THEROS

An integrated toolbox for improved verification and prevention of adulterations and non-compliances in organic and geographical indications food supply chain

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D.5.1: Validation scenarios and pilots evaluation methodology

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		Lead Author	Anthoula Argyri
		Reviewers	Vaso Lyravdou, BIOH
			Jelena Nedeljovic, Svetlana Vitomirovic, OCS

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Document Information

Author(s) – in alphabetical order		
First Name	**Last Name**	**Partner**
Anthoula	Argyri	ELGO
Dimitra	Tsiakou	ICCS
Svetlana	Vitomirovic	OCS
Vesna	Vidić	UNIVER
Vaso	Lyravdou	BIOH
Litsa	Liopa-Tsakalidi	BIONET
Macarena	Garcia	KIWA
Joaquin	Garrido	MEXILLON
Tomas	Zelený	SUMAVA
Kyriaki	Psara	EBOS
Sarka	Horakova	WRLS

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Deliverable leader	Anthoula Argyri (ELGO)	30/12/2024
Quality manager	Kyriaki Psara (EBOS)	27/12/2024
Project Coordinator	Angelos Amditis (ICCS)	31/12/2024

Executive Summary

This deliverable, D5.1: Validation Scenarios and Pilots Evaluation Methodology, is a cornerstone of Task 5.1 within Work Package 5 (WP5) of the THEROS project. It outlines the comprehensive methodology to be employed during the project's pilot demonstrations for evaluating the performance of the THEROS toolbox components. By implementing end-to-end scenarios, the project seeks to achieve a robust evaluation framework that integrates technical, operational, and stakeholder-oriented perspectives.

- The methodology delineates a detailed list of Key Performance Indicators (KPIs), classified into qualitative and quantitative metrics. These KPIs focus on:
- Technical Evaluation: Assessing the precision, reliability, and efficiency of the individual toolbox components, including their interoperability within diverse supply chains.
- Operational Performance: Evaluating the real-world functionality and deployment feasibility of the tools in varied agricultural and food supply chain contexts.
- Stakeholder Assessment: Gathering insights from end-users, including producers, retailers, certification bodies, and consumers, to evaluate the perceived utility, user-friendliness, and business benefits of the THEROS solutions.

The methodology outlined in this deliverable supports pilot demonstrations in Serbia, Greece, Spain, and the Czech Republic, focusing on diverse agricultural contexts and food products. It integrates insights from previous tasks, including end-user needs analysis and the effects of fraud practices, ensuring a robust alignment with the project's goals.

The expected outcomes of the THEROS project include enhanced traceability and transparency across the supply chain through innovative technologies, improved tools for compliance validation and fraud prevention, actionable insights to support sustainability and environmental performance monitoring, and strengthened market competitiveness alongside increased consumer trust in organic and geographical indication (GI) products.

By detailing these methodologies and defining KPIs, this deliverable provides a framework for achieving the THEROS project's mission to modernize supply chain traceability and compliance, ensuring quality, authenticity, and sustainability in organic and GI food products.

Table of Contents

List of Tables

List of Figures

Abbreviations & Acronyms

Abbreviation / acronym	Description
D5.1	Deliverable number 1 belonging to WP 5
dDPP	dynamic Digital Product Passport
DNA	Deoxyribonucleic Acid
EC	European Commission
EO	Earth Observation
GAT	Green Accountability Tool
GI	Geographical indication
GMO	Genetically modified organisms
HRM	High Resolution Melting
IoT	Internet of Things
KPIs	Key Performance Indicators
MEMS	Microelectromechanical systems
PCR	Polymerase Chain Reaction
PO	Project Officer
PU	Public dissemination level
SMEs	Small and Medium-sized enterprises
WP	Work Package

1. Introduction

1.1 Purpose of the document

The main goal of this report is to outline the methodology for evaluating the overall performance of the THEROS toolbox components during pilot demonstrations. This will be achieved through the implementation of comprehensive end-to-end scenarios. The task includes defining, compiling, and documenting a detailed catalog of Key Performance Indicators (KPIs), encompassing both qualitative and quantitative metrics. These KPIs will assess the technical performance and operational efficiency of the THEROS toolbox components, as well as gather feedback from stakeholders. This includes evaluating the quality of information provided by the toolbox, the usefulness of visualized outputs related to supply chain traceability and food fraud detection, the user-friendliness of the toolbox, and the clarity of guidelines provided to stakeholders for implementing the system.

1.2 Intended readership

D5.1 “Validation Scenarios and Pilots Evaluation Methodology” is a public deliverable of the THEROS project and offers significant guidance to its intended audiences, including the European Commission (EC), the Project Officer (PO), and the project consortium members. It serves as a critical resource for planning, implementing, and evaluating the pilot demonstrations of the THEROS toolbox components.

This document provides a structured framework for assessing the effectiveness of THEROS toolbox components across multiple scenarios. It outlines a detailed methodology to deploy and evaluate end-to-end validation processes and Key Performance Indicators (KPIs), ensuring the project meets its technical, operational, and stakeholder expectations. It integrates technological and user-acceptance dimensions, focusing on real-world applicability and alignment with user needs.

While primarily addressing the project's internal stakeholders, this deliverable has been carefully crafted to remain accessible and comprehensible to the general public (Public (PU) dissemination level). It offers insights into the project's evaluation strategies. It fosters transparency and understanding of THEROS's goals in improving traceability, compliance, and sustainability within the organic and geographical indications (GI) food supply chains.

1.3 Document Structure

The structure of this document is as follows: Chapter 1 serves as an introduction to the deliverable, while Chapter 2 outlines the overall approach to the evaluation framework. Specifically, it highlights the connection between the pilot demonstrations and the THEROS toolbox components, providing essential technical and operational details. It also discusses the importance of each component and develops appropriate end-to-end scenarios for deployment. Each scenario is divided into four sections to present its relevance, specific goals, technical guidelines and methodology, measurements to be performed, and expected outcomes.

Chapter 3 of the report outlines the THEROS KPIs and presents a comprehensive KPI catalog for each use case, including measurement methods to assess the potential impact of the THEROS solution in meeting user needs. Finally, Chapter 4 concludes with an overview of the evaluation methodology and KPIs, along with recommendations for future activities during the demonstration pilots to enhance the evaluation of the THEROS toolbox (Deliverable 5.3).

2. Towards KPIs definition thought the THEROS's evaluation methodological framework

Like all successful projects, the THEROS project can be viewed through the lens of a broader concept, which we refer to as the ''**Success Funnel Model'**. This model highlights how a variety of efforts, activities, and factors—many of which are not immediately visible—gradually narrow down into a set of clear, measurable outcomes. The success funnel highlights that every consortium advances through a series of iterative phases, from ideation to implementation, requiring substantial effort and collaboration to accomplish the project's objectives. Similarly, we have applied this approach in designing our evaluation framework, leveraging specific KPIs to monitor and measure progress across the critical phases of the THEROS project. This framework enables us to assess the complete traceability of the supply chain, alongside the integration of all the components of the THEROS toolbox for detecting food fraud. By focusing not only on the final outcomes but also on the critical steps that contribute to them, we ensure that the modernization of supply chain traceability and environmental compliance within THEROS is both comprehensive and data-driven. The Success Funnel Model provides a structured approach for synchronizing key tracking events, and efficiently managing data through the THEROS toolbox, as depicted in Figure 1.

