming. Conversely, the respondent found learning to use the solution to be stimulating and interesting.

### Data and analysis issues

The sole data available on labour productivity pertains to the count of individuals engaged in field visits and irrigation. Unfortunately, details regarding the average hours worked are not furnished. Despite our efforts to acquire this information from the TCL, our attempts proved unsuccessful. In the forthcoming round of data collection, we plan to incorporate analyses that consider this missing information. In theory, and extrapolating from the sole data at our disposal, we anticipate that the rise in labor costs is linked to the necessity for a greater workforce in both irrigation and field visits. This need arises from both an escalation in production and an expansion in the size of the cultivated area.

## 5.21. TC 21 – Vegetables, Tomatoes, Automated greenhouse, Finland

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | LUKE |
| TC sector | Vegetables |
| Crop/ Animal | Tomatoes |
| Biogeographical Region | Boreal Region |
| Country | Finland |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total size of these parcels | 2,487 ha (with DATS: 1,2 ha; without DATS:1,287 ha) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Automated Greenhouse |
| DATS(s) commercial name | Digitally controlled dimmable led lights (by Signum).<br>Kathari water disinfection system for recirculation of irrigation water |
| DATS(s) description | The primary artificial lighting source in the greenhouse consists of dimmable top LED lights from Signum, with red as the dominant wavelength and some blue, generating approximately 500 µmols m-2 s-1 according to theoretical efficacy. These LEDs can be adjusted from 10% to 100% brightness, providing seamless control over light intensity. The grower has the flexibility to determine the start and end times of artificial lighting. The degree of light emission from the lamps is automatically regulated based on the incoming natural radiation, with a predefined threshold determining whether lamp light is required and to what extent. Although the threshold may be influenced by electricity prices, the ultimate decision rests with the grower, with no automatic connection to real-time electricity price data. As the top LED lights serve as the exclusive source of artificial lighting, the irrigation system is now synchronized with the timing of light emission from the dimmable lamps. Previously, during winter, irrigation timing relied on calculated radiation, given the stable light conditions from artificial sources. With the variability introduced by the dimmable lights, irrigation timing is now integrated with light levels. A pyranometer inside the greenhouse measures light intensity, and this, along with natural radiation, is used to calculate prevailing radiation levels.<br>While the grower still manually sets the clock times for the first three morning irrigation cycles, subsequent irrigation timings are automatically determined by radiation levels and water content measurements obtained from the Trutina system's slab sensor. This sensor helps the grower ensure that irrigation aligns with the plant's needs. Simultaneously, prevailing light levels influence adjustments in the greenhouse's temperature and heating systems. When radiation levels decrease, the heating pipes are modified to maintain the required temperature for optimal plant activity, such as transpiration. The integration of these key growth factors—radiation, temperature (heating), and irrigation—marks a significant advancement, aligning with the principles of Plant Empowerment. This concept aims to balance key growth factors (radiation, heat, water, CO2, assimilates) for enhanced yields and improved product quality, presenting a valuable learning opportunity for data-driven cultivation.<br>In addition to the advanced lighting and irrigation systems, a digitally controlled ultrafiltration system (Kathari UF1) from the Van der Ende Group |

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| | |
|---|---|
| | has been implemented for one hectare. Since its installation in March 2023, drainage water is recirculated, and only occasional emissions of flushback water (used for filter cleaning) are directed to the municipal drainage system. The filtration system is digitally integrated with the irrigation system to dynamically adjust nutrient concentrations in the irrigation water, further optimizing the growing environment. |
| DATS(s) cost | • Initial investment: 1101000 €<br>• Maintenance cost: 3015 €/y |

| **EXPECTED BENEFITS (from TCs)** | |
|---|---|
| Crop growth steering | Dynamic use of artificial light according to natural radiation conditions and electricity prices (at the same time plants' needs for light must be taken into account). |
| Cost reduction | Digitally controlled dimmable led lights contributes to decreasing electricity costs as led lights are less energy consuming than the standard high pressure sodium luminaires (used in the non-DAT farm).<br>Kathari water disinfection system makes it possible to reduce the use of agrochemicals (fertilizers) and water due to recirculation of irrigation water. |
| Data collection and decision making | Digitally controlled dimmable led lights (combined with other DATSs) saves time and makes simultaneous management of different growth factors possible without huge cognitive load and constant manual adjustments.<br>Kathari water disinfection system keeps track on the amount of water disinfected and given back to plants through recirculation and thus informs the farmers on the basics of cost reduction concerning water use. The amount of incoming water to the system and water going out to the greenhouse is measured and their difference informs on the amount of recirculated water. |
| worker-power and labour time | Digitally controlled dimmable led lights saves the farmer's time and labour by simplifying decision making concerning steering plant growth and use of inputs (electricity, and through integration with other DATSs, water). The grower still, as before this DAT when he had the standard high pressure sodium lamps, manually determines the clock times of the 3 first irrigation bouts in the morning. But from that onwards timing of irrigation bouts are determined automatically by measurements of the radiation levels inside the greenhouse and the water content of the substrate. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to the reduction in workload and electricity consumption. A concomitant increase in yield was recorded.

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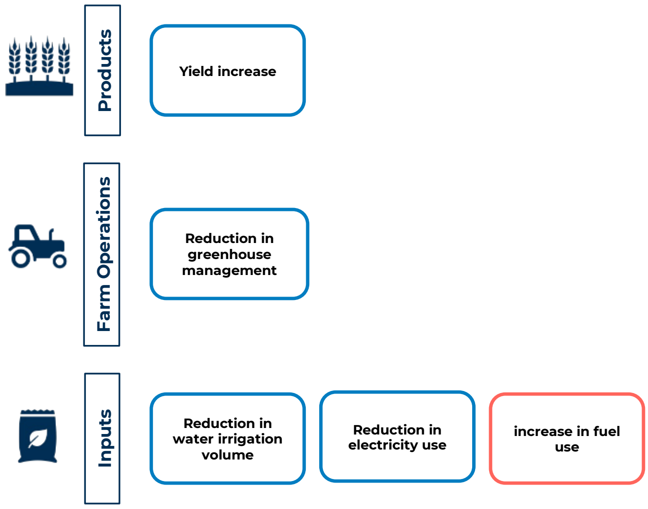
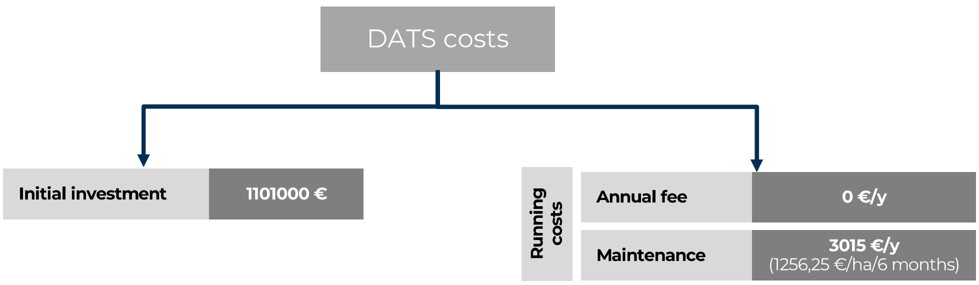



*Figure 66 - Benefits experienced from the implementation of DATS in tomatoes cultivation (TC 21)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

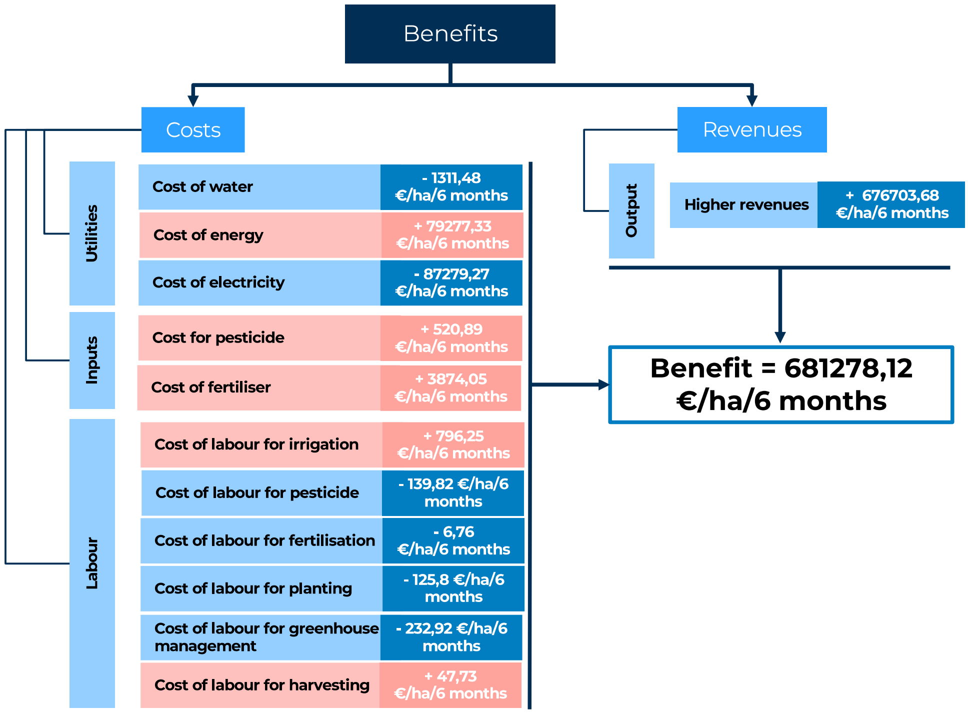



*Figure 67 - Cost-benefit analysis for TC 21*

In this Test Case, the cost of the DATSs is composed by an annual maintenance cost of 3015 €/y (1256,25 €/ha/6 months) an initial investment of 1101000 €. The initial investment includes the acquisition of dimmable LED lights (€1.5 million), their installation (€23,000), and the lease of the Kathari ultrafiltration system (€56,000). It is important to note that in this scenario, the farmer is eligible for a 30% investment subsidy for the lighting fixtures, which amounts to 30% of the total cost. Additionally, they are entitled to a compensation equivalent to 50% of the cost of the Kathari ultrafiltration plant through their cooperative packing house.

With the implementation of DATS, a benefit of + 681278,12 €/ha/6 months was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **+ 680022,87 €/ha/6 months** (681278,12 €/ha/6 months – 1256,25 €/ha/6 months).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 7 months (1101000/(680022,87*2*1,2)).

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**SUSTAINABILITY IMPACT**

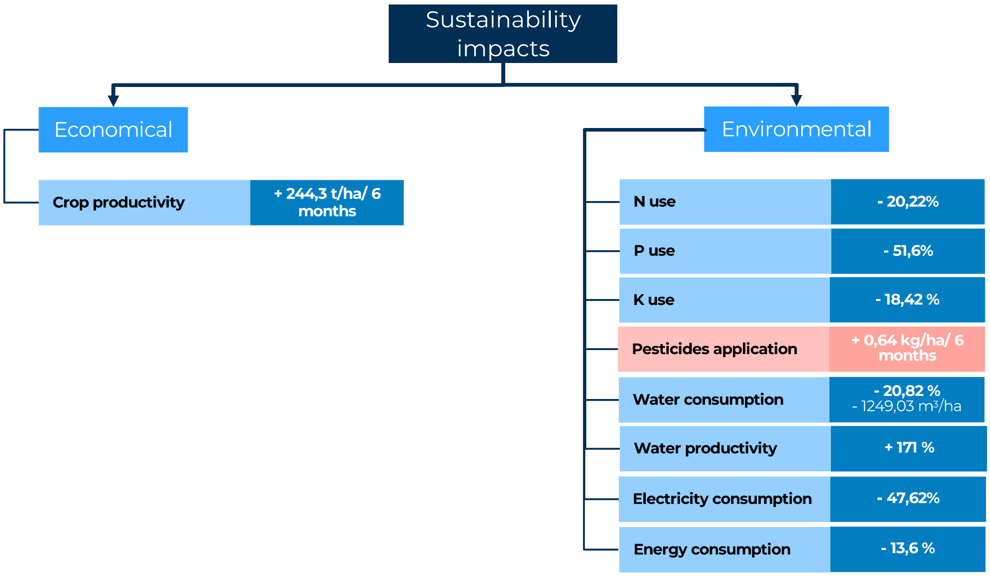



*Figure 68 - Sustainability impacts for TC 21*

## Discussion

Normally, both greenhouses operate throughout the entire year and typically initiate their cultivation cycle in June/July for DATS company or August for non-DATS company. However, during the exceptional crop cycle of 2022-23, the non-DATS company unexpectedly ceased operations in February 2023, laying off workers for a period of 2,5 months, only to resume activities in May. This decision was influenced by uncertainties regarding the development of electricity prices during the winter months. The implementation of DATS, in addition to the benefits outlined below, also mitigated the impact of external variables such as inflation, enabling the user farm to maintain profitable production even in an unfavourable economic situation.

This clarification is crucial for analysis because a company operating at full capacity throughout the year understandably incurs much higher costs compared to a greenhouse producing only during a limited period. Consequently, the analyses were conducted on a per-hectare and per-6-month basis, acknowledging that this approach may not fully account for the variability of all elements (e.g., fuel usage varying between warm and cold periods). Despite the rise in utility prices, DATS has empowered growers to sustain year-round production without the need to shut down their greenhouses. Indeed, the greenhouse using DATSs has been able to better regulate electricity usage (LED lights consume less, even though fuel consumption increases as LEDs produce less heat).

After the implementation of the DATSs, there was a recorded decrease in costs, primarily driven by reductions in water and electricity costs, resulting in a net benefit of + 680022,87 €/ha/6 months. Although there was an increase in labour hours, DATS facilitated more efficient greenhouse management. The benefits from the Kathari system are expected to be revealed fully during the next cropping cycles, when the system is in use throughout the cycles. For the first data year, it was in use only during the first 2,5 months of the cropping cycle, having been installed in March 2023.

In terms of sustainability impacts, it can be stated that the solution has facilitated a better understanding of crop needs and the modification of agronomic choices related to fertilizers, pesticides, and water requirements. Additionally, there was a decrease in electricity consumption and an increase in water productivity. The benefits related to water consumption and water efficiency were also influenced by different substrate management between the two greenhouses. The DATS farms grow in organic substrate (peat, a mixture of peat and moss), resulting in smaller water consumption compared to the non-DAT farm that uses rockwool. The non-DATS farm grows in rockwool and utilizes HPS lamps that create warm conditions in the top parts of the crop, causing higher evaporation.

Regarding energy, it is crucial to acknowledge that despite a decrease in energy consumption, there has been an increase in energy costs. This rise can be attributed to the diverse composition of the energy sources employed for greenhouse heating and their varying prices. It is also essential to consider that the greenhouse equipped with DATSs receives district heating, unlike the one without DATSs. This disparity significantly affects both the quantity and cost of energy utilized for greenhouse heating. Furthermore, in the DATS-free farm, traditional light bulbs generate more heat compared to the new LED lighting system implemented in the greenhouse. This discrepancy has influenced the energy consumption required to maintain the indoor environment at a suitable temperature. The reduction in overall energy consumption has consequently resulted in a decrease in $CO_2$ emissions.

Labour productivity has not been presented in this analysis due to the aforementioned limitations, as it would fail to encompass other activities. None of the hired workers have been trained on the use of DATs. Their use is solely the responsibility of the two owners of the DATS farm. The owners have not taken formal training courses on the use of the two DATs. Shifting focus to the "social questionnaire", it can be affirmed that the implementation of DATS has simplified the execution of complex tasks, enabled more efficient and conscious decision-making, and provided greater flexibility in planning and executing work activities. The respondent reported a positive trend regarding the impact of the solution on the sector's attractiveness and generational transition. DATS has replaced some tasks traditionally performed by farmers.

**Data and analysis issues**

It is important to note that biological insecticides and antagonistic insects are not counted in the cost and impact calculations, although they are the major methods of plant protection in both farms. This choice stems from the primary focus of the analysis, which is cantered on evaluating the influence of DATSs on the usage of synthetic plant protection products, known for their more significant environmental impact.

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

## 5.22. TC 22 – Meat, Poultry, Cleaning robot, United Kingdom

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | FLOX |
| TC sector | Livestock – Meat |
| Crop/ Animal | Poultry farming |
| Biogeographical Region | Atlantic |
| Country | SW England – Tiverton |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total of animals in these parcels | 127500 chickens (with DATS: 64000 chickens; without DATS 63250 chickens) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Cleaning robot |
| DATS(s) commercial name | FLOX |
| DATS(s) description | The DATS system aims to support poultry farm staff in effectively managing their poultry sheds. It works toward minimizing input costs, such as gas and feed overuse, while enhancing bird performance and, crucially, prioritizing bird welfare, which directly influences both performance and inputs. The system generates data that can be shared throughout the supply chain to enhance planning and auditing processes. While DATS operates within the poultry shed, its aggregated data is accessible at the site office, enabling farmers to oversee all their sheds.<br>Focused specifically on the poultry growing phase, this system alleviates the need for farmers to frequently inspect their sheds throughout the day to ensure bird welfare and monitor the shed's climate. Diligent monitoring should translate to positive outcomes when birds are eventually transferred to the factory. Failure in this regard or disease outbreaks can severely impact bird welfare, resulting in significant losses up the supply chain.<br>The system operates 24/7, constantly observing the birds even when farmers are not present, offering crucial alerts and data to mitigate potential welfare-related incidents. Its functionality involves multiple cameras capturing imagery data transmitted via wired cabling, while IoT sensors scattered across the shed monitor temperature, humidity, and at times, ammonia levels using DoL sensors. Data processing occurs in the site office, facilitated by a computer and GPU, and often integrates information from existing farm sensors, such as temperature and water usage. |
| DATS(s) cost | • Initial investments: 40000 €<br>• Set-up (training): 36 €<br>• Maintenance costs: 0,00078125 €/animal |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Labour reduction | DATS makes it possible to reduce the number of visits of the sheds |
| Product quality increase | The system provides farmers with advises key alerts and data to help reduce the risk of events or issues related to welfare harm occur. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to the reduction of workload on the farm and the reduction of inputs used (with the exception of fuel). A concomitant increase in production was recorded.

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

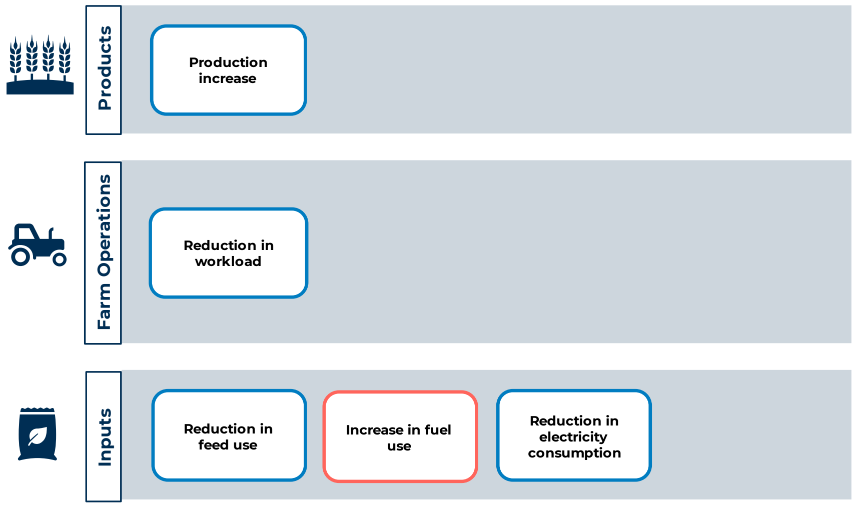
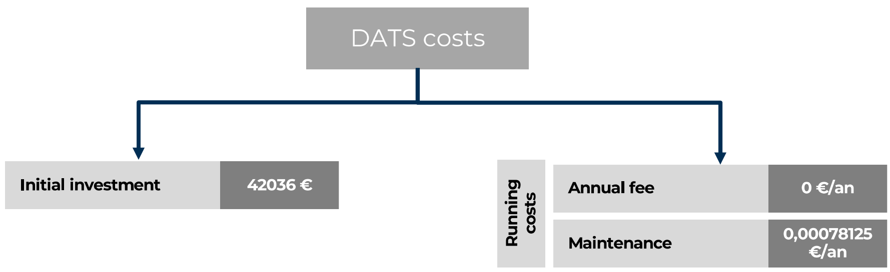



*Figure 69 - Benefits experienced from the implementation of DATS in a poultry farming system (TC 22)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

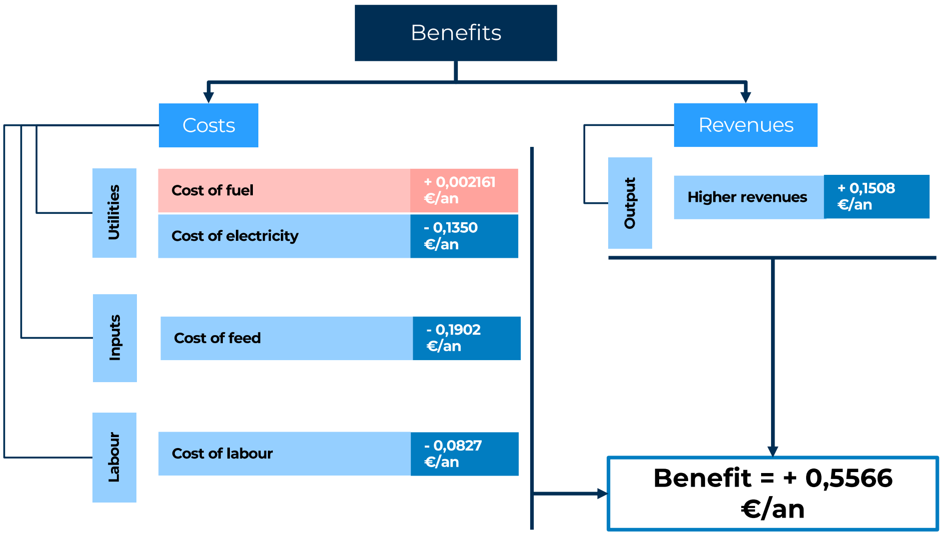



*Figure 70 - Cost-benefit analysis for TC 22*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €0,00078125 per animal and an initial investment of 40036 € (composed of 40000 € for the purchase of hardware and software and 36 € for the set-up).

With the implementation of DATS, a benefit of + 0,5566 €/animal was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 0,5488 per animal** (+ 0,5566 €/animal – 0,00078125 €/animal).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 10 months (40036/(0,5488*64000)).

## SUSTAINABILITY IMPACT

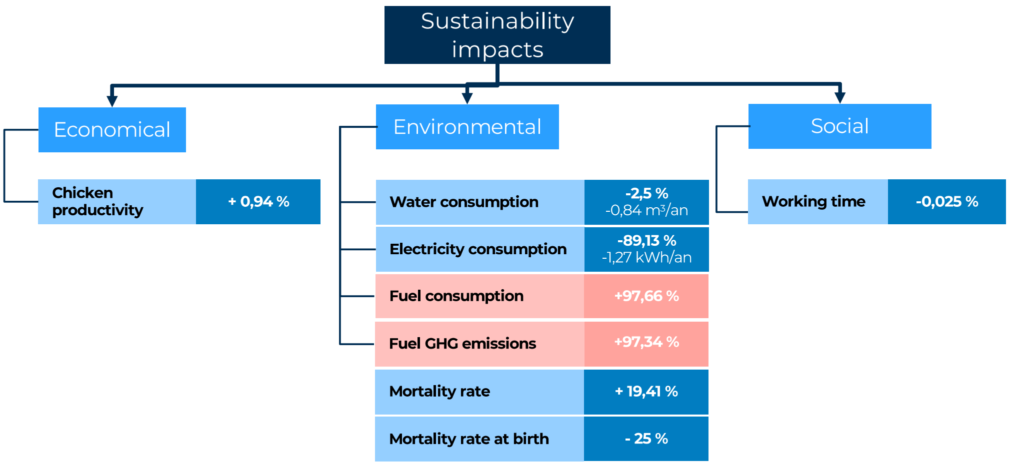



*Figure 71 - Sustainability impacts for TC 22*

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

**Discussion**

The DATS has allowed the farmer to reduce utility costs (excluding fuel), inputs, and labour. Although the selling price of meat remained unchanged, the increase in production enabled an increase in revenues. The combination of the generalized cost reduction and revenue increase resulted in a net benefit of +0.5566 €/animal. The payback period for the investment in DATS is 10 months.

Regarding sustainability impacts, on one hand, DATS has reduced water and electricity consumption, but on the other hand, it has increased fuel consumption. It's worth noting that only water consumption is reported, and its cost is not included as the farmer draws from a private source. The increase in fuel consumption has consequently raised greenhouse gas emissions. In terms of animal welfare, an increase in mortality rate and a decrease in birth mortality have been observed. It is complex to attribute these impacts exclusively to the implementation of the solution using only one round of data.

Additionally, a reduction of 52 hours per year in labour for the DATS user has been recorded. Furthermore, based on responses from the "social questionnaire," it can be stated that the implementation of the DATS solution has had a generally positive impact on work activities. In particular, the solution helps solve unforeseen problems, facilitates the execution of complex tasks, and improves the balance between work and free time. The solution has had a positive effect in making the farmer feel more secure about the future and better able to manage climate changes. The respondent has reported a positive trend regarding the impact of the solution on the sector's attractiveness and generational transition. Regarding the learning curve for using DATS, it did not generate significant stress and was not particularly time-consuming. In fact, learning to use the solution was stimulating and interesting for the respondent.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (The Netherlands).

Fuel price: https://it.globalpetrolprices.com/United-Kingdom/gasoline_prices/

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

## 5.23. TC 23 – Meat, Cows, Feeding robot/ Heat detector/ Calving detectors, France

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | IDELE |
| TC sector | Livestock – Meat |
| Crop/ Animal | Cows |
| Biogeographical Region | Continental |
| Country | France |
| Total number of parcels | 2 (1 with DATS and 1 without) |
| Total of animals in these parcels | 326 cows (with DATS: 203 cows; without DATS: 123 cows) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Feeding robot/ Heat detector/ Calving detectors |
| DATS(s) commercial name | Feeding robot: Developed by Lely;<br>Heat detectors: Provided by Lely with the embedded technology developedby Allflex (MSD now);<br>Calving detectors: Developed by Evolution (Innoval Now). |
| DATS(s) description | Feeding robot: This system independently loads and dispenses feed rations to animals, aiming to enhance ration quality, animal growth, milk production in suckler cows, and align distribution with animal needs. The feeding robot's software tracks total feed distribution (forage, concentrate), feeding sessions, and leftover amounts, accessible via computer software and a smartphone app for remote monitoring. Utilizing loading cells and optical sensors, it accurately measures feed weight and estimates leftovers in troughs. Installation by the manufacturer is necessary, customizing the kitchen, feed grabber, robot route, and fences to suit individual farm conditions.<br>Heat detection system: Worn around the animals' necks, this collar sensor observes behaviours and triggers alerts when an animal is suspected to be in heat. It aims to save farmers' time and improve heat detection accuracy. The software generates activity and rumination patterns, identifies cows in heat with confidence indicators, and integrates this data with herd management software (mating/calving dates, calving intervals). The system's reliability prompts automatic alerts to the inseminator upon detecting a cow in heat. Accessible through computer software and a smartphone app, though the collars require proximity to an antenna for remote access. Utilizing collar-mounted accelerometers measuring neck movements, the system's antennas need installation by the manufacturer, with specific positioning according to each farm's conditions. Afterward, farmers can manage the collars.<br>Calving detection: Placed near the tail of cows or heifers nearing calving, this system sends SMS and phone call alerts during calving. These alerts are visible on a phone for remote monitoring. Sensors, based on accelerometers, detect calving events. Antennas require manufacturer installation, adjusting positioning and numbers based on farm conditions. After setup, farmers can independently manage the sensors. |
| DATS(s) cost | • Initial investment: 181780€<br>• Maintenance: 3,44 €/100kg |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |

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

**Benefits experienced from the implementation of DATS**

Impacts were identified in relation to on-farm operations and the reduction of water. A simplification in administrative activities feeding activities was observed, together with a reduction in workload.

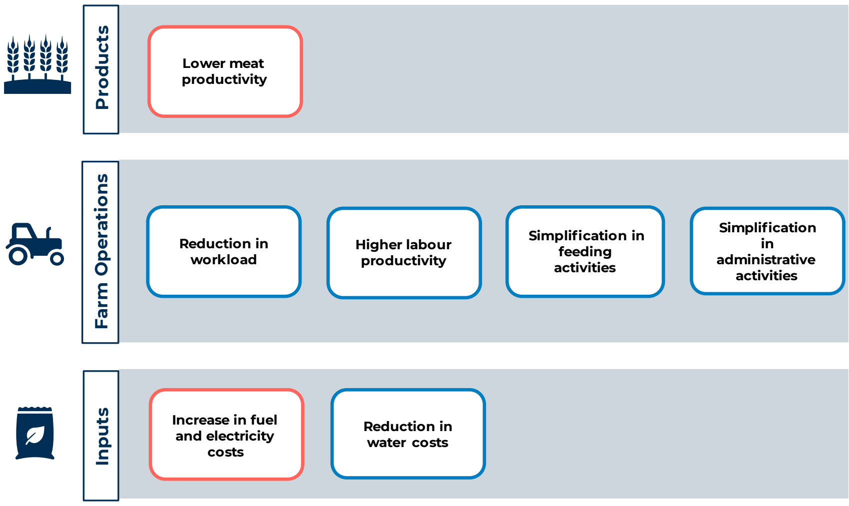
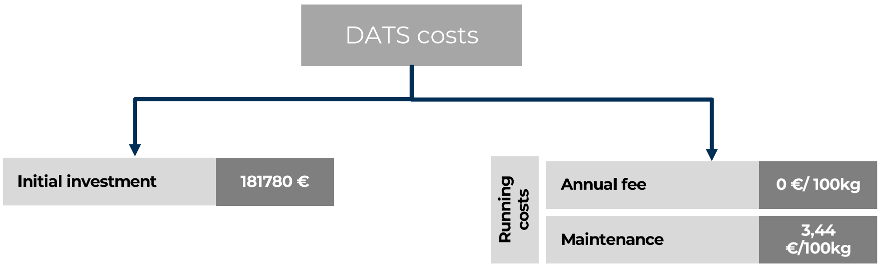



*Figure 72 - Benefits experienced from the implementation of DATS in cattle farm (TC 23)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.



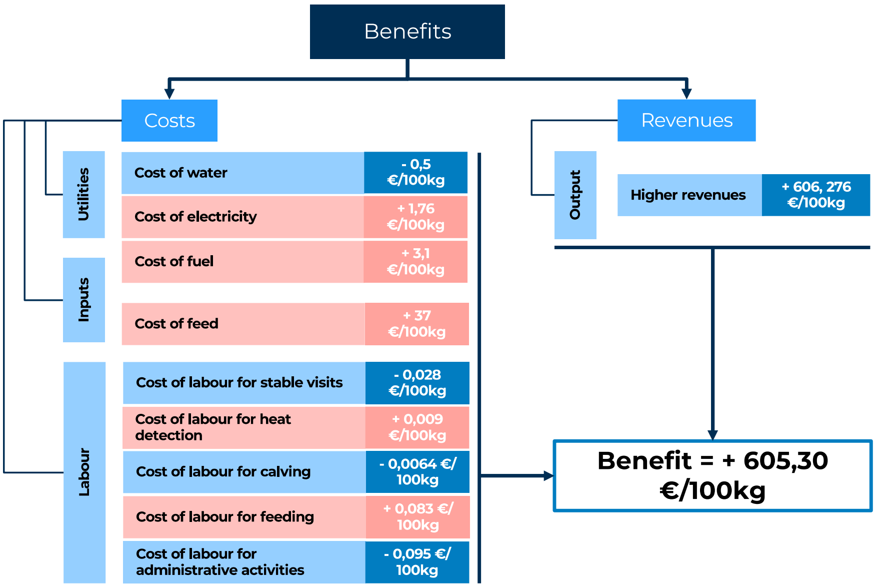



*Figure 73 - Cost-benefit analysis for TC 23*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €3,44 € per 100 kg live weight and an initial investment of 181780 € (composed of feeding robot: 166000 €, heat detection system: 11200 €, calving detection system :4580 €).

With the implementation of DATS, a benefit of + 605,3 €/100kg of live weight was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 601,86 per 100 kg live weight (**+ 605,3 €/100kg of live weight – 3,44 €/100kg of live weight).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 4 months (181780/(601,86*820,28)).

## SUSTAINABILITY IMPACT

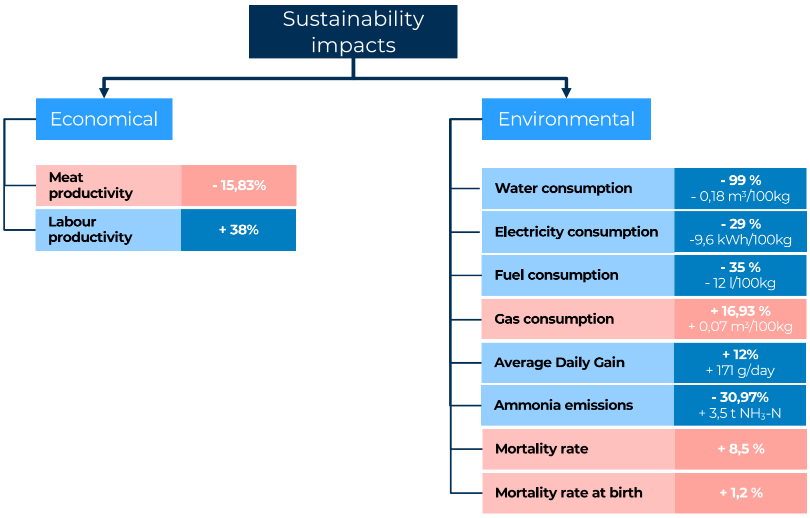



*Figure 74 - Sustainability impacts for TC 23*

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

**Discussion**

The implemented DATS not only aids farmers in monitoring and recording barn and herd data but also assists them in effectively tracking crucial management indicators. This leads to improved herd management and more efficient water usage. Despite the rise in fuel and electricity costs, their consumption has decreased due to a variance in utility costs between the two farmers. If identical prices were enforced, the user farm would experience a reduction in both fuel and electricity costs.

The two examined companies exhibit significantly different levels of meat productivity, which cannot be solely attributed to technology usage. While the user company has witnessed a decline in productivity, the enhancement in meat quality has enabled them to sell the final product at a higher price, resulting in increased revenue. The combination of cost reduction and revenue increase has yielded a **net income of 601,86 per 100 kg live weight**. Financial analysis underscores that the return on investment in DATS is achieved within 4 months.

As mentioned earlier, DATS has reduced work hours and streamlined barn monitoring activities, leading to increased labour productivity. In terms of sustainability impacts, it is crucial to highlight that DATS has reduced utility consumption except for gas. It should be noted that gas is not included in the costs, as the TCs claimed to use biogas produced on the farm. Moreover, the impact of DATS on animal health is not straightforward; it has resulted in an increase in average daily gain but also an uptick in mortality, including at birth. These key performance indicators must be diligently monitored in future data collections. Finally, a reduction in ammonia emissions has been recorded.