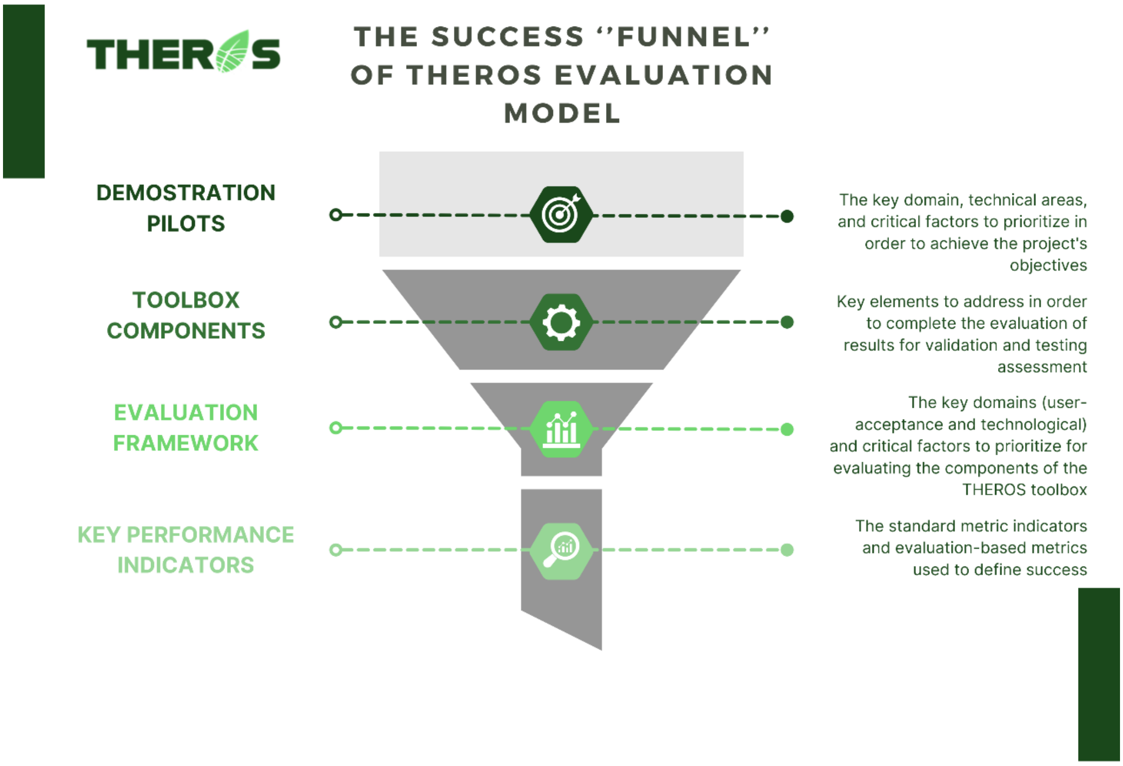

Figure 1 The Funnel theory of success adapted to develop the THEROS's evaluation methodology.

Moving from the project's development phase (WP3 and WP4) to the realization and real-life validation of the THEROS toolbox components, four demonstration pilots (Section 2.1) have been designed in which THEROS envisages to cover all the needs of the relevant stakeholders, as defined through proposal's Section 1.3.6 and D2.1 Identification of end-user needs, analysis of driving forces and effects of fraud practices for organic and GI food products and benchmarking of preventive systems. During this demonstrations, suitable data and processes for fulfilling the requirements of THEROS toolbox components have been identified, while relevant deployment activities have been prioritized and presented in this chapter, along with specific end-to-end scenarios (Section 2.2). These scenarios and their envisaged outcomes are going to drive the development of the THEROS's evaluation framework (Section 2.3), that is built upon two main pillars, namely the user-acceptance and the technological. Driven by a set of example questions THEROS team lead the activities to define KPIs based common metric indicators and metrics used within the framework of demonstration pilots. The idea is to focus on the various domains and critical factors, to address the elements that are needed to complete the evaluation and identification of results to assess validation and testing.

2.1THEROS demonstration Pilots overview

Within the framework of WP5, THEROS is going to demonstrate in four distinct pilots (Serbia, Greece, Spain, and Czech Republic) an integrated toolbox for improved verification and prevention of adulterations and non-compliances in organic and geographical indications food supply chain. In this section, a short overview of the proposed pilots is presented to highlight the user needs and the requirements that should be fulfilled by the deployment of the THEROS toolbox components. An overview of the demonstration pilots and the expected outcomes are presented in Table 1-Table 5.

Table 1 Integrated detailed list with all the pilot's plan (products, THEROS tools and solutions, numbers)

PILOT	PRODUCT	Main THEROS tools and solutions									
		EO based ecosystem services	ML based recommendations	MEMS based photonic system and models	IoT sensors network	DNA-based authenticity test	Block chain-based traceability system	Dynamic digital product passport	Data harmonisation platform and verification engine	Green accountability tool	Digital marketplace
SERBIA	Organic wheat flour	✓	✓	✓			✓	✓	✓	✓	
	Organic sunflower oil	✓	✓				✓	✓	✓	✓	
	Apple juice			✓			✓	✓	✓	✓	
	Cereals (wheat, bearly, oat, rye)	✓	✓						✓	✓	
	Soybean	✓	✓						✓	✓	
	Maize	✓	✓						✓	✓	
	Raspberry, blackberry	✓	✓						✓	✓	
	Sour cherry	✓	✓						✓	✓	
	Apple	✓	✓						✓	✓	
GREECE	Soil	✓	✓	✓							
	Orange	✓	✓	✓			✓	✓	✓	✓	
	Tangerine	✓	✓				✓	✓	✓	✓	
	Lemon	✓	✓				✓	✓	✓	✓	
	Grape fruits	✓	✓				✓	✓	✓	✓	
	Kiwi	✓	✓				✓	✓	✓	✓	
	Maize	✓	✓						✓	✓	
	Alfalfa	✓	✓						✓	✓	
	Wheat	✓	✓						✓	✓	
	Vetch	✓	✓						✓	✓	
SPAIN	Cooked mussel					✓	✓	✓	✓	✓	
	Fresh mussel					✓	✓	✓	✓	✓	

PILOT	PRODUCT	Main THEROS tools and solutions									
		EO based ecosystem services	ML based recommendations	MEMS based photonic system and models	IoT sensors network	DNA-based authenticity test	Block chain-based traceability system	Dynamic digital product passport	Data harmonisation platform and verification engine	Green accountability tool	Digital marketplace
CZECH REPUBLIC	Beef for goulash (package approx. 500g)				✓		✓		✓		✓
	Beef back - top scarf (package approx. 500g)				✓		✓		✓		✓
	Minced beef (package approx. 500g)				✓		✓		✓		✓
	Homemade sausages (pack of 2 approx. 250g)				✓		✓		✓		✓
	Pork ham (pack of 2 approx. 250g)				✓		✓		✓		✓
	Melcher organic Golden Loaf smoked cheese (approx. 300g per piece)				✓		✓		✓		✓
	Melcher's fresh organic butter (piece approx. 300g)				✓		✓		✓		✓
	Ghee organic butter for Melcher (approx. 300g piece)				✓		✓		✓		✓
	Cheese pickled in oil with chili, green pepper, sunflower, pumpkin and spices (glass)				✓		✓		✓		✓
	Pickled cheese in brine (jar approx. 400g)				✓		✓		✓		✓
	Smoked tolstolobik, horseshoe VAC (approx. 300g per piece)				✓		✓		✓		✓
	Carp chips fresh VAC (package approx. 300g)				✓		✓		✓		✓
	Smoked trout (approx. 300g per piece)				✓		✓		✓		✓
	Rainbow rout (approx. 400g per poice)				✓		✓		✓		✓
	Common carp - fillet (approx. 400g per poice)				✓		✓		✓		✓
	Beer Nuželický lager 0.5l				✓		✓		✓		✓
	Sušičák draft light beer 0.5l				✓		✓		✓		✓
	Semi-dark lager beer 0.5l				✓		✓		✓		✓
	Beer wheat lager 4x hopped 0.5l				✓		✓		✓		✓
	Semi-dark lager beer 1l				✓		✓		✓		✓
	New potatoes 1kg				✓		✓		✓		✓
	Carrot 1 kg				✓		✓		✓		✓
	Beet red 1kg				✓		✓		✓		✓
	Red onion (packaging 1kg)				✓		✓		✓		✓
	Cabbage head (packaging 1kg)				✓		✓		✓		✓