When comparing farmers who adopted DATS with those who did not (using the Framework), the introduction of the solution had a neutral impact on workers' tasks, as measured by the hours spent on activities. However, responses from adopters in the "social questionnaire" indicated positive outcomes. Overall, the implementation of the DATS solution has had a positive impact on work activities, enabling farmers to work more efficiently and flexibly. DATS has replaced the farmer in some tasks. Regarding learning to use DATS, it did not induce particular stress and was not particularly time-consuming; in fact, learning to use the solution was stimulating and interesting for most respondents.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (France).

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

## 5.24. TC 24 – Meat, Pigs, Automated monitoring, Belgium

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | KU Leuven |
| TC sector | Livestock – Meat |
| Crop/ Animal | Pigs |
| Biogeographical Region | Continental |
| Country | Belgium |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total of animals in these parcels | 3782 pigs (with DATS: 682 pigs; without DATS: 3100 pigs) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Automated monitoring |
| DATS(s) commercial name | PigUp software, Acerva |
| DATS(s) description | The farm utilizes various data and automation technologies (DAT) to streamline operations. PigUp software manages the pigs, especially the sows. Several systems are in place: automated ventilation, sow feeding, remote light control, piglet weighing scale, and barn climate monitoring. Acerva provided and installed the feeding and ventilation systems, while the farmer installed the others. These DAT aim to reduce workload, enhance efficiency, and importantly, potentially improve pig welfare. They're applied across all stages of pig rearing at the Beselare barn. |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to on-farm operations.

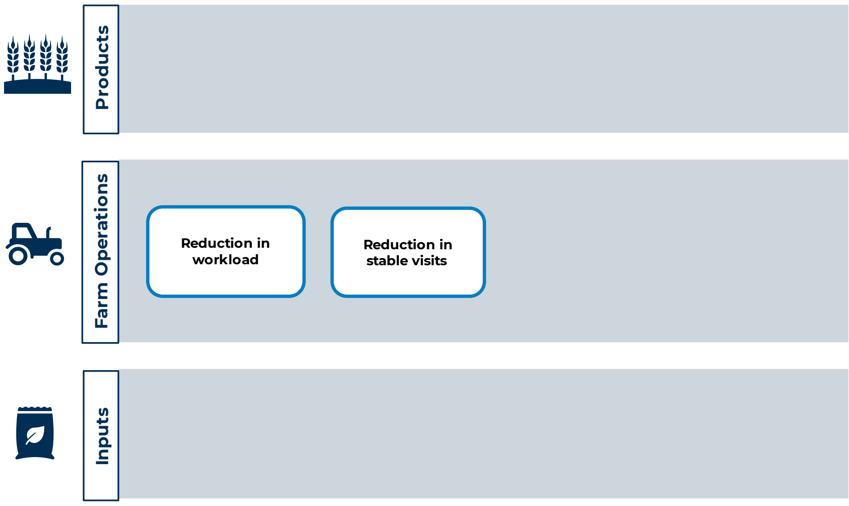



*Figure 75 - Benefits experienced from the implementation of DATS in the swine farm (TC 24)*

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

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

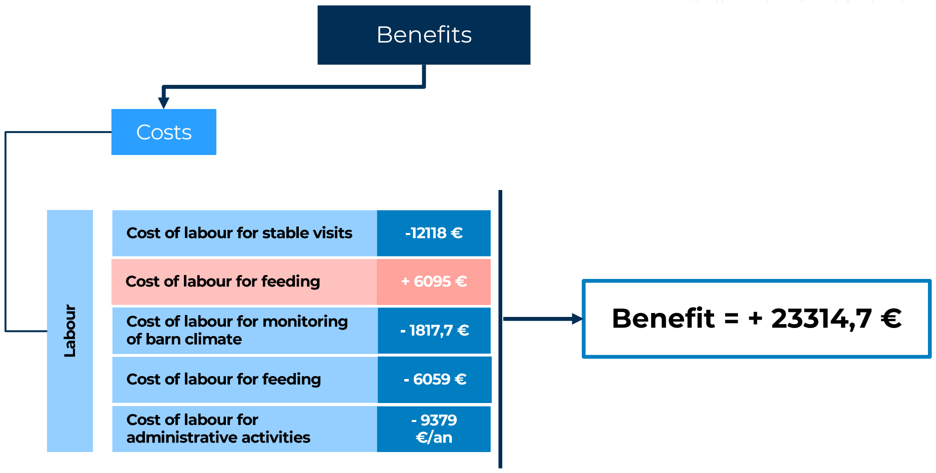



*Figure 76 - Cost-benefit analysis for TC 24*

The cost of the digital solution was not provided by the TC, so we cannot present it in this first analysis. In the next analysis, the investment cost and any maintenance costs or annual fees will be included in the net benefit calculation. With the implementation of DATS, a **benefit of + 23314,7€** was recorded (at company level). The benefit, in this case, refers only to the reduction of labour costs.

## SUSTAINABILITY IMPACT

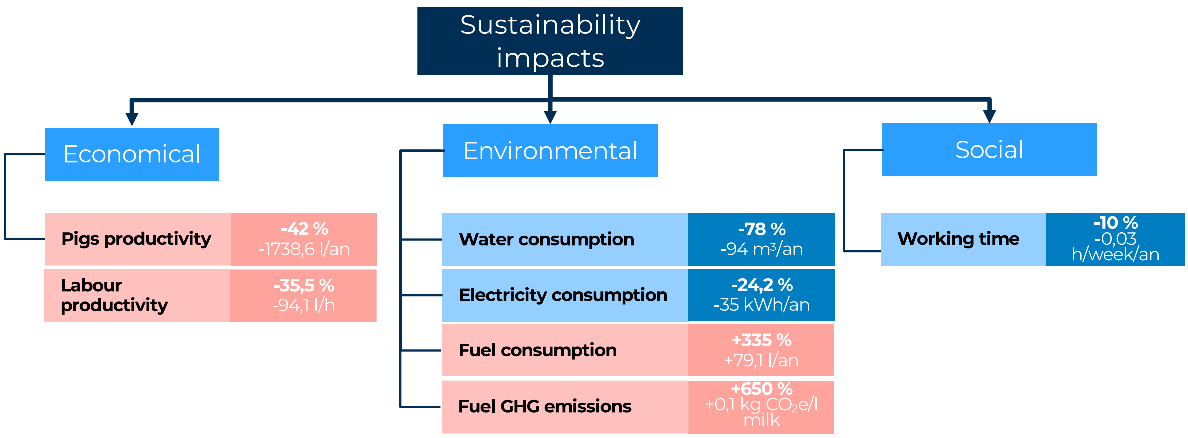



*Figure 77 - Sustainability impacts for TC 24*

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

**Discussion**

The analyses conducted on the TC exclusively consider the impact of DATS on work activities, as there is insufficient data available to conduct analyses on other key performance indicators (KPIs). The missing data related to the non-using farm will be included in the next data collection, enabling updates to the analyses to encompass additional areas of impact.

Regarding the analysed data, it can be asserted that DATS has led to a reduction in the workload for farmers utilizing the solution, enhancing the efficiency of all activities related to barn and animal monitoring. With the exception of the increased labour cost for feeding, all other activities have shown a decrease in hours and, consequently, cost.

This analysis does not present labour productivity due to the aforementioned limitations, as it would fail to cover other activities. Shifting focus to the "social questionnaire," it can be affirmed that the implementation of the DATS solution has generally had a positive impact on work activities, enabling farmers to work more efficiently and flexibly. DATS has taken over some tasks previously performed by farmers. Regarding the learning process of using DATS, it did not induce significant stress and was not excessively time-consuming; on the contrary, learning to use the solution was found to be stimulating and interesting by the majority of respondents.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Germany).

The missing data will be inputted to facilitate analyses for the upcoming data assessment. In addition to providing a more comprehensive analysis of the implementation's impacts, these data will allow us to quantify the net benefits and assess sustainability impacts more accurately.

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

## 5.25. TC 25 – Dairy, Cows, Feeding robot/ Heat detector/ Calving detectors, France

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | IDELE |
| TC sector | Livestock – Dairy |
| Crop/ Animal | Cows |
| Biogeographical Region | Continental |
| Country | France |
| Total number of parcels | 2 (1 with DATS and 1 without) |
| Total size of these parcels | 281 cows (with DATS: 207 cows; without: 74 cows) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Feeding robot/ Heat detector/ Calving detectors |
| DATS(s) commercial name | Feeding robot: Developed by Lely<br>Activity sensors: Developed by Allflex Livestock Intelligence |
| DATS(s) description | Automated Feeding System: This software tracks the distribution of feed (forage, concentrate), detailing amounts dispensed, feeding sessions, leftover quantities, and individual cow milk yields (connected to milking parlour data). This data is accessible via computer software and a smartphone app, enabling remote access. The system relies on loading cells for weighing feed and optical sensors to estimate leftover feed in the troughs. Activity Monitoring: This software generates activity and rumination patterns and identifies cows in heat. For each cow, it provides a confidence indicator, heat date and time, and suggested insemination timing, linking this data with herd management software (including milk yield, mating and calving dates, calving intervals). It's accessible via specific computer software and a dedicated smartphone app developed by the manufacturer, or directly integrated into the farmer's herd management software. Access is available remotely, utilizing accelerometers on ear tags to measure head movements. |
| DATS(s) costs | • Initial investment: 210000€<br>• Maintenance cost: 2800 € (2,18€/1000 l of milk) |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |

**Benefits experienced from the implementation of DATS**

Impacts were identified in relation to on-farm operations and the reduction of fuel. A simplification in milking and feeding activities was observed, together with a reduction in workload. In addition, an increase in milk production was recorded.

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

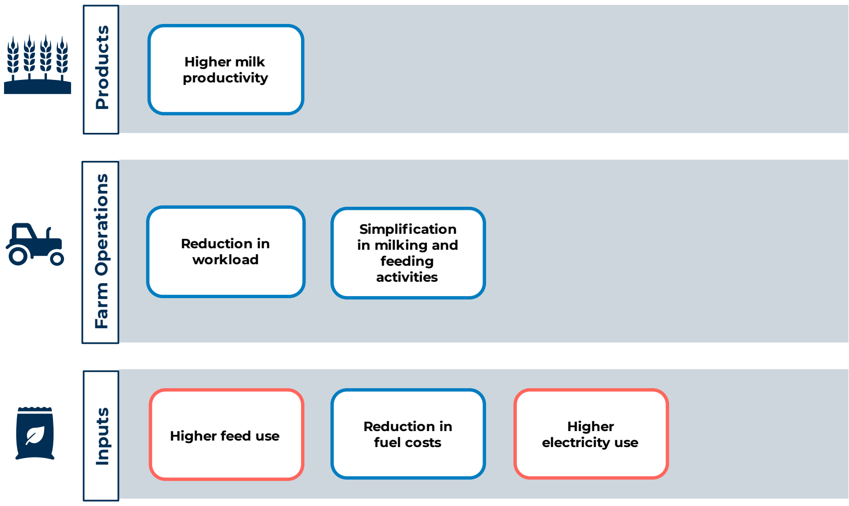
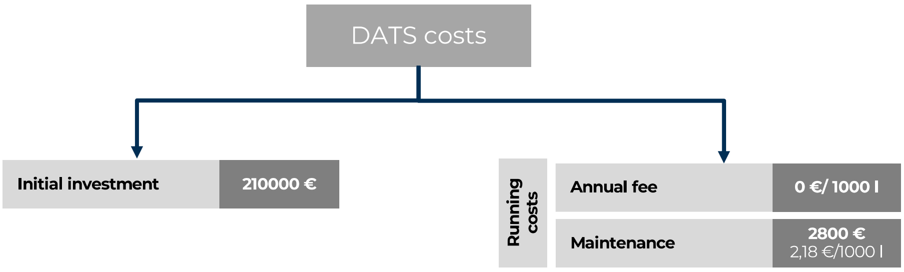



*Figure 78 - Benefits experienced from the implementation of DATS in the dairy farm (TC 25)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.



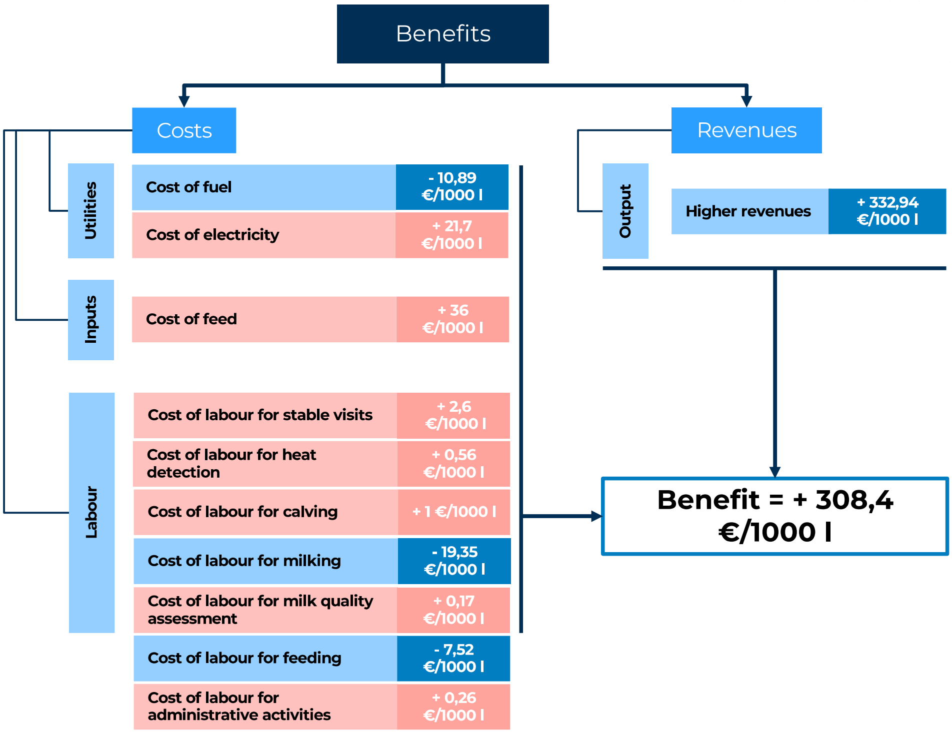



*Figure 79 - Cost-benefit analysis for TC 25*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €2,18 € per 1000 l of milk and an initial investment of 210000 €.

With the implementation of DATS, a benefit of + 308,4 €/1000 l of milk was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 306,21 per 1000 l of milk (**+ 308,4 €/1000 l of milk – 2,18 €/1000 l of milk).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 6 months (210000/(306,21*1281,074)).

## SUSTAINABILITY IMPACT

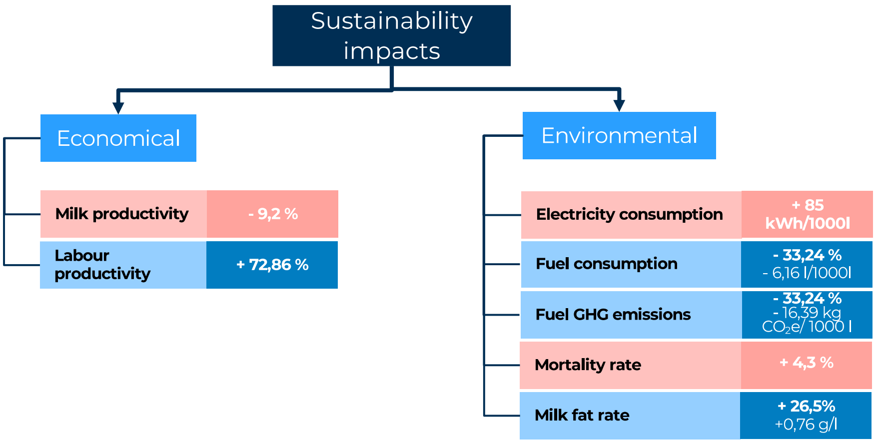



*Figure 80 - Sustainability impacts for TC 25*

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

**Discussion**

The implementation of DATS has not only reduced workload, facilitating the streamlining of milking and feeding activities, but has also contributed to a decrease in fuel usage. The two companies under examination exhibit significantly different levels of milk productivity, a phenomenon not solely attributable to the utilization of technology. In general, there has been a widespread increase in overall costs for utilities (excluding fuel), inputs (in this case, only feed was analysed), and labour costs, with the exception of milking and feeding costs. Despite a decline in productivity experienced by the user company, the improvement in milk quality has enabled them to sell the final product at a higher price, leading to increased revenue. Although costs have slightly risen, the growth in revenue has surpassed the proportional increase, resulting in a net benefit increase of 306,21 per 1000 litres of milk. Financial analysis indicates that the return on investment in DATS is achieved in less than a year. As mentioned earlier, DATS has reduced work hours and streamlined barn monitoring activities, resulting in increased labour productivity.

Regarding sustainability impacts, aligning with the trend of utility costs, there has been an increase in electricity consumption and a decrease in fuel usage. This reduction has allowed for a decrease in greenhouse gas emissions. Furthermore, the impact of DATS on animal health is not straightforward; it has led to an increase in mortality (no impact has been recorded for birth mortality). These key performance indicators need to be diligently monitored in future data collections.

When comparing farmers who adopted DATS with those who did not (using the Framework), the introduction of the solution had a neutral impact on workers' tasks, as measured by the hours spent on activities.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (France).

It is important to highlight that, in this analysis, the production of meat has not been factored in. It can be asserted that the farmer utilizing DATS has observed an augmentation in both cow productivity and its selling price.

Results from the social questionnaire analysis have not been incorporated, as the responses are still pending.

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

## 5.26. TC 26 – Dairy, Cows, Milking robot, Ireland

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | TEAGASC |
| TC sector | Livestock – Dairy |
| Crop/ Animal | Cows |
| Biogeographical Region | Atlantic |
| Country | Ireland |
| Total number of parcels | 2 (1 with DATS and 1 without) |
| Total animals these parcels | 213 cows (with DATS: 180 cows; without DATS: 33 cows) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Milking robot |
| DATS(s) commercial name | DeLaval Dairy Services |
| DATS(s) description | With the DATS, cows are free to enter the milking station whenever they wish. They are attracted by feed or incentives inside the station. Upon entering, the cow is identified through various methods such as RFID tags or 3D cameras. The robot then cleans the cow's udder with brushes and disinfects teats. Robotic arms equipped with teat cups attach to the cow's udder. These cups utilize gentle suction to extract milk from the udder. Sensors monitor milk flow and can detect when milking is complete. Throughout the process, data such as milk yield, quality, temperature, and cow health information are collected and stored for analysis. |
| DATS(s) cost | • Initial investment: 350000 €<br>• Maintenance: 55,55 €/animal |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |
| Animal welfare | DATS reduce incidents of animals falling (as they can be milked at different times – rather than herding all cows to the milking facility at the same time) |

**Benefits experienced from the implementation of DATS**

Benefits were identified in relation to the reduction of milking time and administrative activities. A concomitant increase in milk production was recorded.

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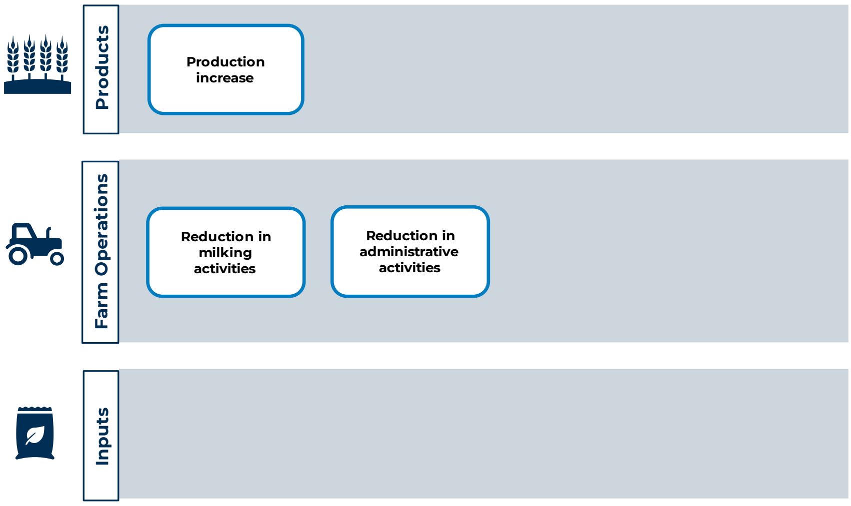
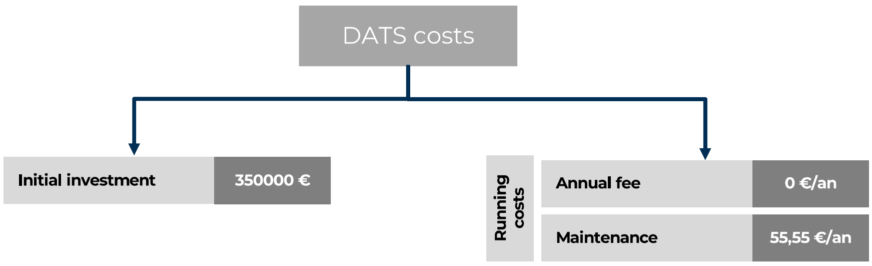



*Figure 81 - Benefits experienced from the implementation of DATS in the dairy farm (TC 26)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

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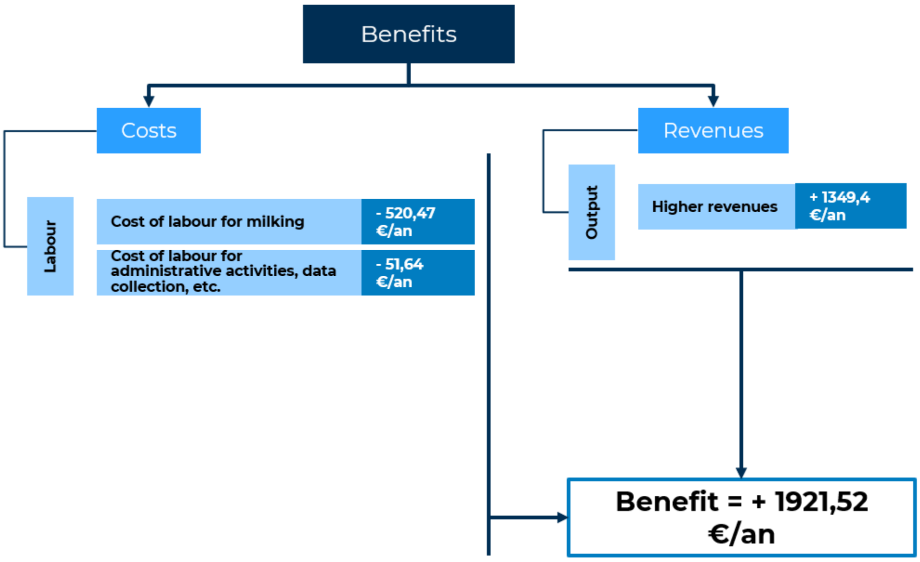


*Figure 82 - Cost-benefit analysis for TC 26*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €55,55 per animal and an initial investment of 350000 €. With the implementation of DATS, a benefit of + 1921,52 €/animal was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 1865,96 per animal (**+ 1921,52 €/animal – 55,55 €/animal).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 13 months (350000/(1865,96*180)).

It should be noted, however, that the calculation of the net benefit and payback period does not take into account some important data relating to inputs and utilities as they were not provided with reference to the non-user farmer. The analyses will be updated once the missing data is received. The TC required more time to collect the data, the three-month postponement of the next 2 Deliverables (D2.3 and D2.4) will benefit data collection.

## SUSTAINABILITY IMPACT

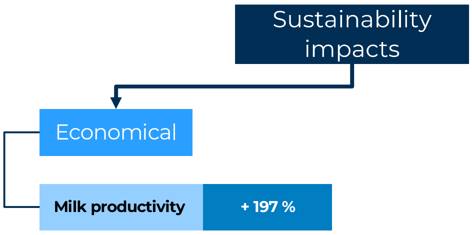


*Figure 83 - Sustainability impacts for TC 26*


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**Discussion**

The TCs shared a limited set of data for the non-user parcel compared to the user parcel, consequently the obtained results are highly limited and do not accurately represent the true financial and environmental state of the farm. Specifically, the analysis only takes into account costs associated with milking and administrative activities, disregarding costs related to inputs and utilities. These overlooked costs are crucial components of the agricultural company's overall expenses, and their exclusion impacts the comprehensive financial assessment.

Nevertheless, it can be confidently asserted that the milking robot has a positive impact on reducing working hours, leading to a substantial 62% decrease in milking time (from 2.6 hours to 1 hour). Similar benefits in terms of working hours have been observed for administrative and data collection activities, showing a reduction from 1 hour without DATS to 0.3 hours with DATS.

Additionally, despite variations in the number of cows in the barns, a noteworthy increase in milk productivity has been documented. This increase, coupled with a 22.22% rise implemented by the farmer using DATS, has significantly bolstered revenues.

In this analysis, labour productivity has not been presented due to the aforementioned limitations, as it would fail to encompass other activities. Turning attention to the "social questionnaire," it can be affirmed that the implementation of the DATS solution has generally had a positive impact on work activities. It has empowered the farmer to make decisions more consciously and efficiently. Although no distinct impact on the sector's appeal to young people has been identified, DATS has facilitated farm succession.

Concerning the learning curve for DATS, it did not induce significant stress and was not excessively time-consuming. Learning to use the solution proved to be stimulating and interesting for the majority of respondents. Lastly, the implementation of the solution has positively influenced the gender gap by fostering women's interest in working on the farm. Women on the farm actively encouraged the adoption of DATS.

**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Ireland).

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## 5.27. TC 27 – Dairy, Cows, Automated monitoring, Germany

(More data needed for the analysis of TC 27)

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## 5.28. TC 28 – Dairy, Cows, Livestock management, Romania

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ANAMOB |
| TC sector | Livestock – Dairy |
| Crop/ Animal | Cows |
| Biogeographical Region | Steppe |
| Country | Romania |
| Total number of parcels | 2 (1 with DATS and 1 without DATS) |
| Total animals | 1190 cows (with DATS: 830 cows; without DATS: 360) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Livestock management |
| DATS(s) commercial name | Boumatic milking |
| DATS(s) description | The software furnishes various indicators derived from individual cow microchip readings, such as milk yield per cow, heat cycles, milk conductivity, and the total number of cows. Additionally, the feeding software provides parameters including feed quantity per cow, the precision of food administration by workers, detection of feed amounts exceeding daily doses, and potential errors in the process.<br>This software-generated information, particularly regarding a cow's readiness for the dry period, proves consistently valuable and serves as a decisive factor in making informed decisions. The software promptly issues warnings when such critical points arise.<br>Remote access to all DATS is feasible via laptops or mobile phones. The data is conveniently accessible through an application program installed on our phones or laptops.<br>For milking technology, numerous sensors are affixed to collars worn by cows, while antennas receive the information transmitted. In the realm of feeding technology, an internet connection facilitates data collection, and a tractor equipped with a scale trailer supports the process. |
| DATS(s) cost | • Initial investments: 56000 €<br>• Set-up (training): 516 €<br>• Maintenance costs: 0,25 €/animal |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |

**Benefits experienced from the implementation of DATS**

Impacts were identified in relation to on-farm operations and the reduction of utilities and feed. A simplification in administrative activities and data management was observed, together with a small reduction in workload.

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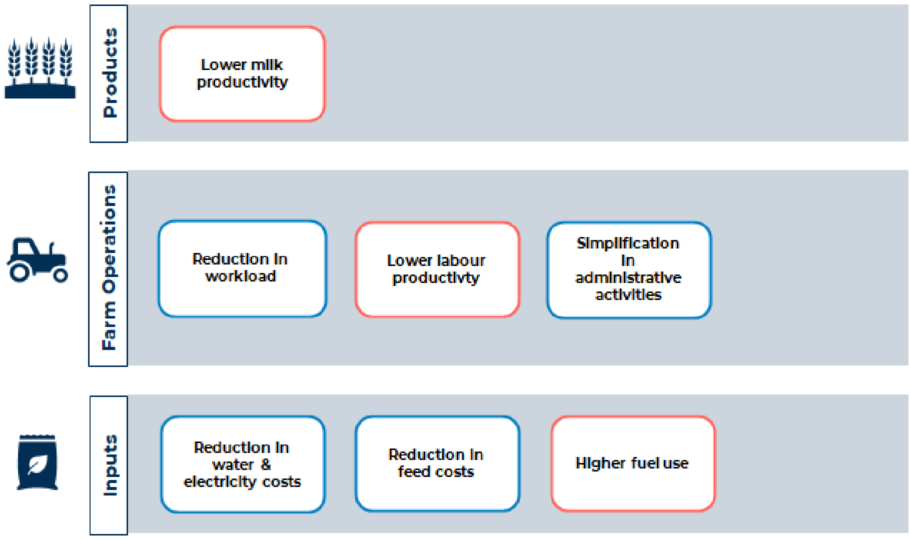
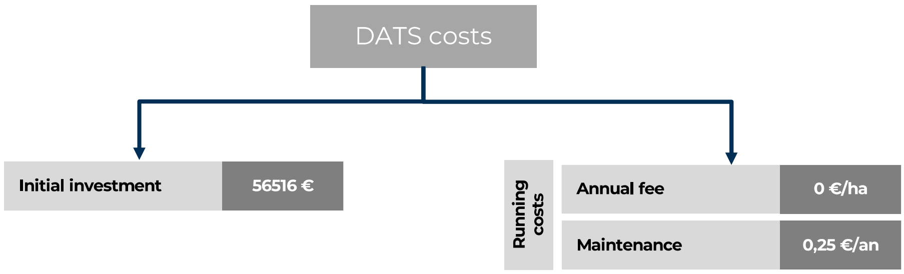



*Figure 84 - Benefits experienced from the implementation of DATS in the dairy farm (TC 28)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.




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

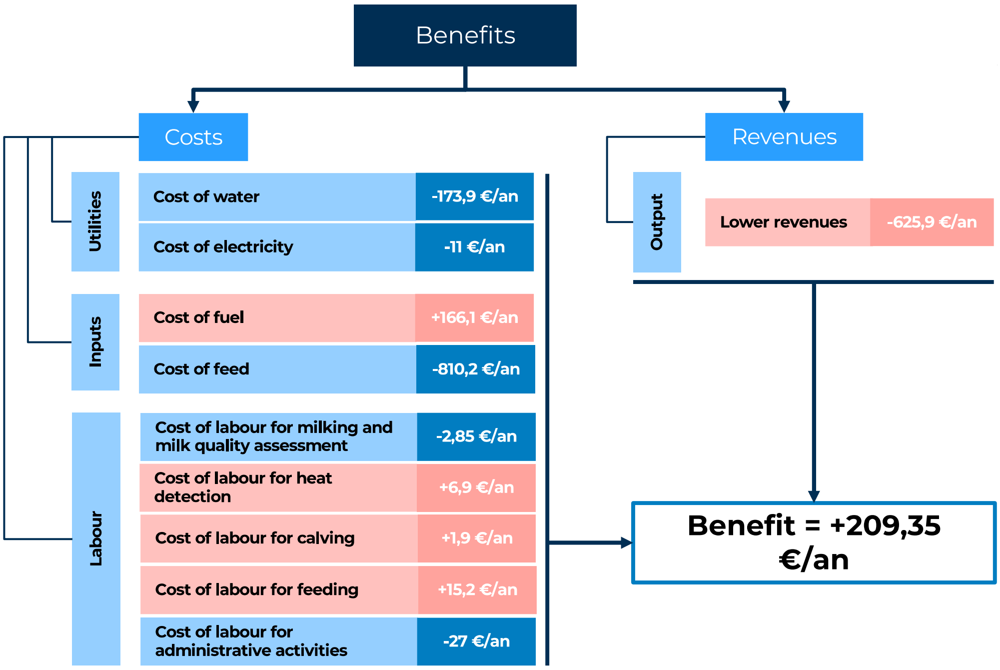



*Figure 85 - Cost-benefit analysis for TC 28*

In this Test Case, the cost of the digital solution is composed by an annual maintenance cost of €0,25 per animal and an initial investment of 56516 € (composed of 56000 € for the purchase of hardware and software and 516 € for the set-up).

With the implementation of DATS, a benefit of + 209,35 €/animal was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 209,1 per animal** (+ 209,35 €/animal – 0,25 €/animal).

The farmer is expected to payback the initial investment made to acquire the DATS within approximately 4 months (56516/(209,1*830)).

## SUSTAINABILITY IMPACT

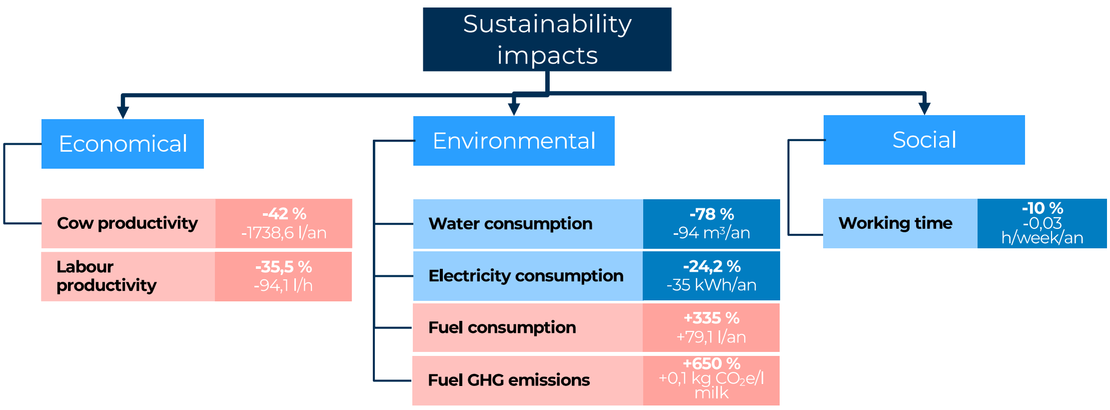



*Figure 86 - Sustainability impacts for TC 28*

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### Discussion

The implemented DATS not only aids farmers in monitoring and recording stable and herd data but also assists them in effectively tracking crucial management indicators. This results in a better herd management and a more efficient use of inputs. The 2 Farms examined show rather different levels of milk productivity, hardly resulting from the use of technology. The Farm without DATS has a higher productivity, measured as total milk production/cow, compared to the farm with DATS and this explains the negative value when we compare the revenues of the 2 Farms (Revenues with DATS – Revenues without DATS). Despite this limitation, the cost savings likely attributable to the DATS result in the observed **net benefit** being equal to + **209,1 € per animal**. The biggest saving concern feeds and water, while the DATS cost plays a minor role. The financial analysis underlines that the return on investment in DATS is realized within a year. The lower productivity of cows in the Farm with DATS explain the lower labour productivity shown among the sustainability impacts. Instead, a saving in terms of water and electricity is evident. The use of DATS is also helping the farmer in saving time, with a reduction of 10 % in the working hours/week/animal. The adoption of the DATS solution has demonstrated a favourable influence on work activities, enabling farmers to make more informed and efficient decisions. In terms of acquiring proficiency in using DATS, it did not induce any significant stress and proved to be not excessively time-consuming. Instead, the learning process was found to be engaging and interesting by the majority of respondents.

### Data and analysis issues

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Romania).