Table 2 Serbian demonstration overview and envisaged outcomes

ADDRESSED STAKEHOLDERS: ☒ Farmers ☒ Certification bodies ☒ Supply chain operators ☒ Consumers
Overview: The Serbian organic and geographical indication (GI) food sector faces several challenges, including regulatory alignment with EU standards and ensuring compliance through annual inspections. However, these inspections are insufficient to fully assess the vast agricultural areas, creating opportunities for non-compliance and fraud, particularly during critical farming periods. Certification bodies are responsible for evaluating organic production, but their current resources are often stretched thin, leading to peaks in workload and inefficiencies. Certification bodies face significant limitations in continuously monitoring the entire system throughout the year and cannot cover all parcels effectively. Due to limited resources and staff, certification bodies conduct periodic inspections, which makes it challenging to ensure year-round compliance across all organic farms. This issue is particularly relevant in organic farming, where strict adherence to standards is essential. Consequently, specific parcels may receive less frequent monitoring, creating potential gaps in oversight and increasing the risk of non-compliance with organic standards in some areas. All the results and data that will be reached through the project itself will give retailers a clear path towards positioning as organic product producers and help them to expand their niche in that segment. The results will provide consumers with an insight into each segment of production and communicate both the quality of the product and the method and process of its production. Using THEROS services will enable producers to deliver a superior product and promote and distribute it more effectively. Consumers will be able to know and better understand the entire production process, which will be utterly transparent compared to other products of that kind.
Main idea: To address this, the first steps in improving compliance monitoring involve implementing innovative technologies such as Earth Observation (EO) and machine learning to track farming practices remotely. Additionally, blockchain technology will enhance traceability throughout the supply chain. These tools will help identify fraudulent practices, such as mislabeling and substituting, while reducing the burden on certification bodies by automating aspects of the compliance process. MEMS portable spectrometer analyses the unique spectral signatures of food items like wheat flour and apple juice to assess their purity and compliance with organic standards. The mobile app processes data from the spectrometer, enabling real-time analysis and providing immediate results on the food product's authenticity. This solution aims to make food authentication accessible, affordable, and practical for consumers and businesses, enhancing food safety and transparency. Blockchain-enhanced traceability networks will be employed and utilised by all actors, including producers, packagers, and transporters, along with the interfaces exposed by the THEROS dynamic digital product passport and green accountability tool. It is necessary to maintain traceability, transparency and security between the actors involved in complex supply chains of quality labelled organic food products. This will also be explored in the context of the pilot demonstration. Nowadays, it is essential and highly recommended that we keep up with innovations, so implementing innovative technologies is always welcome.
Envisaged impact: • Large-scale monitoring of organic farming using EO and machine learning.

• More efficient detection of fraud and adulteration in organic products. • Implementation of blockchain technology to ensure supply chain traceability. • Integration of data harmonization and verification engine to streamline compliance validation. • Improved workload management for certification bodies, with fewer physical inspections required. • Increased compliance with EU regulations. • Financial implications for producers. • Market access and competitiveness.

Table 3 Greek demonstration overview and envisaged outcomes

ADDRESSED STAKEHOLDERS: ☒ Farmers ☒ Certification bodies ☒ Supply chain operators ☒ Consumers
Overview: The organic and geographical indication (GI) sector is facing, in general, significant challenges, including, among others, compliance with the European Regulations. This compliance is implemented through the annual inspections established by the European Regulation. In the period between, the tendency of a product to become non-compliant is high. The Certification Bodies put much effort and invested resources into minimising this risk, but this possibility will never be zero. During the inspection, the inspector relies only on the visual inspection and the review of each producer's records without being able to identify non-conforming acts which the producer might have engaged in and which are so far detectable by simple observation by the inspector. Farmers need transparent mechanisms to verify compliance and protect their certifications. The tools which will be developed within the framework of the THEROS project will enable producers to continuously demonstrate the compliance of their products with the requirements of the European Regulations for organic products. At the same time, tracking their products along the food supply chain will be possible up to the final customer securing our products' integrity in the organic terms.
Main idea: Monitoring through the technology of Earth Observation (EO) the distinction of areas which are cultivated organically or not can enable both producers and certification bodies to understand and take preventive measures, which will not allow contamination of organic plots by possible interventions from substances not allowed for organic, but which are permitted for conventional agriculture. The MEMS-based photonic system and the respective mobile applications will help the producers, who, with their use, will have the possibility to demonstrate the measurements during the inspection process to strengthen the documentation they demonstrate during the inspection, which concerns the use of prohibited, for the organic farming, substances such as herbicides or chemical fertilisers. On the other hand, it can be of great help to Certification Bodies when, during the inspection, with the use of the MEMS photonic system and the respective mobile application, the inspector decides whether further control and sampling of products can lead to the discovery of applications of non-permitted

substances by producers of organic products and in this way increases the reliability of the inspection process and ultimately the certification. The Blockchain traceability network, combined with the Dynamic Digital Passport of Products and the Green Accountability Tool, enables all participants in the food supply chain of organic products to monitor and confirm the movement of their products as well as control the possibility of sabotage by the length of the supply chain until the organic product reaches the final consumer. This approach supports stakeholders and promotes sustainability and competitiveness in the organic sector.
Envisaged impact: • By using all the tools of the THEROS program, producers can improve the management of organic cultivation techniques and take measures that allow them to implement better practices that ensure the organicity of their products. • The certification organisations can verify, in actual conditions, the evidence presented during the inspection. At the same time, they can also make decisions that can lead to the recording of non-conformities, thus increasing the reliability of the inspection. • All stages of the supply chain of organic products up to the final consumer can be tracked, mainly to ensure the avoidance of fraud and adulteration in organic products. • Promotes sustainable growth: Enhances product quality and supports long-term environmental and economic goals in organic agriculture.

Table 4 Spanish demonstration overview and envisaged outcomes

ADDRESSED STAKEHOLDERS: ☒ Farmers ☒ Certification bodies ☒ Supply chain operators ☒ Consumers
Overview: The Mexillon de Galicia PDO as geographical indication (GI) faces several challenges, including regulatory alignment with EU standards, ensuring compliance through periodic annual inspections, and the relevant fight against fraud. Being conscious about the importance of providing several layers of protection to the final consumer and despite the PDO being subject to inspections, which are a significant step to assess the vast mussel production from Galicia, we understand that the wide acknowledgement of the Galician Mussel generates non-desired opportunities for non-compliance and fraud, particularly during the transformation/commercialisation. The PDO Regulatory Council (Consello Regulador da D.O.P. Mexillón de Galicia) is responsible for providing the guarantee of origin at the different stages, and they are aware that the resources are stretched thin, leading to possible grey areas hardly monitored.
Main idea: The Spanish pilot will focus on the deployment and real-life validation of THEROS toolbox components through the DNA-based authenticity kit and the blockchain-based traceability system. One way to address the issues highlighted above is to reinforce the traceability chain from the beginning of the production to the last step, the final consumer, by going through the different links from the chain. Blockchain technology will be employed to enhance traceability throughout the supply chain. The integration of this technology of those DNA tests, which will ensure the authenticity of the products being used in the different steps of

the supply chain, will help to provide that "friendly to use" solution that will help the consumer to identify fraudulent practices, such as mislabeling or substitution while decreasing the workload on certification bodies by automating aspects of the compliance process. This project is an opportunity to provide the final consumer tools that will ensure that this purchase decision, which previously had to be made in a biased information situation, now would be done with a higher level of accuracy in terms of information, and this will be directly translated into trustworthy on those actors which fulfil the requirements stated by the certification bodies.
Envisaged impact: • Increase consumer confidence. • Help the retailers provide verified significant information regarding the goods they offer to the final customers. • Verify the product's origin across different stages of the value chain. • Provide an additional layer of security. • Tracking and tracing of GI food assets.

Table 5 Czech Republic demonstration overview and envisaged outcomes

ADDRESSED STAKEHOLDERS: ☒ Farmers ☒ Supply chain operators ☒ Consumers
Overview: As a part of the European Theros project, we are in charge of implementing innovative technologies into practice. These technologies prevent the confusion of conventional foods with organic products; they ensure the delivery of products with the certified protected brand Bioproduct, Šumava-original product, Regional food of the Pilsen region and Klasa, subject to compliance with the appropriate transport conditions for both our and commercial transport. This initiative aims to increase the availability of organic food by creating and implementing a new business model. By mapping local suppliers and retailers, the project aims to create a rational, transparent path for organic goods "from the farm to the table" and ensure they meet strict quality standards.
Main idea: Thanks to the new Marketplace business model, this project also increases the availability of these foods to many customers, who can choose from a wide range of certified products in one place. We follow the motto here: "From the farm to your table", and we adhere to strict quality standards using tracking technologies that monitor the location and temperature of the delivered goods throughout the transportation.
Envisaged impact: The comprehensive approach aims to protect consumers and empower local certified food producers by giving them the tools and visibility they need to compete in the larger market. The project focuses on accredited products, prioritising those most prone to counterfeiting and those in high demand among local consumers. The standards for selecting these products include their popularity in the region, the feasibility of implementing tracking and verification technologies, and the need for better supply chain transparency.

2.2End-to-end scenarios for THEROS toolbox components deployment

Through the four demonstration pilots, THEROS will document how to tackle food fraud and prevent adulterations and non-compliance while demonstrating enhanced security, transparency and interoperability in the quality labelled food supply chain by implementing an integrated toolbox that can verify organic and geographical food labels.

A short overview of the main components that constitute the THEROS toolbox is provided as follows:

- EO based ecosystem services component utilizes satellite imagery and machine learning to monitor agricultural activities and compliance with organic farming practices. Key markers include homogeneity, greening, harvest, bare-soil, crop type, and organic/non-organic classification markers. These enable large-scale and efficient monitoring of farming parcels.
- MEMS based photonics system which is a low-cost spectrometer designed to detect adulteration and fraud in food products such as wheat flours and apple juice. It works by analyzing the spectral signatures of food products to identify adulteration levels or non-compliance with organic standards. Also, the mobile application that handles the MEMS-based photonics system, enabling on-site food authentication by scanning products with the MEMS spectrometer. The mobile app facilitates real-time analysis and provides immediate results on the potential adulteration or authenticity of the food product being tested.
- IoT sensors network it's a network of sensors designed to monitor environmental conditions (such as temperature and humidity) during the transportation of food products. It ensures that the quality of products is maintained throughout the supply chain.
- DNA based authenticity kit is a portable DNA analysis system that verifies the species origin and provenance of food products. It helps in detecting food adulteration and ensuring that the product matches its labeling regarding species and geographical origin.
- Blockchain enhanced traceability system that provides an immutable record of all supply chain events, from production to retail. This system ensures transparency and trust across the supply chain by securely tracking product life cycles, including production, transformation, and transportation.
- Dynamic digital product passport for organic/GI food assets tracks the product's journey through the supply chain. It allows users to verify key

tracking events, such as pick-up, transportation, and delivery, providing real-time information on the product's status and compliance.

- Green accountability tool aims at monitoring and visualizing the environmental performance of food production practices, ensuring sustainable practices are followed.
- Business model driven digital marketplace designed to connect stakeholders across the organic and geographical indication (GI) food supply chain. The marketplace facilitates trade between producers, traders, retailers, and consumers by providing a transparent and trusted platform where verified organic and GI products can be traded.

As part of the THEROS demonstration pilots, the previously mentioned technological components will be implemented to address the data and operational challenges faced by decision-makers (Figure 2). This section introduces the deployment of end-to-end scenarios for each THEROS toolbox component during the pilot demonstrations. These scenarios will clearly define the experimental parameters, including the number of participants, testing tools, location and timeline, factors to be examined, and outcomes to be evaluated. These experimental end-to-end scenarios will facilitate the development of an evaluation framework for assessing the overall performance of THEROS, supported by detailed plans to be implemented across all four pilots (Task 5.2-5.5).

Each of these scenarios is separated in four sections: the introduction and the component's importance, the component's specific goals, the activity description and the envisaged outcomes. The introduction describes the importance of each toolbox component proposed and contains information to clearly identify why each component is being conducted and what it is intended to accomplish, including its ultimate and specific goals. In the activity description section, the deployment site where the measurements will take place, the experimental procedures and equipment used, along with the expected timeline are included, along with any remark being made. Finally, the collected information part and the examined components constitute a description of the envisaged outcomes. Altogether are going to be further analysed to support the development of the evaluation methodological framework.

2.2.1 EO based ecosystem services

EO based ecosystem services end-to-end scenario	
Hypothesis	Until now, a variety of applications have demonstrated the critical role of Earth Observation (EO) services in enhancing transparency and traceability within organic and geographical indication (GI) supply chains. However, the current implementations have shown optimal results when monitoring large-

	scale, uniform agricultural fields, with limitations in accurately assessing highly fragmented landscapes and smaller organic farms. In this context, the integration of high-resolution EO data into the THEROS system can significantly expand its capacity to monitor compliance across diverse agricultural environments, including smaller, irregularly shaped plots. This enhancement will facilitate more precise detection of non-compliance or fraudulent activities and support certification bodies in overseeing organic and GI practices with greater accuracy, even in complex terrain.
Specific Goals	The purpose of high-resolution EO data generation in the THEROS project is closely aligned with the goal of improving traceability and compliance monitoring across organic and geographical indication (GI) supply chains. Specifically, the objectives include the creation of enhanced maps to detect and monitor farming practices, such as land use changes and crop-type verification. More specifically, the goals here are to: • Enable continuous and real-time monitoring of organic and GI-certified fields across participating countries, providing high-resolution datasets that will allow certification bodies to remotely inspect even small, fragmented agricultural plots; • Contribute to the production of highly accurate monitoring markers (e.g., crop-type classification, greening, harvest, land cover) with enhanced spatial and temporal resolution, offering better insights into organic farming practices and detecting possible non-compliance or fraudulent activities in real-time.
Activity Description	**Deployment Sites**
	The component is deployed to monitor pilot sites in Greece and Serbia. The focus is on monitoring large areas situated across the whole country to demonstrate the capability of the component to monitor large numbers of parcels with different geographic characteristics. Below we see cartographic representation of the parcels being monitored across Serbia and Greece.

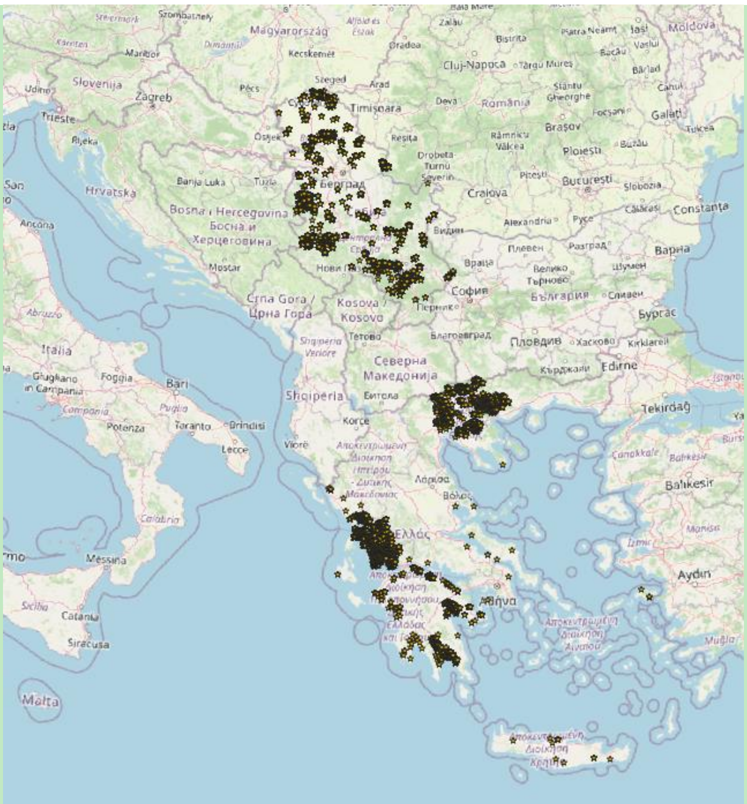

Figure 2 Areas of computed markers in Serbia and Greece.

Experimental Procedures

Within this component we develop markers - insights about what is happening on the parcel by applying statistical and machine learning methods to satellite (or other aerial) imagery timeseries.

Some markers use pretrained models, while other markers are trained on the reference data provided by the certificate agency.

The experimental methodology for developing and evaluating the markers is as follows:

1) Preprocessing of the reference data provided by the Control Bodies
2) Training the models using the reference data
3) Evaluation of the models on the left-out set of the reference data
4) On the spot validation of the results

Based on the shortcoming found during the evaluation, we can try and make improvements to the developed markers. Either by gathering more reference data or by adjusting the parameters of the models.

Tech Components

The EO based ecosystem services module uses Sentinel Hub to efficiently retrieve Satellite Imagery and allow for retrieval of temporal statistics over parcels to generate signals that are used as input for the markers.

The marker module delivers computed markers for parcels of interest. The marker provider is connected to the Theros data harmonization tool through a Rest API.

We also offer access to a frontend application that allows Control Bodies to investigate results of the markers on a map.

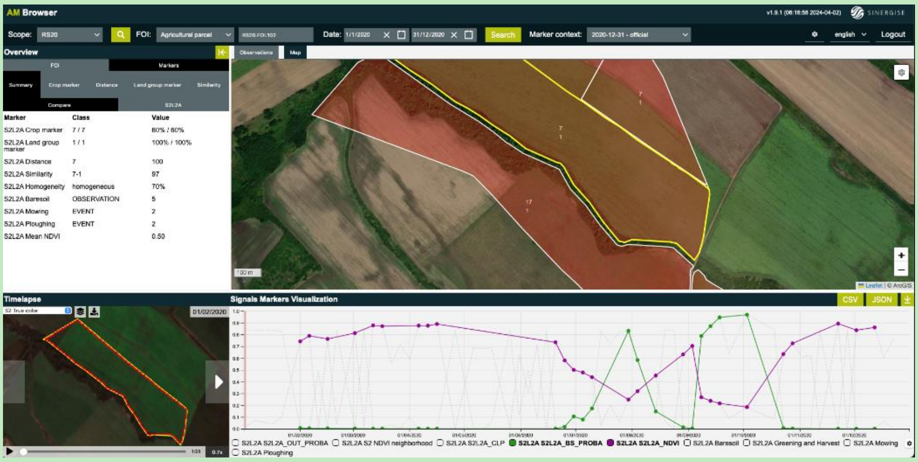

Figure 3 AM Browser to explore the results.