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## 5.29. TC 29 – Apiculture, Bees, Automated monitoring, Lithuania

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | ART 21 |
| TC sector | Apiculture |
| Crop/ Animal | Bees |
| Biogeographical Region | Boreal |
| Country | Lithuania |
| Total number of beehives | 20 beehives |
| Total size of these parcels | 20 beehives (with DATS: 10 beehives; without DATS: 10 beehives) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Automated monitoring |
| DATS(s) commercial name | ART 21 |
| DATS(s) description | The DATS offers both SaaS (Software as a Service) and HaaS (Hardware as a Service) options, tailored to the customer's needs and commercial potential. The software provides indoor temperature in Celsius, indoor humidity percentage, active bee count (based on weight loss), weight in kilograms, outside weather pressure in Pascals, sound frequency in Hertz, and the hive's total noise level amplitude.<br>Through this software, potential threats to the colony can be identified, and upcoming events anticipated. This includes predicting swarm formation, detecting potential loss of the queen bee, recognizing assaults on the colony, assessing bee health, and identifying sudden fluctuations in temperature, humidity, or sound within specific ranges. It's important to note that the information displayed to the farmer is in the form of recommendations; the ultimate decision rests with the farmer.<br>The system, installed within the beekeeper's hive (known as the Autonomous Sensory Device), connects to a central server via a gateway. Continuously gathering data on ambient and swarm temperature, humidity, and acoustic signals, this system transmits the collected information to the server. Once there, it undergoes processing and is then displayed within the system for interpretation and analysis. |
| DATS(s) cost | • Initial investments: 1500 €<br>• Annual fee: 500 €/y<br>• Maintenance costs: 10 €/y (for batteries) |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise the use of input and to save time. |

**Discussion**

The DATS and non-DATS users refer to the same farmer operating a beekeeping farm on a part-time basis, with beekeeping not being his primary source of income. Currently, the honey produced on the farm is not being sold, leading to a scarcity of actual data and a reliance on information derived from literature. Our analyses concentrate exclusively on data collected directly from the farmer. Upon examination, it was observed that there is a decrease in the number of hours worked, primarily stemming from a reduction in time spent on farm visits. This reduction has implications for both the overall workload and labour costs. The implementation of DATS has empowered the farmer to make decisions


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more consciously and efficiently. It has also allowed him to shift focus to other tasks or explore new ones. Furthermore, this solution has the potential to generate interest among the younger generation to engage in the agricultural sector.

**Data and analysis issues**

The constraint of relying on literature-based data rather than actual empirical data presents a notable limitation in analysing this particular test case. Consequently, in the forthcoming data collection phase, it is imperative to implement a slightly modified approach. This entails organizing discussions with both the TCL and the farmer to jointly evaluate and determine the feasible data that can be collected.

## 5.30. TC 30 – Aquaculture, Oysters, Sensors for quality assessment, Croatia

| GENERAL INFORMATION | |
|---|---|
| Test Case Leader | BENCO |
| TC sector | Aquaculture |
| Crop/ Animal | Mussels and European flat oysters – (Ostrea Edulis) |
| Biogeographical Region | Mediterranean |
| Country | River Krka Estuary, Croatia |
| Total number of parcels | 2 (1 with DATS and 1 without) |
| Total size of these parcels | 10000 $m^2$ (with DATS: 5000 $m^2$; without: 5000 $m^2$) |

| DATS INFORMATION | |
|---|---|
| DATS(s) | Sensors for quality assessment |
| DATS(s) commercial name | BENCO |
| DATS(s) description | The DATS furnishes crucial information on the key quality metrics concerning the chemical composition of oysters: glycogen, protein, lipids, and water content. This data empowers farmers to gauge the oysters' well-being and make informed decisions accordingly.<br>The information doesn't prescribe specific actions for farmers but offers insights into the oysters' welfare and nutritional status during evaluation. This knowledge enables farmers to adjust growth conditions or take necessary measures based on supported decisions. Farmers are familiar with interpreting specific parameter deficiencies as they routinely conduct similar analyses.<br>Users access this information through an online platform, providing a personalized account to store all past analysis data. Remote accessibility to the analysis and results platform is advantageous as it allows access from any internet-connected device, extending beyond the confines of the oyster farm.<br>Sample information is collected through spectroscopy analysis using a portable ATR-FTIR spectrometer. This device employs infrared light to analyse the sample's chemical composition. It detects the portion of light absorbed by the sample, generating an absorption spectrum. The observed spectral bands are linked to the sample's chemical composition by exciting molecular vibrations using infrared light. Analysing these spectra in the DATS yields qualitative and quantitative data on the oysters' quality parameters. |
| DATS(s) costs | • Initial investment: 0 €<br>• Annual fee: 500 €/y |

| EXPECTED BENEFITS (from TCs) | |
|---|---|
| Cost reduction | DATS makes it possible to optimise farm management. |
| Product quality increase | The solution can provide farmers with information on the key quality metrics concerning the chemical composition of oysters. |

**Benefits experienced from the implementation of DATS**

There was an increase in yields and a reduction of oyster transport to zero in the laboratory.

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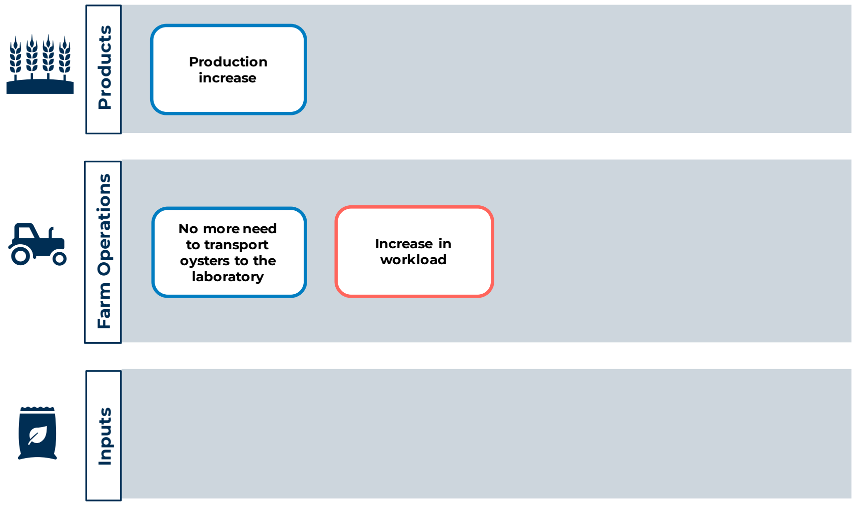


*Figure 87 - Benefits experienced from the implementation of DATS in the aquaculture system (TC 30)*

## COST-BENEFIT ANALYSIS (MONETARY IMPACT)

The monetary impact resulting from the cost-benefit analysis, following the application of the Assessment Framework, is outlined below.

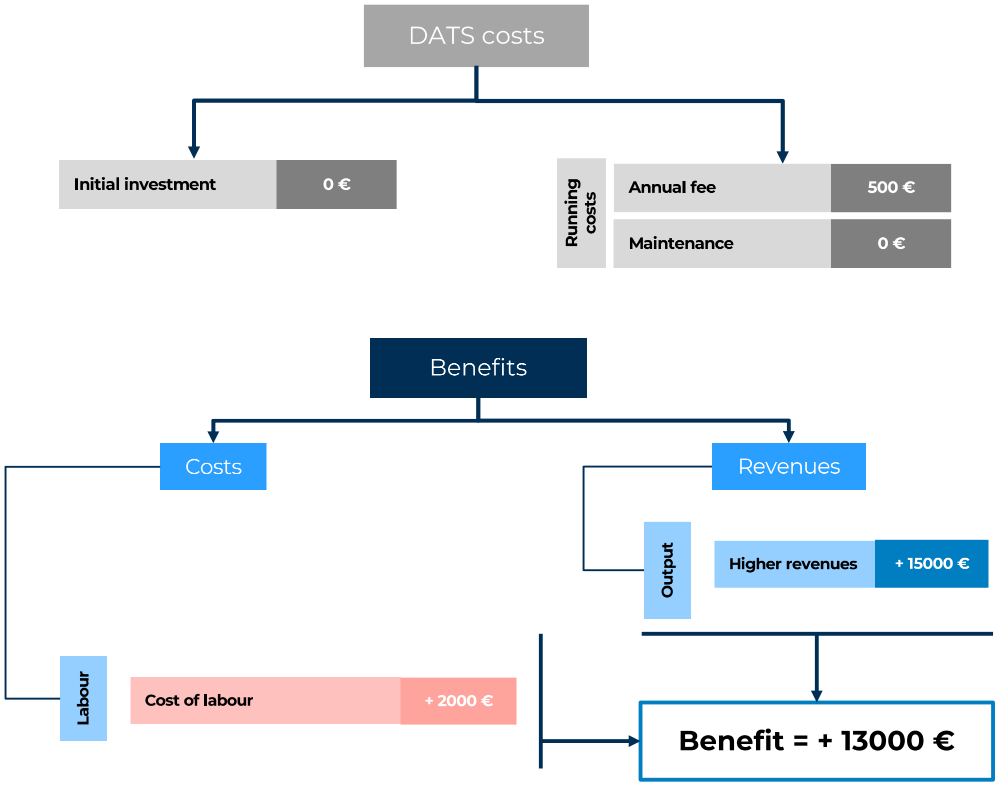


*Figure 88 - Cost-benefit analysis for TC 30*

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In this Test Case, the cost of the digital solution is composed only by an annual fee of €500. No costs of initial investments are required, due to the fact that the solution is provided by Benco (technological provider).

With the implementation of DATS, a benefit of +13000 € was recorded. Consequently, the net benefit deriving from the cost-benefit analysis is **€ 12500** (+ 13000 € – 500€).

Since the farmer made no initial investment, the payback period was not calculated.

**SUSTAINABILITY IMPACT**

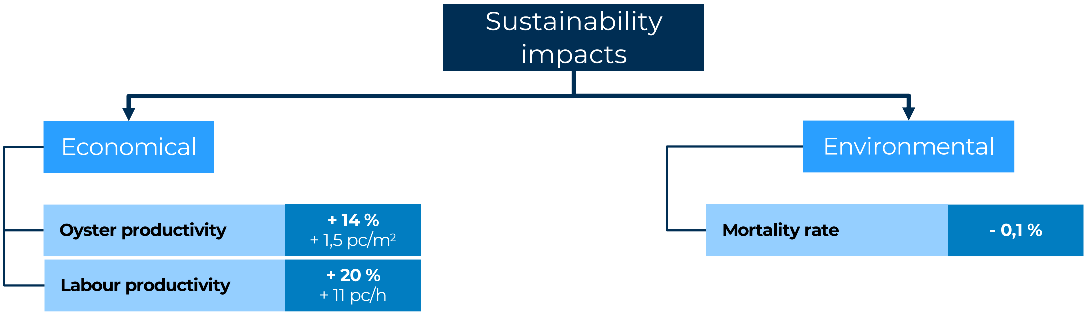


*Figure 89 - Sustainability impacts for TC 30*

**Discussion**

The TC30 analysis was conducted at the parcel level, considering that data for both parcels pertained to the same size: 5000 $m^2$. Following the implementation of DATS, the company recorded a net benefit of +€12,500. This positive outcome was achieved due to a substantial increase in revenues outweighing the rise in costs. It is noteworthy that the overall increase in costs is exclusively attributed to the extended time required for oyster collection (directly tied to increased production) and an upsurge in visits.

Crucially, the implementation of DATS eliminated all costs associated with transporting oysters to the laboratory. The more-than-proportional increase in oyster production per unit, compared to the increase in hours worked, resulted in enhanced labour productivity. Additionally, the integration of sensors for quality assessment positively impacted the reduction of oyster mortality. Water-related KPIs are not included in the analysis, as they are incalculable due to the constant immersion of oysters on-site, and water is not pumped.

Focusing on social impacts, DATS has facilitated: i) the resolution of unforeseen problems, ii) flexibility in planning and executing work activities, and iii) more conscious and efficient decision-making. Finally, DATS has positively influenced the farm's succession plan and has cultivated interest among the younger generation to engage in farming or the agricultural sector.

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**Data and analysis issues**

The cost estimates for labour were carried out using Eurostat data on average wages for the Country (Croatia).

During the initial year of data collection, the TC did not provide specific details regarding crucial quality metrics associated with the chemical composition of oysters, such as glycogen, protein, lipids, and water content. This information will be analysed from the upcoming data collection.

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# 6. Lesson learned from Test Cases analysis

Assessing the costs and benefits of a digital solution is fundamental to encourage the adoption of technology; this is particularly true in the agricultural sector, where we see a progressive increase of the adoption of DATSs across Europe, but we are still far from a wide and homogeneous diffusion. Farmers, and more in general stakeholders in the agricultural sector, need to be aware of monetary impacts of the adoption of digital solutions; at the same time, it is necessary to assess the impact on sustainability and to make them conscious about the importance of innovation to preserve the environment and the society. **For these reasons, a tool as the QuantiFarm Assessment Framework has been warmly welcomed by farmers and stakeholders during meetings and conferences in which has been presented, because it has been considered practical, effective and consistent with farmers' needs.** As a member of a research centre participating in a dissemination meeting said,

*"We are enthusiastic about QuantiFarm project and to be updated on its results. I think the Assessment Framework is a very useful tool, because it is at the same time effective and comprehensive, it "puts order" in the KPIs and methodologies for digital solutions evaluation already existing but not always completely applicable to the agricultural sector."*
*(Alex Giordano, Scientific Director of Rural Hack and Agrifood Future;*
*Member of the Community of the Smart AgriFood Observatory)*

**Aggregate results from TCs**

The first pilot application of the Assessment Framework to the 30 Test Cases has highlighted preliminary results in terms of cost-benefit analysis and sustainability impacts. In general, **the benefit recorded in the majority of cases was the increase in the revenues due to the increase of yields and the positive impact in reducing the workload.** These benefits are quite common to the majority of the Test Cases; but while it is not always easy to understand, in this first pilot testing activity, the clear link between yield increase and the use of DATSs, the impact of digital solutions on the reduction of the workload and the improvement of working conditions clearly emerges from the assessment made using the Framework and from the social questionnaire. A first important result, also considering the public debate on the social impact of digital innovation on workers life and jobs.

From the environmental perspective, we often see a reduction in the use of water (and its productivity), energy and fuel, with relevant positive consequences in terms of burden of the environment; on the contrary, a positive impact on pesticides and nutrients use was not always achieved and it is subject to more uncertainties. Anyway, this result was expected, at least for this first year: as well known, agriculture relies on natural resources, and it is strongly affected by climatic changes and adverse conditions. Thus, an increase in pesticides or fertilizers applications in farms using the DATSs could be due to, for example, increase in humidity, rains, or a particular dry season. In this perspective, a "net loss" should not be judged immediately as a negative result, particularly when we see, on the other hand, an increase in yields. In general, if the impact on yield and labour are quite clear, more data and analysis on the forthcoming years will be necessary to better understand the relationship between economic and environmental sustainability (fig. 90).

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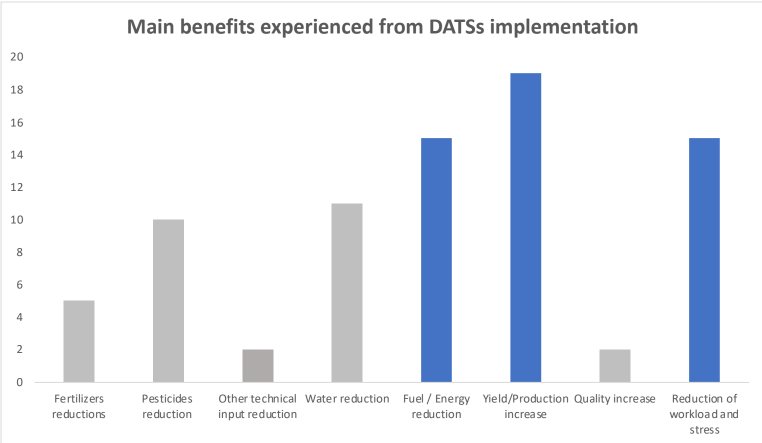


*Figure 90 – Main benefits experienced from DATSs implementation (sample: 30 TCs)*

Additionally, **from the social point of view, it appears clear that DATSs can play a fundamental role in improving farmers' working conditions and have a positive impact, wider, on the overall sector**.

Answers given to the social questionnaire have shown a general positive perception of DATSs from farmers. For most farmers (71%), DATSs simplified complex tasks and for more than half allowed to solve unforeseen problems. These benefits have been gained without excessive stress or time devoted to learning. Considering that almost all farmers implementing the DATSs had to learn to use the solution (87%), more than 90% of farmers answering to the social questionnaire declared that learning to use the DATS was interesting and motivating, even for a minority generated stress and was time-consuming (fig. 32). Additionally, in many cases, farmers have noticed that the introduction of digital solutions fostered the interests of young generations for farming (the own farm or the agricultural sector in general, fig. 33), strengthening the idea that digital innovations can support the generational change and give continuity to the agricultural sector.

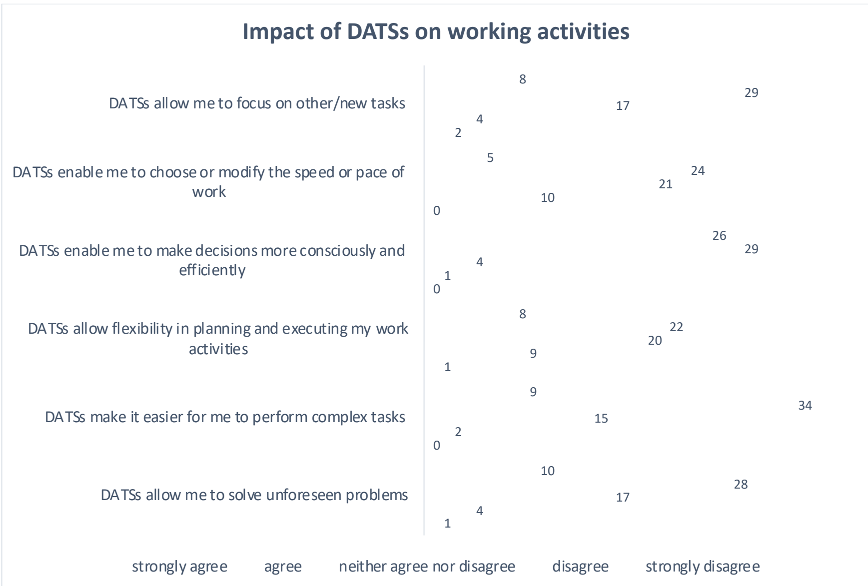



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*Figure 91 - Impact of DATSs on working activities (sample: 60 farmers)*

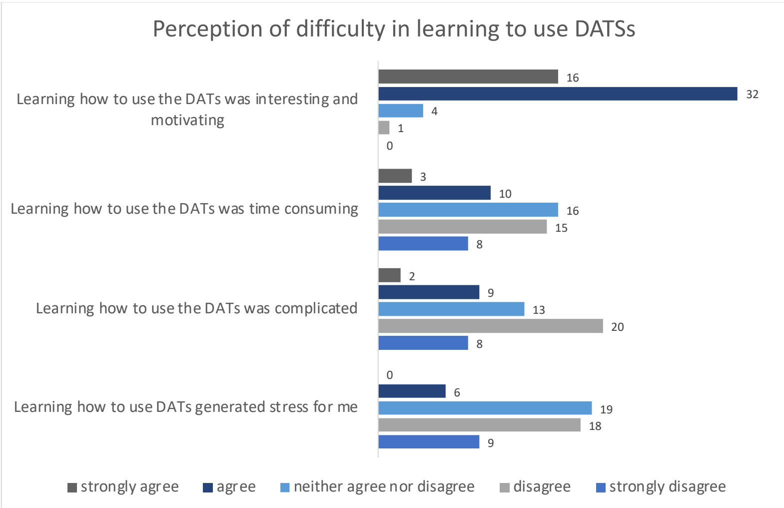


*Figure 92 - Perception of the difficulty in learning to use DATSs (sample: 52 farmers)*

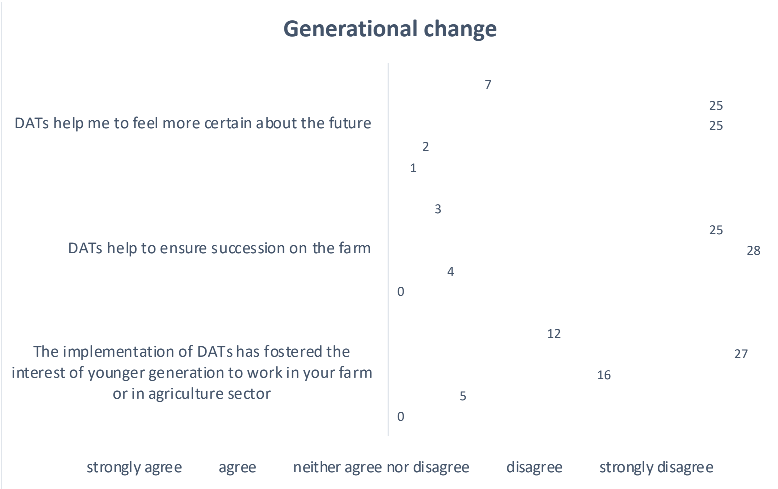


*Figure 93 - Impact of DATSs in generational change (sample: 60 farmers)*

**Technicalities, data collection requirements and operational challenges[11]**

As highlighted in the Methodology, the development of the QuantiFarm Assessment Framework has undergone some changes during the first 18 months of the Project. The first version, mainly based on a top-down approach, has been revised considering the feedback given by Partners and particularly from Test Cases. The process of continuous feedback and interactions with Test Cases, indeed,

[11] More details on these operative aspects are contained in WP4 Deliverable 4.2.

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highlighted some points of attention, mainly related to the topic of "data". First of all, the issue of the quantity of data that farmers must provide. Several discussions arose about the **trade-off between having a large amount of data for analysis' consistency and accuracy and the importance to not stress farmers with the request of lots of data**. It is a matter of difficulty in retrieving certain data (high level of granularity is useful for a comprehensive understanding of the impact of DATSs on the specific process/activity but it is often time consuming) and of concern about sensitive information.

*"The required volume of data is high and includes highly sensitive information about their business… filling out the forms with the data of each farmer for the project has been very tedious and confusing for them."*
*(TC Leader from TC3)*

This aspect has been carefully considered during the development of the Framework. For this reason, the Framework has been revised with the objective to be consistent and to include the most relevant aspects related to DATSs impact but, at the same time, to be effective and realistic to be used. The initial list of KPIs has been maintained but a subset of indicators has been then actually used, to maintain consistency between the use of DATSs and their impact.

Regarding the operational challenges, **some issues arose in the process of data collection, mainly due to the amplitude of data required, unit of measures and file format**. The "format" used for data collection (the "data collection template"), although shown on several occasion to Test Cases, appeared a little bit confusing for farmers (mainly because it was organized by "sustainability areas" and KPIs), resulting in incomplete templates and the necessity of organizing several calls and emails to clarify data. For this reason, a new, simpler, data collection template has been developed for the forthcoming collection of data.

**Timeliness**
**A fundamental operational challenge** (as highlighted in the Deliverable "Test Case evaluation report for reporting period 1" of WP4) **was related to the timing of data collection and deadlines**. Although the proposed deadline for sending the data collection template was the 30th of November 2023, until October 31st, only 11/30 TCs were able to complete the first draft of data collection using the templates. Additionally, only 5/11 drafts were validated in the first run by WP2 and WP4 and made it to analysis stage. The remaining 6 drafts had issues like missing data, unspecified units, different file formats, etc. All the other cases sent their files after the proposed deadline.

**The majority of TCs experienced problems in respecting the deadline for data collection for the lack of experience on this kind of activity (data collection, use of a template, etc.) and for the duration of the growing season**. Being full of work during the ending period, farmers felt too pushed and stressed regarding the data collection; data were incomplete, or not clear, so it was necessary to organize calls and meeting during a period that was already very busy for them. This issue was carefully discussed with Partners and TC Leaders during the 4th Project Meeting (12-13 December 2023). Some TC Leaders are quite confident about the fact that the next rounds of data collection will be smoother due to the experience gained until now, but other confirmed that some data will be available only by the end of November. Considering the experience gained until now, to ensure a proper data collection and analysis process is then fundamental to have more time between the data submission and the presentation of the overall analysis, hence, to set a new deadline. For this reason, consortium's intention is to request a three-month extension, to better align with timeline of TCs, the growing season and farmers' activities.

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**Framework evolution and way forward**

**The first results from TCs analysis confirmed that to have a clear idea of the impact of digital technologies in agriculture it is fundamental to adopt a holistic approach** that considers various aspects: looking only at indicators of a specific domain or category can led to misleading results. Additionally, it is fundamental to collect data from several years: indeed, **the analysis on the impact of DATSs has highlighted that it is not always feasible to "isolate" the effect of the technology on some KPIs without considering the external factors.** Agriculture is greatly impacted by external factors as weather and soil conditions; hence it is necessary to understand the specificity of each case and the conditions of year to which data refer. This is true particularly for yield variations and for some cultivations. For example, for olives, yield can vary according to different plant management, trees arrangements, soil diversity. In general, there is natural variability of soil and plants (also in farms placed near each other) that can have a certain impact on yield.

Lessons learnt to date lay the foundation for the next steps of QuantiFarm Assessment Framework development and application to the TCs. In particular:

- Continuous interactions with Test Cases will help the researchers to better understand the relationships among different impacts. As mentioned, the Framework is a "leaving tool": it could eventually include new indicators, if new and unexpected impacts of DATSs will be evident;
- the methodology for the "normalization" of data will be implemented – using data from the next round of collection and, where needed, historical data – in order to try to decouple the effect of exceptional events and external factors that can have a strong influence on KPIs calculation. This methodology will also lead to the final definition of the best way to represent the results (through the multidimensional set of indicators).

WP2 will also continue to work closely with WP3, to study the best way of presenting the results in the QuantiFarm Toolkit. Indeed, it is important to have in mind the purpose of the Assessment Framework: to guide farmers in understanding the impacts of DATSs) and not **to use it to compare different DATSs of Test Cases,** applied in different context, geographical area, etc. Although the Assessment Framework aims to guide farmers in the choice of implementing DATSs through a comprehensive analysis of their costs and benefits, it is not intended to allow comparisons between DATSs implemented in the different cases, since it wouldn't make sense to compare solutions with different purposes and applied in different crops, area, etc. The risk will be mitigated working in close cooperation with WP3.

# 7. Governance Framework

## 7.1. 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.

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In the following paragraph the principles that are guiding the design of the governance structure are listed:

1.1. *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 held 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 DATS 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 DATS and subsequently for performing the cost/benefit analysis.

1.2. *Impartiality:* The data will be collected by different participants of the Test Case, either the Producer or the DATS Provider or in case of various functions the DATS Test Case Leader. 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 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.

1.3. *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 DATS Provider 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.

1.4. *Credibility:* KPIs need to be evidenced by appropriate means. Given the divergent nature of DATSs and the respective context, the means could differ significantly between the various DATSs. 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 on each DATS and will be further determined in the governance framework itself.

1.5. *Relevance:* Since the framework is addressing a great variety of KPIs it must be ensured that the focus for each DATS is put on the right set of KPIs allowing for a well-grounded cost/benefit analysis of the DATS. For instance, collecting a huge set of data related to social compliance in the context of a GIS or smart farming DATS is not efficient and will not allow to identify the potential benefits of the DATS. 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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## 7.2. Introduction to the Governance Framework

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 DATSs 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 DATS assessments. The governance will be followed by all participants involved in the execution and evaluation of the DATSs.

## 7.3. Stakeholders, Roles and Definitions

For the aims of the governance framework, the following definitions will apply:

3.1 **DATS**: A Digital Agriculture Technology Solution ("DATS") 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.

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

3.3 **DATS Providers**: Refers to companies developing and/or supplying DATSs to producers.

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

3.5 **DATS Test Case Leader**: Refers to a single entity responsible for conducting the DATS 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.

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

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

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

## 7.4. Baseline Conditions

4.1. Baseline conditions should be determined through adequate data collection, through a known technical methodology. The process of data collection requires consistency and alignment among DATS Test Cases and non-DATS Test Cases, for reliable and valid comparability. This will ensure the outcome of the Test Case Assessment is well grounded and based on proper

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(causal) criteria. In addition, it will also ensure the selection process of producers for DATS Test Cases was not biased.

4.2. 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:

4.2.1. **Farm size:**
Benefits of a DATS can vary depending on the size of farms, therefore, any benefits derived from a DATS Test Case should clearly state the farm size that is required to demonstrate the beneficial results of the DATS. 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.

4.2.2. **Product type:**
The evaluation of DATSs should also be able to state for which product type (e.g. specific crop, dairy, livestock, honey etc.) a certain DATS yields optimal results. For example, to state whether the variable rate application has the same benefits for Canola as for Wheat.

4.3. In case it is known through literature review, expert interview or TC that a specific DATS 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 DATS results.

## 7.5. Producer's Consent

5.1. DATS Test Case Leaders should ensure that the producers 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:

5.1.1. Declare with their signature to have read and understand the purpose of the DATS Test Case,
5.1.2. Approve QuantiFarm's use of any data associated with their farm,
5.1.3. Confirm that any data they provide during the assessment phase is accurate and complete,
5.1.4. Declare the identity of the person and/or company details as well as their contact.
5.1.5. Allows access to the premises where the DATS is being used.

## 7.6. TC Leader Declaration

6.1. DATS Test Case Leader(s) should sign a declaration form where they:

6.1.1. Declare the full identity of the company and persons responsible for overseeing the DATS Test Case and collecting relevant data.
6.1.2. Declare any affiliation with companies developing or providing any of the DATSs which they are assessing.
6.1.3. Declare the nature of any previous relationship with the producer.

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6.1.4. Agree to share the results of the DATS Test Case Assessments with the producer.

## 7.7. Competence of TC Leaders and Verifiers

7.1. Appropriate records of the education, training, skills, and experience of each DATS Test Case leader and Verifier working within QuantiFarm should be maintained.

7.2. 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:

7.2.1. Proven understanding and experience in applying the assessment framework and its governance;

7.2.2. Proven training and experiences for the relevant DATS, agricultural and/or agri-related industries;

7.2.3. Specific reference, where applicable, to training on amendments and changes within the assessment framework and its governance.

## 7.8. Qualification of TC Verifiers

8.1. To ensure that the DATS Test Case Verification is unbiased, verifiers should be able to demonstrate the following criteria:

8.1.1. Verifier is independent of the DATS being assessed;

8.1.2. Have no potential conflict of interests;

8.1.3. Have received training and demonstrate understanding and compliance with the training requirements in the technical area(s). This will happen prior to conducting DATS Test Case verifications.

8.1.4. Have the appropriate specific skills required for conducting the verifications related to the assessment framework and its governance, as well as a good understanding of the DATS Test Case scope.

## 7.9. Application of the Assessment Framework

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

**9.2. Means of data collection:**

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

9.3. **Type of data to be collected:**

9.3.1. *Operational costs*: Data related to reductions in operational costs such as labour, agrochemicals, energy, water bills etc.

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9.3.2. *Production:* Data related to production parameters such as yield, quality of produce as well as revenues.

9.3.3. *Environmental emissions:* Data related to emissions such as GHG and Nitrogen.

9.3.4. *Environmental impact:* Soil and water quality indicators include waste generation and their management, as well as release of harmful agrochemicals.

9.3.5. *Animal welfare:* Indicators covering the general wellbeing of animals such as disease prevalence, adequate shelter, space, nutrition, pain-free handling, and humane slaughter.

9.3.6. *Biodiversity and Land use:* Indicators that measure the impact of DATSs on the preservation of species diversity, avoidance of land use conversion and restoration of natural landscapes.

9.3.7. *Social impact:* Data related to the social benefits of DATSs such as on child/forced labour, worker and community rights and benefits etc.

**9.4. 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:

9.4.1. Location on the field where samples are collected from, either randomly, or otherwise from the most suitable location if specific knowledge is available.

9.4.2. Frequency and timing of samples also considering the proximity to the time where agrochemicals have been applied.

9.4.3. Proper sealing of the samples and recording the seal ID prior to dispatching to the Laboratory for analysis

The DATS Test Case leader 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.

**9.5. Documentary Evidence:**

DATS Test Case leaders should ensure that the DATS Test Case assessments are supported with adequate documentary evidence such as but not limited to:

9.5.1. *Invoices:* For evidencing production claims, yield, quantity and type of agrichemicals used;

9.5.2. *Utility bills:* For evidencing usage of energy and water;

9.5.3. *Pay slips:* For evidencing labour costs;

9.5.4. *Farm maps:* For evidencing the size and location of farms;

9.5.5. *Laboratory analysis:* For evidencing improvements in water and soil quality and detection of agrochemical residues.

**9.6. Frequency of assessments:**

9.6.1. *Initial:* Conducted at the beginning of the DATS 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.

9.6.2. *Follow-up:* Conducted at least once a year.

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### 9.7. Producer's review and signature:

Every DATS 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.

## 7.10. DATS Test Case Evaluation

In alignment with the initial goals of the QuantiFarm Project, the DATS evaluations should present a multidimensional index, consisting of a monetary quantitative measure (derived from the cost-benefit analysis), in combination with a set of descriptive indicators on the impact of DATSs to reflect the complexity of the sustainability aspects, according to the environmental, economic, and social dimensions. Preferably, a "normalization" mechanism should also be developed allowing the efficient measurement of the direct and indirect impacts of the DATS compared to producers who are not using the respective DATS.

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# 8. Conclusion and next steps

The aims of this report deliverable D2.2 were to explain step by step the components of the Assessment Framework, in view of the changes occurred during the last 12 months of project, and to explain how it has been applied to the 30 Test Cases and the obtained results.

After introducing the relevance of assessing the cost and benefits of the DATSs from both the monetary and sustainability perspective, the document explains in depth the methodology followed to define the two components of the Assessment Framework: the economic cost-benefit analysis and the sustainability impact set of indicators. Particularly, compared to the first version of the Framework, the document reports the process that has led to the improvement and adaption of the tool to the specific context and the needs of farmers. Additionally, beside the already existing sustainability impact indicators, the cost-benefit analysis has been introduced in the model and carefully explained; this is an essential component to understand the monetary impact of DATSs in the short term, and their profitability in the middle-long term. Lastly, the document reports the results of the application of the Assessment Framework to the 30 TCs and the results of the analysis, leading to a first view on the monetary and sustainability impact of digital solutions.

Similarly, the governance principles of compliance, impartiality, reliability, transparency, credibility, meaningfulness are presented as crucial elements for ensuring an effective and unbiased credible assessment.

As the QuantiFarm project progresses, the process of data collection from TCs will be carried on and a second round of analysis will be developed, to have a clearer view of the impact of DATSs. The collection of data will be accompanied by constant interactions with TCs, to gather their feedback that will allow a better understanding of the results. According to the feedback and gained experience, the Assessment Framework and Governance Mechanisms will be eventually revised and updated. The model for the representation of aggregated indicators will be refined. Finally, where considered pertinent and feasible, the Framework could be complemented with further methodologies to better understand the impact of DATSs on farmers and on wide environment and society.

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# Reference list


Ali, M. M. (2019). Role of ICT in crop management. *Agronomic crops*, pp. 637-652.

Arandia, A. I. (2011). Incorporating social and environmental indicators in technical and economic advisory programmes in livestock farming. *Options Méditerranéennes A*, 100: 9-15. .

Batalla, M. P. (2014). Environmental, Social and Economic Aptitudes for Sustainable Viability of Sheep Farming Systems in Northern Spain. *Paper presented in the 11th European IFSA Symposium 'Farming systems facing global challenges: Capacities and strategies'*.