Time plan

First versions of the markers over pilot sites were delivered in early summer 2024. We will proceed with the next iteration of the markers in 2025 to allow for targeted on the spot checks by the Control Bodies.

In early 2025, we plan to run the markers on super-resolved Sentinel-2 imagery in order to try and improve the performance over smaller parcels.

Outcomes

- High-resolution EO data allows for continuous monitoring of organic and GI-certified fields, even in fragmented and irregularly shaped plots, significantly improving traceability.
- The use of advanced markers (e.g., crop-type classification, greening, harvest) aids in detecting non-compliance or fraudulent activities in real-time, ensuring that organic farming practices adhere to established standards.
- The system can monitor large agricultural areas with diverse characteristics, providing certification bodies with tools to conduct remote inspections effectively.
- By generating high-resolution datasets and detailed monitoring markers, the system supports certification agencies in making informed decisions and identifying areas requiring attention.
- Improved capacity to detect fraudulent practices such as land use changes or mislabeling, thereby enhancing trust in organic and GI supply chains.

2.2.2 MEMS based photonics systems and mobile application

MEMS based photonics systems end-to-end scenario	
Hypothesis	Until now, portable spectroscopic technologies have demonstrated the potential of proving quality assurance in agricultural supply chains. MEMS-based photonic systems will implement real time and in-situ analysis with the precision needed to ensure transparency and traceability in various stages of

	the supply chain. In this context, the integration of MEMS-based photonics systems into the THEROS framework can significantly enhance the ability to monitor organic farming compliance by certification bodies, adulteration detection from retailers and the assessment of soil and product properties by producers in diverse environments.
Specific Goals	The MEMS-Based Photonics Systems and Mobile Application in the THEROS project aim to revolutionize quality assurance and traceability in organic and GI food supply chains. A primary goal is to enable real-time detection of food adulteration, providing retailers with a fast and efficient way to identify compromised products. By integrating MEMS-based photonics systems with mobile applications, the project offers on-the-spot analysis capabilities that enhance transparency and trust in the supply chain. Supporting organic compliance monitoring is another critical objective. Certification bodies can utilize these tools during inspections to assess produce quality and identify potential non-compliance issues. Additionally, the MEMS system empowers farmers and producers to evaluate soil properties, such as Soil Organic Carbon (SOC), clay content, and pH, directly on-site. This feature promotes sustainable farming practices by giving producers actionable insights into their soil's health. The MEMS-based photonics system is designed to seamlessly integrate with the broader THEROS toolbox. This integration ensures that the system contributes to improving transparency, traceability, and quality assurance across the supply chain. Advanced machine learning models, trained on extensive spectral databases, enable the MEMS system to deliver accurate and real-time insights into food and soil quality, providing stakeholders with reliable data for decision-making. User-centric design is a key focus, ensuring the technology is accessible and practical for farmers, retailers, and certification bodies. Mobile applications are developed to provide a user-friendly interface, allowing stakeholders to interact with the system efficiently. Pilot demonstrations in Greece (e.g., BIONET for soil scanning) and Serbia (e.g., UNIVER for adulteration detection in wheat flour and apple juice) validate the system under diverse operational conditions, ensuring its adaptability and reliability. The project also emphasizes enhancing food traceability by providing on-the-spot quality assessments during the supply chain process. Tailored outputs, such as purity indices and soil property reports, are customized to meet the specific needs of different stakeholders, ensuring that the MEMS-based tools are valuable for a wide range of applications. Ultimately, the MEMS-Based Photonics Systems and Mobile Application aim to strengthen transparency, improve sustainability, and foster trust across organic and GI supply chains.
Activity Description	**Deployment Sites**
	The pilot demonstration site for the MEMS based photonics system within the THEROS project is set in Serbia and in Greece. An important collaborator in Serbia is UNIVER which will be able to deploy the system with a smartphone application in order to detect possible adulteration in wheat flour (i.e. substitution). The possible areas of deployment would be in AUTH facilities where flour samples from UNIVER would be sent and analyzed or during THEROS 4th plenary meeting. Additionally, MEMS would be also deployed in the Greek pilot and a possible testing site is near the Mesologgi

	area. During the pilot, adulteration prevention in fresh/bulk organic agri-products (i.e. oranges) would be executed along with the determination of soil properties (i.e. SOC, clay and ph).
	Experimental procedure
	MEMS-based photonics systems coupled with THEROS mobile application utilizes an online spectral database of soil and food. By deploying accurate machine-learning models, the system is able to provide real-time estimations of food products' purity, indicate organic compliance and display key soil properties. During the pilot demonstrations, end-users will be able to assess the tool which will be tailored to their needs. Specifically: • Producers/farmers (Greek pilot: BIONET) using the MEMS-based photonics system, will be able to scan soil samples directly on site and a report of key soil properties would be available via THEROS mobile app. • Retailers (Serbian pilot: UNIVER) using the MEMS-based photonics system, will be able to scan food products (I.e. wheat flour and apple juice) in order to detect possible adulteration. A purity index would be displayed via THEROS mobile app which provides an estimate of the detectable adulterant if it exists. Otherwise, an indication marks the product as pure. • Certification bodies (Greek pilot: BIOHELLAS) using the MEMS-based photonics system, will be able to scan produce (I.e. oranges) and determine whether or not non compliances regarding organic farming occur.
	Tech Components
	THE MEMS based photonics system utilizes a field-deployable Vis-NIR scanning device which is connected with the mobile app. The system via a simple "point-and-shoot" method, captures data securely, stores metadata (e.g. location, timestamp, and photos in a central database) and accesses deep learning models which transform Vis-NIR spectra into appropriate outputs for each end-user.
	Time plan
	With the start of T5.2 (Serbian pilot) and T5.3 (Greek pilot), bilateral communication will indicate the timing of the analyses. Concerning the Serbian pilot, the analyses will take place during Q1-Q2 2025 while for the Greek pilot during harvesting season in late Q2 2025.
Outcomes	By using the operational MEMS based photonics system via the THEROS mobile app: • Producers/ farmers could determine soil properties • Retailers could identify possible adulteration on their products • Certification bodies could verify or not the implementation of forbidden substances by the EU Regulation and also in case they see results, which are not according to the declaration of the producers regarding with the use or not of forbidden substances, they have the ability to take a sample, in order to confirm the MEMS results and

	with this way degrade the organic products to conventional according the inspection and certification procedure

2.2.3 IoT sensors network

IoT sensors network scenario	
Hypothesis	IoT sensors are important components to collect in situ data about the environmental conditions of food products. It can measure and provide real-time information about the conditions of products. Data can be collected during the transport of products to prove the stability of the conditions of the delivery chain. Monitored delivery can increase the trustability of fresh product transport and increase the coverage of local producers' supply. IoT sensor observations are a source of data for further processing and supporting the propagation of digital marketing of local producers and fresh food supply.
Specific Goals	The purpose of the IoT sensor network is to increase the traceability and trustability of the delivery process of fresh products from local producers to final customers in regions. Monitoring the conditions of fresh products during the complete delivery process provides valuable information for sellers as well as for customers. It supports small and medium producers in increasing the potential of customers from wider distances. The goal is to monitor the environmental conditions of the food during the whole delivery process. And transfer measurements to the main data storage in near real-time to track the package and its internal conditions until the package is handed over to the final customer. The measurements of the IoT sensors are further processed by the THEROS components – Verification engine and Digital Marketplace until finally presented to the customer.
Activity Description	**Deployment Sites**
	The pilot deployment of the IoT sensor network within the THEROS project is set in the Klatovy region of the Czech Republic. A key operational partner in this region is Šumavaprodukt, a local dealer of regional products. Šumavaprodukt is also a direct partner of the THEROS project, playing a crucial role in the deployment and integration of the marketplace.
	Experimental Procedures
	The main experimental procedure was designing and developing the IoT sensor network suitable for the size and materials of packages for the delivery of fresh products. The IoT sensor network was developed, and the data collection and integration process was set up. Testing delivery of packages was organised by the partner Šumavaprodukt's delivery vans and a local delivery company. The operation status of the IoT sensor network during the testing delivery