Bates H., P. M. (2021). Real-Time Environmental Monitoring for Aquaculture Using a LoRaWAN-Based IoT Sensor Network. *Sensors, 21*((23)), 7963.

Baur, P. (2022). When farmers are pulled in too many directions: comparing institutional drivers of food safety and environmental sustainability in California agriculture . *Social Innovation and Sustainability Transition*, (pp. 241-260).

Benbrook, C. M. (1996). Pest management at the crossroads.

Bockstaller, C. G. (2009). Comparison of methods to assess the sustainability of agricultural systems. A review. . *Agronomy for Sustainable Development*, 29(1), 223-235.

Bockstaller, C. L.-J.-D. (2008). Assessing biodiversity in arable farmland by means of indicators: an overview. *OCL - Oilseeds and fats, Crops and Lipids, 18*((3)), 137-14.

Bonney, R. E. (1990). Hive management: a seasonal guide for beekeepers. *Garden Way Publishing*.

Bosona, T. &. (2013). Food traceability as an integral part of logistics management in food and agricultural supply chain. . *Food control, 33*((1)), 32-48.

Bourne, M. M. (2000). Designing, implementing and updating performance measurement systems. *International Journal of Operations & Production Management, 20*((7) ), 754–771.

Bourne, M. N. (2002). The success and failure of performance measurement initiatives: Perceptions of participating managers. *International Journal of Operations & Production Management, 22*((11)), 1288–1310.

Boyd, C. E. (1985). Water quality management in aquaculture. *CMFRI special Publication*(22), 1-44.

Bruinsma, N. A. (2012). World agriculture towards 2030/2050: The 2012 revision. Retrieved from http : / / www . fao.org/3/ap106e/ap106e.pdf

Bruinsma, N. A. (2012). World agriculture towards 2030/2050: The 2012 revision.

Brunori, G. G. (2016). Are local food chains more sustainable than global food chains? Considerations for assessment. *Sustainability,, 8*((5)), 449.

Burton, A. J. (2004). Simulated chronic NO3− deposition reduces soil respiration in northern hardwood forests. *Global Change Biology, 10*((7)), 1080-1091.

Castilla, N. (2013). Greenhouse technology and management. *Cabi*.

Castle, M. B. (2015). Precision Agriculture Usage and Big Agriculture Data . *Cornhusker Economics, University of Nebraska-Lincoln Extension*.

Cornell University, INSEAD, & WIPO. (2017). The global innovation index 2017. *Global innovation index*, 1-39.


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

Dantsis, T. D. (2010). A methodological approach to assess and compare the sustainability level of agricultural plant production systems. *Ecological Indicators*, 10(2): 256-263.

D'Eusanio, M. S. (2018). Assessment of social dimension of a jar of honey: A methodological outline. *Journal of Cleaner Production*(199), 503-517.

D'Eusanio, M. S. (2018). Assessment of social dimension of a jar of honey: A methodological outline. *Journal of Cleaner Production*(199), 503-517.

Diazabakana, A. L. (2014). A Review of Farm Level Indicators of Sustainability with a Focus on CAP and FADN.

Diazabakana, A. L. (2014). A Review of Farm Level Indicators of Sustainability with a Focus on CAP and FADN.

Dillon, E. H. (2008). Assessing the sustainability of Irish agriculture. Contributed paper presented at the 107th EAAE Seminar "Modelling of Agricultural and Rural Development Policies". 15p.

European Commission. (2020). *Economic sustainability in the CAP*. Retrieved from Agriculture and rural development: https://agriculture.ec.europa.eu/sustainability/economic-sustainability/cap-measures_en

European Environment Agency. (n.d.). *Biogeographical regions in Europe*. Retrieved 30/11 2022 , from https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2: https://www.eea.eu

FAO. (2013, December). SAFA - Sustainability Assessment of Food and Agriculture Systems – Guidelines. Version 3.0. . *Natural Resources Management and Environment Department, Food and Agriculture Organisation*, 267p.

FAO. (2013b). SAFA - Sustainability Assessment of Food and Agriculture Systems – Indicators. *Natural Resources Management and Environment Department, Food and Agriculture Organisation*, 281p.

FAO. (2017). *Pathways to sustainable food and agriculture.*

FAO. (2018). Agriculture to Achieve the SDGs. 20 Interconnected Actions to Guide Decision-Makers. . *Food and Agriculture Organization of the United Nations: Rome, Italy.*

FAO. (2021a). Standard operating procedure for soil total nitrogen – Dumas dry combustion method. *FAO*.

FAO. (2021b). Standard operating procedure for soil nitrogen – Kjeldahl method. *FAO*.

FAO. (2021c). Standard operating procedure for soil available phosphorus, Bray I and Bray II method. *FAO*.

FAO. (2021d). Standard operating Procedure for soil available phosphorus – Mehlich I method. *FAO*.

FAO. (2021e). Standard operating procedure for soil available phosphorus – Olsen method. *FAO*.

Fleur, M., Debruyne, L., Triste, L., Gerrard, C., Padel, S., & Lauwers, L. (2014). Key Characteristics for Tool Choice in Indicator-Based Sustainability Assessment at Farm Level. *Ecology and Society*, *19*(3).

Fourrié, L. E.-B. (2013). Référentiel AB : Présentation des Indicateurs. *CASDAR project RéfAB*, 172 p.

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

Genovese, A. M. (2017). Assessing redundancies in environmental performance measures for supply chains. *Journal of Cleaner Production*(167), 1290–1302.

GHG Protocol. (2021). 2021. GHG Protocol Agriculture Guidance. In: GHG Protocol website [online]. Washington, D.C.

Hacking, T. &. (2008). A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment. *Environmental Impact Assessment Review*, *28*((2-3)), 73-89.

Iffat Ara, L. T. (2021). Application, adoption and opportunities for improving decision support systems in irrigated agriculture: A review,. *Agricultural Water Management*, *257*.

IFOAM. (2005). Retrieved from Principles of Organic Agriculture, 4p. : http://www.ifoam.org/sites/default/files/ifoam_poa.pdf

Jacobs, C. B. (2019). Climate change adaptation in the agriculture sector in Europe. *European Environment Agency (EEA)*.

Khan, F. I. (2004). An overview and analysis of site remediation technologies. *Journal of environmental management*, *71*((2)), 95-122.

Khan, M. A. (2011). Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. *Journal of Dairy Science*, *94*((3)), 1071-1081.

Khriji, S. E. (n.d.).

Khriji, S. E. (2014). Precision irrigation based on wireless sensor network. *IET Science, Measurement & Technology*, *8*((3)), 98-106.

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), 1-21.

Kiropoulos, K., Bibi, S., Vakouftsi, F., & Pantzios, V. (2021). Precision Agriculture Investment Return Calculation Tool. *17th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, (pp. 267-271).

Kirwan, J. M. (2017). Acknowledging complexity in food supply chains when assessing their performance and sustainability. *Journal of Rural Studies*(52), 21-32.

Lebacq, T. B. (2013). Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development*, 33: 311-327.

Lefley, F. (1996). The payback method of investment appraisal: A review and synthesis. *International Journal of production economics*, *44*, 207-224.

León-Bravo, V. &. (2021). Sustainability assessment in the food supply chain. In Handbook of Sustainability-Driven Business Strategies in Practice. *Edward Elgar Publishing*, pp. 260-277.

León-Bravo, V. &. (2021). Sustainability assessment in the food supply chain. In Handbook of Sustainability-Driven Business Strategies in Practice. *Edward Elgar Publishing.*, (pp. 260-277).

León-Bravo, V. M. (2021). A roadmap for sustainability assessment in the food supply chain. *British Food Journal*.

Maffezzoli, F. A. ( 2022). Agriculture 4.0: A systematic literature review on the paradigm, technologies and benefits. *Futures*, 142.

MarketsandMarkets. (2021). Digital agriculture Market by Technology, Type, Operation, Operation and Region - Global Forecast at 2027. Retrieved from Available at: https://www.marketsandmarkets.com/Market-Reports/digital-agriculture-market-235909745.html

Medici M., P. S. (2021). A web-tool for calculating the economic performance of precision agriculture technology. *Computers and Electronics in Agriculture, 181*.

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.

Meul, M. v. (2008). MOTIFS: a monitoring tool for integrated farm sustainability . *Agronomy for Sustainable Development* , 28: 321-332.

Nugawela S., S. D. (2020, June 20-24). Analysis of Farm Mangement Information Systems: Opportunities and Pathways for Future Value. *Pacis 2020 Proceedings*.

Observatory, S. A. (2020). *Agricoltura 4.0: lo stato dell'arte del mercato italiano.* Osservatori Digital Innovation, Politecnico di Milano.

OECD. (2008). *Handbook on constructing composite indicators: methodology and user guide.* .

OECD. (2017). *Green Growth Indicators* . Retrieved from https://www.oecd.org/greengrowth/green-growth-indicators/

Olsson, J. (. (2009). Sustainable development from below: institutionalising a global idea-complex. *Local Environment*, *14*((2)), 127-138.

Pereira, L. S. (2002). Irrigation management under water scarcity. *Agricultural water management, 57*((3)), 175-206.

Pineau, M. A. (2009). Response-inducing sustainability evaluation (RISE) linking agricultural practices and water productivity. . *CGIAR Challenge Program on Water and Food,*, 110.

Riccardo Bertoglio, C. C. (2021). The Digital Agricultural Revolution: a Bibliometric Analysis Literature Review. *IEEE Access*, *9*, 134762–134782.

Ripoll-Bosch, R. D.-U. (2012). An integrated sustainability assessment of mediterranean sheep farms with different degrees of intensification. *Agricultural Systems*, *105*((1)), 46-56.

Rosnoblet, J. G. (2006, September ). Analysis of 15 years of agriculture sustainability evaluation methods. *In 9th ESA Congress*, 707-708.

Ruegg R.T., M. H. (1990). Payback (PB). In *Building economics: Theory and Practices* (pp. 92-104).

Sadok, W. A. (2009). MASC: a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems. *Agronomy for Sustainable Development*, 29(3): 447-461.

Schnepf, R. (2004). Energy Use in Agriculture: Background and Issues. *CRS Report for Congress.* .

Schroeder, J. W. (1997). Mastitis control programs: Bovine mastitis and milking management.

Smart AgriFood Observatory. (2020). *Il glossario dell'Agricoltura 4.0.* Osservatori Digital Innovation, Politecnico di Milano.

Sponchioni, G. V. (2019). The 4.0 revolution in agriculture: A multi-perspective definition. *Proceedings of the Summer School Francesco Turco 1*, 143-149.

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Stobierski, T. (2023, 12 7). *HOW TO DO A COST-BENEFIT ANALYSIS & WHY IT'S IMPORTANT*. Retrieved from Harvard Business School Online: https://online.hbs.edu/blog/post/cost-benefit-analysis

Tahir, A. C. (2010). The process analysis method of selecting indicators to quantify the sustainability performance of a business operation. *Journal of cleaner production, 18*((16-17)), 1598-1607.

Talukder, B., Hipel, K., & vanLoon, W. (2017). Developing composite indicators for agricultural sustainability assessment: Effect of normalization and aggregation techniques. *Resources, 6(4)*(66).

Ten Hompel, M. &. (2008). Warehouse management.

Trapview. (2022, 12 05). Retrieved from www.trapview.com

Troskie, D. P. (2000). Characteristics of the agricultural sector of the 21st century. *Agrekon,, 39*((4)), 586-596.

UN. (2015). Retrieved from THE 17 SDG: https://sdgs.un.org/goals

Valenti, W. K.-V. (2018). Indicators of sustainability to assess aquaculture systems. *Ecological indicators*, 88, 402-413.

van Cauwenbergh, N. B. (2007). SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. *Agriculture, Ecosystems & Environment, 20*((2-4)), 229-242.

van der Werf, H. P. (2002). Evaluation of environmental impact of agroculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture, Ecosystems & Environment*, 93(1- 3): 131-145.

Vilain, L. (2008). La méthode IDEA : indicateurs de durabilité des exploitations agricoles. *Educagri ed., France*, 164p.

Wilson, E. O. (1988). Biodiversity.

Zahm, F. V. (2008). Assessing farm sustainability with the IDEA method – from the concept of agriculture sustainability to case studies on farms. . *Sustainable Development*, 16: 271-281.

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# Annex 1 – Review of Test Cases

The 30 TCs are heterogeneous in terms of sector, geographical location and DATSs used. Aiming at further characterizing the TCs and identifying the areas of activity DATSs 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 DATSs 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 DATSs more rigorously for identifying which activities are impacted by such DATSs.

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 DATSs. 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 DATS training.

Moreover, regarding the activities identified as being impacted by the use of the DATS 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 DATS are summarised in the following Table 17.

| Sector | Activity impacted by the DATSs | Description | # TCs per activity |
|---|---|---|---|
| Arable, Horticulture and | Irrigation management | Monitoring the application of water to crops. It is used to manage the volume, flow rate and | 16 |

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| | | | |
|---|---|---|---|
| Horticulture in-door farming | | timing of water application (Pereira et al., 2002). | |
| | 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 |
| | 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 |

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| | | | |
|---|---|---|---|
| | Training on DATs | All the activities (programmes, courses, etc.), funded by the employer, providing meaningful information on the use of DATSs. | 30 |

*Table 9: Activities impacted by the DATSs*

Before proceeding with the presentation of the DATSs 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 DATS;
2. The main DATSs 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 DATSs they are implementing.
4. In many cases, the category of DATS 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 DATSs were identified: automated greenhouses, DSS, precision irrigation systems, VRT, digital pest control systems. These DATSs impact the activities presented in Table 16.

In the following tables (17, 18, 19, 20, 21), the DATSs and the activities impacted are presented. An "O" indicates those activities that could be impacted by DATSs 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 DATSs and being actually used by the TC.

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| TCs # | Main DATSs | Irrigation Management | Fertilisers Management | Pesticides management | Crop monitoring | Warehouse management | Logistics management | Heating, cooling and ventilation management | Administrative tasks | Training on DATSs |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | DSS (water) + DSS (fertilisation) + digital pest control system | X | X | X | X | | | | X | X |
| 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 DATSs and O= activities that could be impacted by DATSs but which the TC has decided not to exploit*

*Table 10: Specific provider of DATSs and impacted activities in the arable, horticultural and horticultural in-door farming sector*

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

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

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

*Table 11: Specific provider of DATSs and impacted activities in the livestock and dairy sector*

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

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

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

*Table 12: Specific provider of DATSs and impacted activities in the apiculture*

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

| TCs # | Main DATSs | 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 DATSs and O= activities that could be impacted by DATSs but which the TC has decided not to exploit*

*Table 13: Specific provider of DATSs 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 DATSs 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 DATS 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.

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# Annex 2 – 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.<br><br>Emissions sources are categorized as direct or indirect and then further divided into '*scopes*':<br>• Direct sources: Owned or controlled by the reporting company. All direct sources are classified as scope 1.<br>• 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).<br>Overview of agricultural emission sources (p. 24-32)<br>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.<br>Setting organisational boundaries (p. 34-41) |

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Summary of requirements and main recommendations:

- Companies shall separately account for and report on scope 1 and 2 minimum.
- 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

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|---|---|
| | periods.<br>• Companies shall report quantitative information on GHG fluxes following requirements in the Corporate Standard.<br>• Companies should follow a set of additional 'best practice' recommendations for reporting agricultural GHG fluxes.<br>• Any offset credits or renewable energy that are generated on farmland but sold off-site shall not be reflected in inventory totals.<br><br>Tool for calculating GHG fluxes (p. 88-96)<br>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 14: Greenhouse gases emissions*

| **EN-WA-1** | **Water consumption**<br>**Water productivity**<br>**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**<br>*Water consumption:*<br>– *Irrigated crops:* volume of water applied for irrigation or other purposes / irrigated area<br>– *Non irrigated crops*: volume of water used / cultivated area<br><br>*Water productivity:*<br>– *Irrigated crops:* crop yield / volume of water applied for irrigation<br>– *Non irrigated crops*: crop yield / volume of water used<br>**Dairy and livestock**<br>*Water consumption:* total volume of water used<br>**Apiculture**<br>*Water consumption:* total volume of water used / number of beehives<br>**Aquaculture**<br>*Dependence on water:* total volume of water consumed / production |

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| | |
|---|---|
| Unit of measurement | **Arable and horticulture**<br>*Water consumption:* $m^3$ / ha; l / $m^2$<br>*Water productivity:* t / $m^3$; kg / l<br>**Dairy and livestock**<br>*Water consumption:* $m^3$; l<br>**Apiculture**<br>*Water consumption:* $m^3$ / beehive<br>**Aquaculture**<br>*Dependence on water:* $m^3$ / t |
| Notes | **Arable and horticulture**<br>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).<br>**Dairy and livestock**<br>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.<br>**Aquaculture**<br>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<br>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 15: Water Consumption, Water Productivity and Dependence on Water*

| EN-SO-1 | Total Soil Nitrogen<br>Available Soil Phosphorus<br>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 |

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<table>
<tr>
<td>Notes</td>
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<u>General Sampling Guidelines:</u><br>
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.<br><br>
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:<br>
1) Keeping the soil cool (but not frozen)<br>
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 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.<br>
2) Air drying the soil<br>
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.<br><br>
<u>How often to sample</u>:<br>
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.<br>
<u>Time of Sampling:</u><br>
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.<br>
<u>Sampling depth</u><br>
Nitrogen > The recommended sampling depth is 30 cm<br>
Phosphorus and Potassium > The recommended sampling depth is 15 cm deep<br>
<u>Laboratory analysis</u><br>
• <u>Total Soil Nitrogen</u><br>
Dumas dry combustion method (FAO, 2021a) or Kjeldahl method (FAO, 2021b)<br>
• <u>Available Phosphorus</u><br>
Bray I and II, Mehlich I, Olsen (FAO, 2021c; FAO, 2021d; FAO, 2021e)<br>
• <u>Available Potassium</u><br><br>
Mehlich III (Mehlich, 1984)
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<tr>
<td>Reference</td>
<td>
Sampling procedure<br>
Poon D., Schmidt O. (2010) Soil Sampling for Nutrient Management. Nutrient Management Factsheet – No. 2 in Series.<br><br>
Laboratory analysis
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</table>