	was properly monitored, including the sensors' activity, data transfer, and measurement integration to the main data storage.
	Tech Components
	The IoT sensor network consists of 2 parts - hardware and software. The hardware part is the main physical device for the measurement process – it contains the AgroNode data logger and the AM2320 Digital Temperature and Humidity Sensor. Data are transferred by radio module (used LoRaWAN, but optionally NbIoT or GSM can be used). The software part is mainly the SensLog solution, which is the sensor data management tool for static and mobile sensors. SensLog receives, stores, processes, and publishes data. The connection to other components of the THEROS infrastructure is managed by the SensLog Connector, which provides a translation of different interfaces.
	Time plan
	Technology Integration and Testing (Months 17-27) Activities: ➢ Implement IoT for transport monitoring, THEROS system integration; ➢ Conduct internal testing to ensure technical functionality and security compliance; ➢ Perform limited testing with a select group of producers and consumers to refine the platform. **Pilot demonstration (M25-M30)** Activities: ➢ Perform testing with a wider group of producers and consumers to validate the monitoring process and operational status of packages; ➢ Testing of different delivery methods; **Official Launch and Operational Scaling (M31- M36)** Activities: ➢ Monitor usage of sensor-equipped packages and monitoring process and data flow; Implement a continuous improvement process, incorporating user feedback to refine and expand marketplace features.
Outcomes	Operational IoT sensor network providing near real-time monitoring of environmental conditions of fresh products during the delivery process and traceability of packages based on selected delivery methods. Verification of the delivery process by monitoring the conditions and monitoring of potential package disruption. Enhanced Traceability and Transparency - a transparent supply chain, allowing consumers to verify the origin and journey of each product. This will enhance consumer trust and potentially increase market demand for verified organic and GI products.

2.2.4 DNA based authenticity kit

<table>
<tr><th colspan="2">DNA based authenticity kit end-to-end scenario</th></tr>
<tr><td>Hypothesis</td><td>One of the most extensively grown and sold bivalve species is the Mytilus genus, which is valued for its flavor and high protein content. For many coastal areas, mussel aquaculture is a significant economic activity. The European legislation on the common structure of the markets in fisheries and aquaculture products now requires that the species' scientific name and commercial identification be declared on the label. The purpose of this particular traceability criterion is to verify the items' legitimacy. A low-cost product may be labeled as costly due to species substitution. Due to undeclared species, it may potentially impact food safety through unreported allergen ingestion. The history of seafood mislabeling is extensive; it affects both the authenticity of the item and the choices made by customers. These days, DNA-based species verification techniques are helping to highlight the extent and complexity of mislabeling.</td></tr>
<tr><td>Specific Goals</td><td>The objective of the DNA-based authenticity kit aligns with the goal of improving traceability, compliance and transparency across the supply chain of mussels’ production, by identifying mislabeling and substitution cases.

Specifically, the DNA based authenticity kit module comprises of portable DNA based molecular methods, allowing rapid extraction of DNA profiles and their automated transformation on meaningful information regarding the verification of species origin, provenance of the food product and protecting the final consumers from adulteration issues.
Allows for the complete transparency of the supply chain, from the production phase until the product reaches the consumers, detailing all the information related to the product identity.
Allows participants to extract the results in PDF format through the analysis software of the portable device.
Validates information through the Verification Engine.</td></tr>
<tr><td rowspan="4">Activity Description</td><td>Deployment site</td></tr>
<tr><td>The DNA based authenticity kit will be implemented in the Spanish pilot, for the identification of the Galician mussels.</td></tr>
<tr><td>Experimental procedures</td></tr>
<tr><td>The main experimental procedure consists of 3 steps:
<u>Sampling and DNA extraction</u>
Sampling procedures are performed according to the standard procedures that are applied for GMO detection (based on ISO/FDIS 6498:2011). Four subsampling operations are implemented to reduce the subsampling errors, (Esbensen and Paasch-Mortensen, 2010): 1. Composite subsampling (or incrementing), 2. Comminution (particle size reduction), 3. Mixing/blending, 4. Representative mass reduction.
DNA is extracted from multiple samples of the product under investigation through the application of specific molecular methods to obtain genetic material (DNA).
The molecular methods of DNA extraction will be applied on cultivation sites and through different preparation stages</td></tr>
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(packaging, transportation, etc.) of the final product, all the way to the selling points of the products, in order to prevent any adulteration issues.

Figure 4 Sample preparation for DNA extraction.

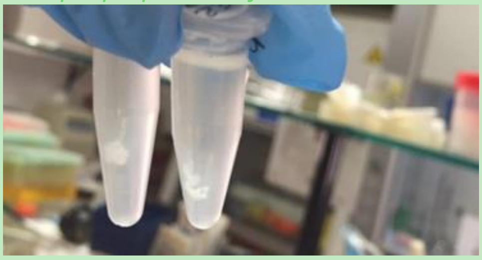


Figure 5 Extracted DNA.

2. **PCR & HRM Analysis:**
    - PCR analysis is performed on a portable device that is connected to a laptop powered by a portable battery.
    - PCR analysis is based on a specific molecular method that allows the amplification of a specific gene of interest, in our case, the COI gene region for fresh samples and PAPM gene region for canned samples that will allow the rapid identification of the species origin, based on the nucleotide differences of the DNA sequences.
    - After the PCR analysis, HRM analysis is performed on the amplified DNA sequences based on their melting temperatures.

Figure 6 Preparation of PCR components and reaction.

Figure 7 micPCR device and laptop.

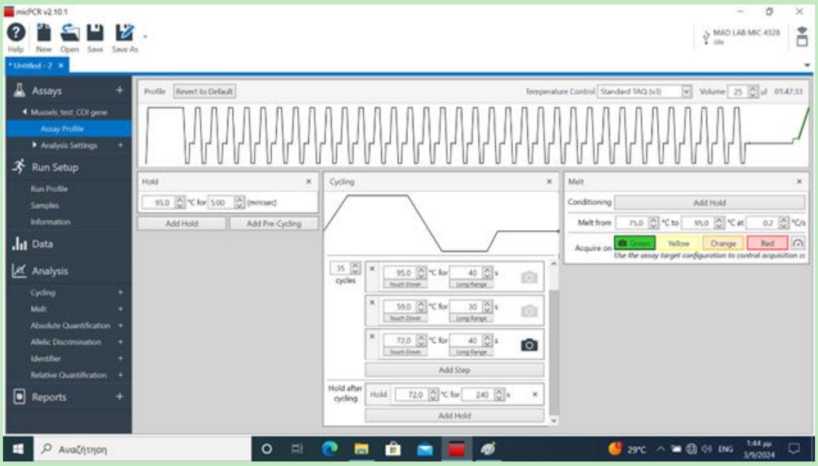
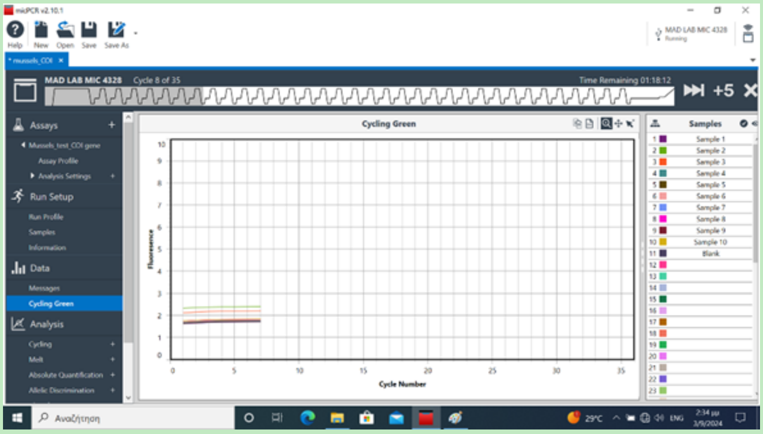
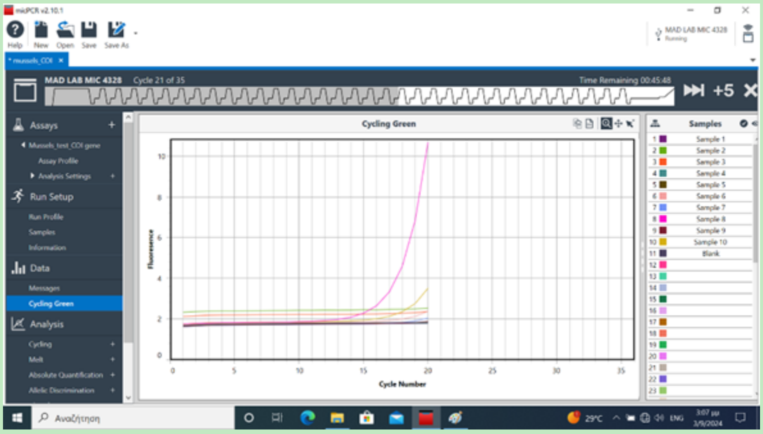


Figure 8 micPCR software run conditions.