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| | |
|---|---|
| | 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<br><br>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<br><br>FAO (2021b) Standard operating procedure for soil nitrogen – Kjeldahl method. Rome, FAO. Available at: https://www.fao.org/3/cb3642en/cb3642en.pdf<br><br>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<br><br>FAO (2021d) Standard operating Procedure for soil available phosphorus – Mehlich I method. Rome, FAO. Available at: https://www.fao.org/3/cb5427en/cb5427en.pdf<br><br>FAO (2021e) Standard operating procedure for soil available phosphorus – Olsen method. Rome, FAO. Available at: https://www.fao.org/3/cb3644en/cb3644en.pdf<br><br>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 16: Total Soil Nitrogen, Available Soil Phosphorus and Available Soil Potassium*

| **EN-EI-1** | **Fuel oil/diesel/propane consumption**<br>**Gas consumption**<br>**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<br>*Gas*: total consumption<br>*Electricity*: total consumption |
| Unit of measurement | *Fuel oil/diesel/propane*: l<br>*Gas*: $m^3$<br>*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 17: Fuel oil/diesel/propane consumption, Gas consumption and Electricity consumption*

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

| EN-EI-2 | Share of renewable energy |
|---|---|
| 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 18: 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

| EN-EI-3 | **Nitrogen applied / Nitrogen use**<br>**Phosphorus applied / Phosphorus use**<br>**Potassium applied**<br>**Nutrient use efficiency** |
|---|---|
| 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.<br>For **arable crops 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.<br>For **arable crops and horticulture**, *Nutrient use efficiency* refers to the ratio between the amount of nutrient (N, P or K) exported from the field by the harvested agricultural product and the amount of that nutrient applied through fertilisation. This indicator is calculated for N, P and K. |
| Metrics | **Arable and horticulture**<br>*Nitrogen applied*: amount of nitrogen applied / cultivated area<br>*Phosphorus applied*: amount of phosphorus applied / cultivated area<br>*Potassium applied*: amount of phosphorus applied / cultivated area<br>*Nutrient use efficiency*: (nutrient removal with harvest/Nutrient input with fertilizers) * 100<br>**Aquaculture**<br>*Nitrogen use*: amount of nitrogen applied / production<br>*Phosphorus use*: amount of phosphorus applied / production |
| Unit of measurement | **Arable and horticulture**<br>*Nitrogen applied*: kg N / ha<br>*Phosphorus applied*: kg P / ha<br>*Potassium applied*: kg K / ha<br>*Nutrient use efficiency*: %<br>**Aquaculture**<br>*Nitrogen use*: kg N / kg<br>*Phosphorus use*: kg P / kg |
| Notes | To calculate how much of a nutrient is applied, consider the following:<br>Amount of nutrient applied (e.g., kg N / ha) = Amount of fertiliser (kg / ha) * % nutrient in fertiliser ÷100<br>To calculate the amount of nutrient content in the harvested agricultural product, average data for N, P and K concentration derived from technical and scientific literature have been used. |
| 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<br>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.<br>OECD (2022), Measuring the Environmental Performance of Agriculture Across OECD Countries, OECD Publishing, Paris, https://doi.org/10.1787/4edcd747-en.<br>Roberts, T. L., & Johnston, A. E. (2015). Phosphorus use efficiency and management in agriculture. Resources, conservation and recycling, 105, 275-281.<br>Congreves, K. A., Otchere, O., Ferland, D., Farzadfar, S., Williams, S., & Arcand, M. M. (2021). Nitrogen use efficiency definitions of today and tomorrow. Frontiers in Plant Science, 12, 637108. |

*Table 19: Nitrogen applied/Nitrogen use, Phosphorus applied/Phosphorus use, Potassium applied and Nutrient use efficiency*

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

| EN-EI-4 | Herbicides use<br>Insecticides use<br>Fungicides use |
|---|---|
| Domain | Environmental |
| 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<br>*Insecticides use:* amount of active ingredient / cultivated area<br>*Fungicides use:* amount of active ingredient / cultivated area |
| Unit of measurement | *Herbicides use:* kg a.i. / ha<br>*Insecticides use:* kg a.i. / ha<br>*Fungicides use:* kg a.i. / ha |
| Notes | To calculate the amount of active ingredient, consider the following:<br>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 20: Herbicides use, Insecticides use and Fungicides use*

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

| EN-WA-1 | Amount of waste generated |
|---|---|
| Domain | Environmental |
| 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.<br>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.<br>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 21: Amount of waste generated*

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

| EN-AHW-1 | Ease of movements<br>Total indoor area |
|---|---|
| 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<br>*Total indoor area*: net area available to animals / number of animals |
| Unit of measurement | *Ease of movements:* d / y; h / d<br>*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.<br>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 22: Ease of movements and Total indoor area*

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

| **EN-AHW-2** | **Mortality rate**<br>**Mortality rate at birth**<br>**Cows with high SCC**<br>**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<br>*Mortality rate at birth:* number of animals died in the first 24 h / Total number of animals born * 100<br>*Cows with high SCC:* number of cows producing high SCC milk / Total number of cows * 100<br>*Quantity of drugs used:* total quantity of drugs used per type of drug |
| Unit of measurement | *Mortality rate:* %<br>*Mortality rate at birth:* %<br>*Cows with high SCC:* %<br>*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<br>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 23: Mortality rate, Mortality rate at birth, Cows with high SCC and Quantity of drugs used*

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

| 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.<br>Tsolakis N, Anastasiadis F, Srai JS (2018) Sustainability performance in food supply networks: Insights from the UK industry. Sustainability, 10(9), 3148 |

*Table 24: Production costs*

| 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 25: Sales revenue*

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

| 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 DATSs |
| 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 26: Other income*

| EC-PD-1 | Productivity |
|---|---|
| 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<br>*Labour productivity*: total production / hours of labour employed<br>*Milk productivity*: total milk production / total number of cows<br>*Bees productivity*: total production / colony<br>*Oyster productivity*: area used / production |
| Unit of measurement | **Arable and horticulture**<br>*Land productivity*: tons / ha or kg / $m^2$<br>*Labour productivity*: kg / h<br>**Dairy**<br>*Milk productivity*: kg / cow / day<br>**Apiculture**<br>*Bees productivity*: kg / colony<br>**Oyster**<br>*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 27: Productivity*

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

| 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<br>or<br>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 28: Feed Conversion Ratio*

| EC-EF-2 | Rate of time for quality analysis |
|---|---|
| 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 29: Rate of time for quality analysis*

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

| 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 30: 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 31: Number of wrong orders*

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

| 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 DATSs 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 DATSs |
| Reference | Aramyan, L., Ondersteijn, C. J., Van Kooten, O., & Lansink, A. O. (2006). Performance indicators in agri-food production chains. Frontis, 47-64. |

*Table 32: Intrinsic product quality*

| SO-IS-1 | Training hours (for the use of DATS) |
|---|---|
| Domain | Social |
| Category | Internal social sustainability |
| Sub-category | Training and education |
| Description | It measures the average hours of training per year per employee <u>specifically dedicated to the use of DATS.</u><br>*Training* refers to:<br>• all types of vocational education and training;<br>• paid leave for study purposes offered by the organization to its employees;<br>• training or education provided externally and paid for, in whole or in part, by the organisation;<br>• training on specific topics<br>The training does not include on-site coaching activities by supervisors.<br>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 33: Training hours (for the use of DATS)*

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

| 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).<br>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 34: 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).<br>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 35: 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).<br>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 36: 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.<br>Horodnic, Ioana Alexandra, and Colin C. Williams. "Evaluating the working conditions of the dependent self-employed." International Journal of Entrepreneurial Behavior & Research (2019). |

*Table 37: Working conditions index*

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

| 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 38: Contribution to local employment*

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# Annex 3 – The social questionnaire

## Social Indicators Questionnaire

The purpose of this questionnaire is to explore the social impacts linked to the implementation of the Digital Agriculture Technologies (DATs).
The questionnaire is organized into two main sections in order to gather comprehensive data on the farmers' working context and the impact of DATs on their work.
The initial section aims to explore the farmer's work environment, focusing on quality or working time. Specifically, questions regard weekly working time, whether atypical hours are worked, and about working flexibility. The second part, is exclusively addressed to farmers who are implementing DATs; hence, this section focuses on the study of the impacts of the adoption of DATs on farmers' work. We kindly ask you to provide as accurate responses as possible that best depict your current situation.

**The questionnaire takes less than 10 minutes to complete.**
Your answers will be saved automatically while filling in and - if necessary - you will be able to go back through the questionnaire to change them. It will also be possible to interrupt the questionnaire and resume it at a later date by accessing the same link.

**The answers will be treated confidentially.** We will only publish aggregated results and the answers will only be used for statistical purposes. **No specific data relating to your compilation will be disseminated individually.**

If you have any questions related to filling in or if you have problems completing the questionnaire, please do not hesitate to contact us at the following e-mail address: francesco.parigi@polimi.it

**General data**

- Sector arable
- Specify crop/animal
- Farm location

**A) Questions on work environment context**

| | never | rarely | sometimes | often | always |
|---|---|---|---|---|---|
| 1.A Do you work long hours (48 hours per week or more)? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2.A Do you have enough recovery period? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3.A Do you work night shifts more than twice a week? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4.A Do you work more than 5 consecutive days per week? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5.A How often do you work on Saturdays? | ☐ | ☐ | ☐ | ☐ | ☐ |

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| | | | | | |
|---|---|---|---|---|---|
| 6.A How often do you work on Sundays? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7.A Is it easy/ flexible at your work to ask for short time off (1-2 hours)? | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8.A Are you asked to work in your free time (longer shifts, work in the recovery period, vacations)? | ☐ | ☐ | ☐ | ☐ | ☐ |

| | <5h | 6-10h | 11-15h | 16-20h | 21-25h | 26-30h | >30h |
|---|---|---|---|---|---|---|---|
| 9.A How many hours a week do you spend with your family and/or friends? | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

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**B) Questions on the impact of DATs (only for farmers implementing DATs)**

- Have you implemented a DATs? Yes

**If the answer to the question is NO, you have completed the questionnaire.**

- (if yes) What type of DATs have you implemented?

| | strongly disagree | disagree | neither agree nor disagree | agree | strongly agree |
|---|---|---|---|---|---|
| 1.B DATs allow me to solve unforeseen problems | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2.B DATs make it easier for me to perform complex tasks | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3.B DATs allow flexibility in planning and executing my work activities | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4.B DATs enable me to make decisions more consciously and efficiently | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5.B DATs enable me to choose or modify the speed or pace of work | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6.B DATs allow me to focus on other/new tasks | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7.B DATs help me decrease work intensity | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8.B DATs help me decrease work complexity | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9.B DATs help me to improve the balance between work and free time | ☐ | ☐ | ☐ | ☐ | ☐ |
| 10.B The implementation of DATs has fostered the interest of younger generation to work in your farm or in agriculture sector | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11.B DATs help to ensure succession on the farm | ☐ | ☐ | ☐ | ☐ | ☐ |
| 12.B DATs help me to feel more certain about the future | ☐ | ☐ | ☐ | ☐ | ☐ |

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| | | | | | |
|---|---|---|---|---|---|
| 13.B DATs make it easier to learn new things | ☐ | ☐ | ☐ | ☐ | ☐ |
| 14.B I feel that DATs negatively affect my physical well-being | ☐ | ☐ | ☐ | ☐ | ☐ |
| 15.B I feel that DATs negatively affect my emotional well-being | ☐ | ☐ | ☐ | ☐ | ☐ |
| 16.B DATs support me in dealing with pressures from climate change | ☐ | ☐ | ☐ | ☐ | ☐ |
| 17.B DATs replace me in my tasks | ☐ | ☐ | ☐ | ☐ | ☐ |
| 18.B DATs help to deal with complex standards and regulations | ☐ | ☐ | ☐ | ☐ | ☐ |

19.B DATs allow me to have more spare time? No

**If the answer to the question 19.B is NO, you can proceed to the next section.**

| | strongly disagree | disagree | neither agree nor disagree | agree | strongly agree |
|---|---|---|---|---|---|
| 20.B (if yes) The spare time you gain allows you to spend more time with your family and/or friends | ☐ | ☐ | ☐ | ☐ | ☐ |

21.B Did you have to learn new things to use DAT? No

**If the answer to the question 21.B is NO, you can proceed to the next section.**

| | strongly disagree | disagree | neither agree nor disagree | agree | strongly agree |
|---|---|---|---|---|---|
| 22.B (if yes) Learning how to use DATs generated stress for me | ☐ | ☐ | ☐ | ☐ | ☐ |
| 23.B (if yes) Learning how to use the DATs were complicated | ☐ | ☐ | ☐ | ☐ | ☐ |
| 24.B (if yes) Learning how to use the DATs were time consuming | ☐ | ☐ | ☐ | ☐ | ☐ |

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| | | | | | |
|---|---|---|---|---|---|
| 25.B (if yes) Learning how to use the DATs were interesting and motivating | ☐ | ☐ | ☐ | ☐ | ☐ |

26.B Do women on the farm use the DATs? No

**If the answer to the question 26.B is NO, you have completed the questionnaire.**

| | strongly disagree | disagree | neither agree nor disagree | agree | strongly agree |
|---|---|---|---|---|---|
| 27.B (if yes) Women on the farm encouraged the purchase of DATs | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28.B (if yes) The implementation of DAT has fostered women's interest in working on my farm | ☐ | ☐ | ☐ | ☐ | ☐ |

**Thank you for filling in our questionnaire!**

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# Annex 4: QuantiFarm – Producer's Consent

(Document to be translated to the local language which is understood by the producers)

**About QuantiFarm**

QuantiFarm is an EU funded project to evaluate the performance benefits of Digital Agriculture Technologies (such as digital apps, satellite or drone mapping, sensors etc.). The goal of QuantiFarm is to compare the economic, environmental, and social performance of producers that use Digital Agricultural Technologies with producers who do not use such technologies.

| | |
|---|---|
| Name of producer | |
| Contact Details (phone/email) | |
| Name - trading entity of producer | |
| Full Address | |
| Geo-coordinates of the farm (when fields are spread out, mention coordinates of the farm main location) | |
| Total size of farm in hectares | |

| | **Producer Declaration** |
|---|---|
| **1** | I, as a producer, agree to participate in QuantiFarm and provide information about the fields that are relevant to the study's purpose.<br>I as a producer agree to participate in QuantiFarm and declare fields relating to purpose of study |
| **2** | I welcome QuantiFarm Test Case Leaders and show them my fields, respond to their questions and allow them to take e.g. soil, water and crop samples. |
| **3** | I maintain adequate written bookkeeping of all input and output products for my farms. |
| **4** | Evidence of the above-mentioned requirements (e.g. such as invoices, utility bills and maps etc.) are readily available and can be provided during the assessment and upon request. |

By signing this document, I give my permission for the information gathered about my farm as part of the QuantiFarm project, which is studying the advantages of Digital Agricultural Technologies, to be shared. This sharing will only involve authorized QuantiFarm staff and will solely be used for the purposes mentioned. Moreover, I confirm that only anonymized and processed data will be made accessible to the public, following proper formatting.

Place, Date: ____________________

Signature (producer):________________________________________

*More information about QuantiFarm can be found on the website (https://quantifarm.eu/).*

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# Annex 5: QuantiFarm Test Case Leader Declaration

| | |
|---|---|
| Test Case Description (TC number, product, country, DATS etc.) | |
| Name of organization/ consultant performing the TC assessments | |
| Full Address | |
| Contact (email, phone, website) | |
| Nature of relationship to producers (e.g. farmers) involved in the DATS Test Case | |
| Nature of relation with organizations developing, providing or promoting any of the DATSs being assessed in this test case. | |

| | **Declaration** |
|---|---|
| **1** | I as a DATS Test Case Leader have read and understood the Governance Framework available in the document *D2.1 Governance Mechanisms* . |
| **2** | I will conduct all assessments and data collection of relevant producers in compliance to the QuantiFarm governance. |
| **3** | I will share all information collected during the DATS Test Case assessment with QuantiFarm. |
| **4** | I agree to share the outcome of my assessments with the producer and get their signature. |
| **5** | I agree that my assessments and data will be verified by an independent verifier. |

Name (DATS Test Case Leader):________________________________________

Position:________________________________________

Signature:________________________________________

Place, Date: ________________________________________

*More information about QuantiFarm can be found on the website (https://quantifarm.eu/).*

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# Annex 6: Test Case Verifier Declaration

| | |
|---|---|
| Test Case Description (TC number, product, country, DATS etc.) | |
| Name of organization/ consultant performing the TC verification | |
| Full Address | |
| Contact (email, phone, website) | |

| | **Declaration** |
|---|---|
| **1** | I as a DATS Test Case Verifier have read and understood the Governance Framework available in the document *D2.1Assessment Framework and Governance Mechanisms.* |
| **2** | I will conduct the verification of the TC in compliance to the QuantiFarm governance principles. |
| **3** | I declare that I or my organization do not have any relationship with any organizations developing, providing or promoting any of the DATSs being assessed in this test case. |

Name (DATS Test Case Verifier):_________________________________________

Position:_________________________________________

Signature:_________________________________________

Place, Date: _________________________________________

*More information about QuantiFarm can be found on the website (https://quantifarm.eu/).*

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