3. **<u>Analysis of High-Resolution Melting profiles:</u>**
   - High-resolution melting (HRM) profiles are generated, providing numerical data corresponding to melting temperatures.

- Melting temperatures are specifically based on the amplified DNA sequences and can detect any DNA alterations specific to each organism.
- Specific melting temperatures from each sample correspond to a specific species' origin.
- The software provides results in a pdf file regarding the confidence values of the results.





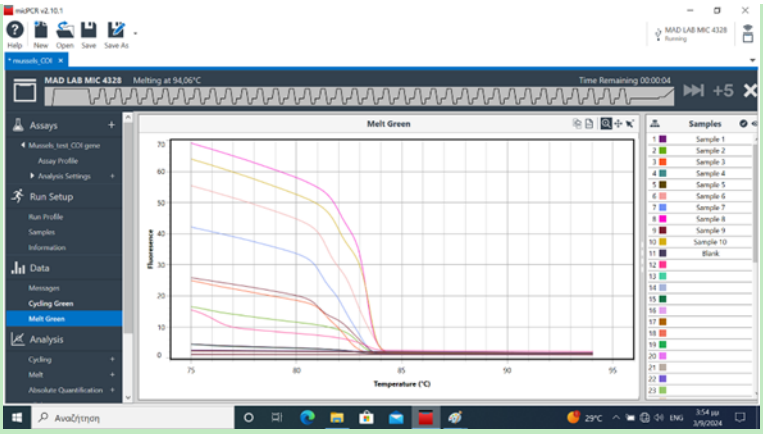


Figure 9 Real-time monitoring of the run and melting analysis.

Figure 10 Quantification results.

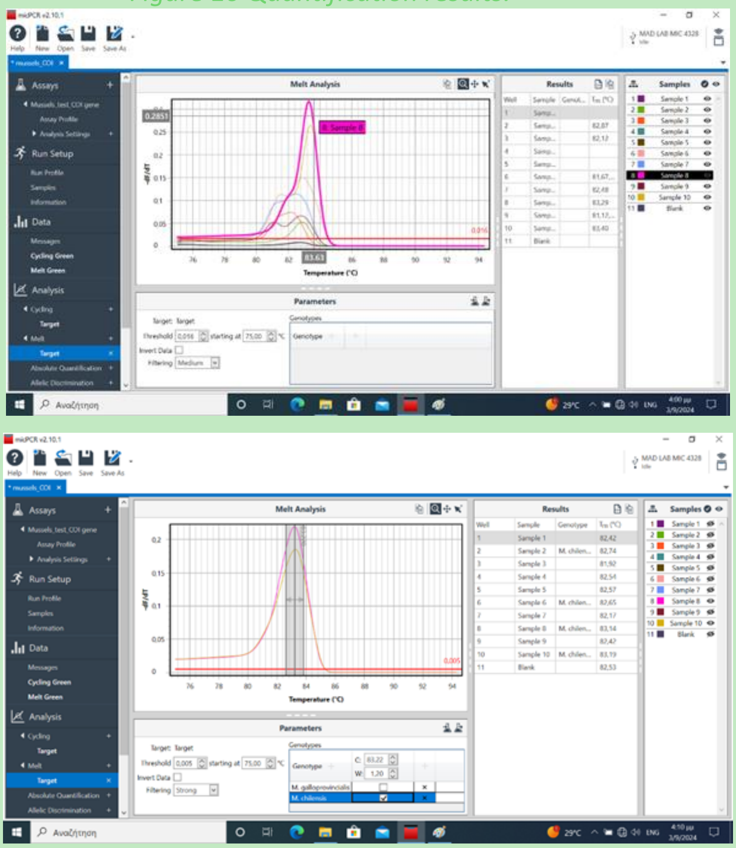


Figure 11 Melt analysis.

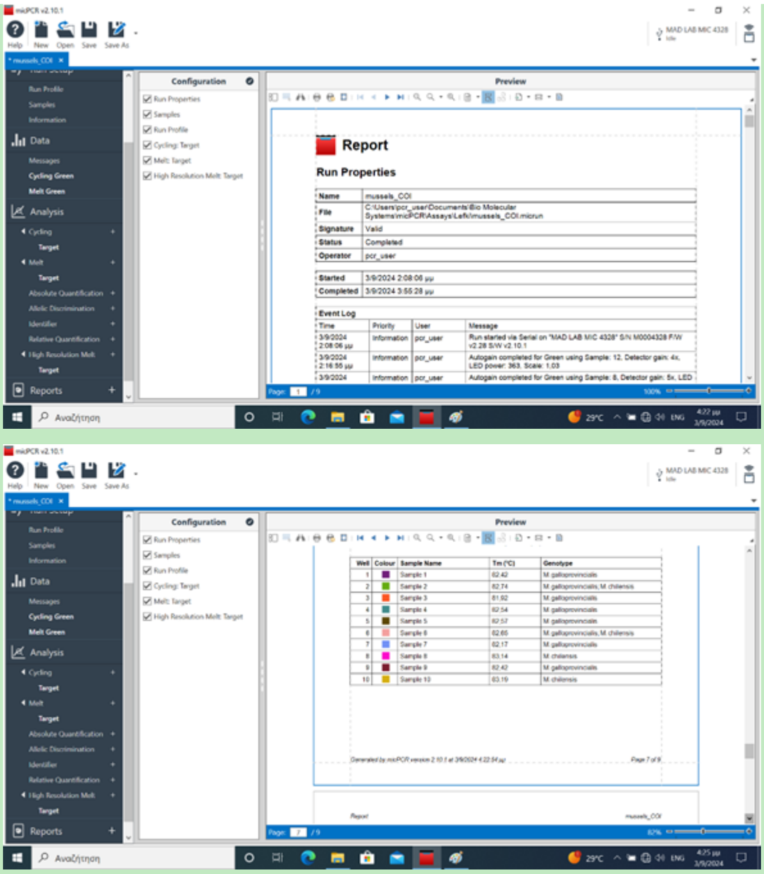


Figure 12 Results report generated by software.

The checkpoints where the DNA test will be applied are 3. The first point will be at the landing port where the mussel is offloaded by the producers (Verification point 1). The other DNA samples will be done in the transformation stages at the 2 processing companies. One of the products tested will be fresh product (Verification point 2) and the other cooked canned product (verification point 3).

Tech components

The DNA based authenticity kit consists of 2 parts: hardware and software. The hardware part is the main device for the HRM analysis process, that contains the micPCR instrument and the laptop that is attached to the device.

The software part is the micPCR v2.10.1 (Bio Molecular Systems Pty Ltd), which is the main analysis tool that receives, processes and reports data and results.

The output of the tool will be harmonized and properly aligned with the critical tracking events of the product through the THEROS data management and harmonisation platform, whilst allowing the information to be available through the blockchain based traceability network. All data collected and provided will feed the THEROS rule-based verification engine that will validate with respect to species and origin and enable the execution of transactions only if the genetic signature of the product has not been altered/manipulated.

Time plan

	The first version of the kit was finished in early summer 2024, and from that time onwards it has been tested internally with different biomarkers in order to ensure full functionality. We are working on the next version to include the use of specifically designed biomarkers for fresh and canned mussels' products. The time plan for the next steps contains: • Perform internal testing to ensure full functionality and the repeatability of the results (until M27). • Perform testing with a group of producers and consumers to validate the operational procedure and user experience (until M27). • Perform the acquired training of the end users and demonstrate the operation of the kit on the pilot site (M28-35).
Outcomes	Increased traceability and transparency for the producing and supply chain of the mussels' products, providing the consumers with validated information regarding the species identity and the geographic origin of the products. This module significantly enhances monitoring capabilities for adulteration issues and mislabeling of the food products. The application of specialized and robust molecular methods will be applied to fresh and canned products throughout the whole process of cultivation, packaging, transportation and selling points, ensuring that the final consumers are protected from adulteration events. The module is suitable for stakeholders in the food sector who acquire accurate information on the origin of the food products. Also, it is suitable for certifications authorities as it facilitates a more accurate identification method of possible adulteration events based on specialized molecular techniques.

2.2.5 Blockchain enhanced traceability system

Blockchain enhanced traceability system end-to-end scenario	
Hypothesis	Nowadays there is an increased need for transparency in the supply chain due to the existence of malpractices, such as adulteration of products, which in turn decreases trust of the consumers in said products. This traceability is difficult and expensive due to the heterogeneity of systems in different businesses and industries. By centralizing all this information in a single, shared repository, such as the Blockchain enhanced traceability system, all actors will converge in a common space where the information will be interoperable and readily accessible for all of them. Also, by using blockchain technology data becomes immutable, preventing data tampering through the supply chain.
Specific Goals	The objective of the Blockchain enhanced traceability system aligns with the goal of improving traceability, compliance and transparency across the supply chain of products.

	Specifically, the Blockchain enhanced traceability system records all the information related to the different characteristics of a product its life cycle, which in turns: • Allows for the full transparency of the supply chain, detailing all the information related to the product. For this purpose the systems stores data following global stardards: GS1 for data structure & CTE (critical tracking events) to structure the events that products go through during the supply chain. • Validates said information thanks to the use of the Verification Engine. Data from other toolbox components (EO, MEMS, DNA & IoT) is validated with the business rules defined, to ensure the authenticity of products traced by the system. • Allows participants to input their information in JSON format either through screens or through APIs.
Activity Description	**Deployment**
	The Blockchain enhanced traceability system will be used by the 4 pilots: Czech Republic, Greece, Serbia and Spain. It will allow the input of data through specific screens for the different actors in the Greek and Czech Republic pilots. The rest of participants will supply their information through APIs and automated integrations with their ERPs. The Verification Engine will be used by all pilots through the Data Harmonization Platform. Each pilot will be paired with the necessary tool in order to verify their products.
	Time plan
	The first version of the platform was finished in early summer 2024, and from that time onwards it has been tested internally and by the stakeholders in order to ensure full knowledge and lack of bugs. Meanwhile a new version that includes improvements and corrections that have been done during this testing time, also with keycloack integration, has been deployed to be ready for the next iteration e2e testing phase.
Outcomes	An overall increased trust and transparency for the supply chain of the participating products. More involvement of the final consumer in the information they can receive.

2.2.6 Dynamic digital product passport for organic/GI food assets

Dynamic digital product passport	
Hypothesis	The use of dynamic Digital Product Passport (dDPP) for organic products and geographical indication will increase traceability as well as contribute to data transparency across the supply chain. The tool can contribute to efficient communication of product related information, in the long run contributing to more informed decision making for consumers.
Specific Goals	• The solution will be accessible through a mobile application with user friendly interfaces • The supply chain actors will be able to access information related to the traceability across the supply chain

	• Users will access the product specific information by using product identification number or by scanning the QR code • Integration with other THEROS tools will allow users to see verification data relevant to specific product and other information of interest • The dDDP app will provide interfaces for the blockchain traceability system allowing for 2nd step confirmation of the supply chain steps by respective responsible stakeholders • DPP will be coupled with an integrity framework, a component increasing the degree of trust by verifying the time and location of critical tracking events recorded in the traceability platform and taking place across the supply chain
Activity Description	**Deployment Sites**
	The dDPP will be deployed at 3 demonstration sites (Serbia, Greece, Spain) as part of THEROS demonstration activities. In all 3 cases the dDPP will allow the users to obtain information about selected products through scanning the QR codes or inputting the product code. The information coming from the harmonization platform and verification engine concern specific product information, verification data, traceability data, certifications and possibly sustainability data. The dDPP will provide interfaces for the blockchain enhanced traceability, allowing the relevant actors to utilize it through track and trace functionality available in the dDPP. The user interfaces will assure time and location integrity of the interactions between the users with the role of supply chain actor (pick up/pick out confirmation) The enhancement of traceability, transparency and security aspects through using the dDDP (directly) and blockchain traceability platform (through the dDPP interfaces) will be explored by supply chain actors represented by and linked to UNIVER actors, including producers, packagers and transporters (Serbia), transporters and wholesalers linked and represented by BIO-NET (Greece) and stakeholders collaborating with MEXILLON (Spain).
	Experimental Procedures
	Initial consultations (questionnaires) with stakeholders (M12-M13) from following groups: producer, supply chain actors, certification bodies to understand i) user needs, requirements and expectations ii) data availability iii) the potential benefits from the use of the dDPP by specific user groups. **Testing activities (M23-M24)** towards the results for MS6 with specific focus on user experience, tool usefulness, DPP content, etc, but also to ensure that digital information in the DPP is valid and consistent with the actual product. Users having different roles in the supply chains of Spanish, Greek and Serbian demo are asked to download, log in, access the products, and assess the app by replying to a questionnaire.

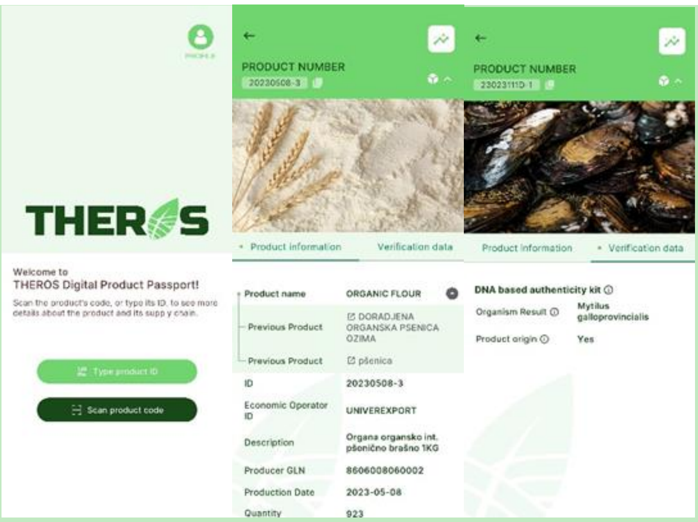


Figure 13 Screenshots from the version of the app used for testing (M23-M24).

Tech Components

The dDPP is divided into front-end and back-end components.

The back-end component is a FastAPI application, hosted on an ICCS server. This service fetches EPCIS events from the traceability platform, in order to provide a comprehensive, digital profile of a product. It then extracts data from the available events for a product, and organizes them in the following five categories:

- Product Information
- Verification data
- Certifications
- Track & Trace
- Sustainability - ongoing

The front-end component is an Android application. After the user enters their email and company name, they are prompted to select their role in the supply chain based on their actual involvement (supply chain actors may have more than one role). The user can then either scan a QR code of a product, or type the product identification number. The app then queries the back-end service, which returns all information available for this specific product. The user can then navigate to different tabs each gathering data from above mentioned categories in order to see the relevant information.

The Product Information tab also shows the previous products of the same supply chain, allowing the user to click on them and trace back through the supply chain to gather detailed information about each product.

The Track & Trace tab, in addition to displaying the timeline of supply chain events, also offers the user the ability to confirm the Pick Up/Pick Out events. These actions create new events, which are stored in the blockchain.

The integrity framework is designed to enhance the accuracy and reliability of location and time used in the mobile application. The framework will use correction services like EDAS (EGNOS Data Access Service) to provide

	trustworthy data, to address potential inaccuracies in GPS signals caused by factors such as atmospheric interference or satellite errors. This process can be used to ensure the integrity of the Pick Up/Pick Out events.
	Time plan
	The initial months of the project were dedicated to defining user groups, the types of data to be visualized in the dDDP together with their sources and consultations with stakeholders. The alpha version of the dDDP was delivered in M18 (June 2024) as D4.1. As the development phase has continued the enriched alpha version is currently (M23) being tested by different users groups from future deployment sites, which will be reported in MS6 (due in M24-December 2024). The feedback obtained will allow for improving the tool towards the final version, which will be available by M27 (March 2025), marking the beginning of the deployment activities described in the "Activity description" section. Prior to the deployment activities integration with the carbon footprint calculator and integrity framework will be performed.
Expected Outcomes	Some of the expected outcomes can be summarized as: • User friendly app providing information about the product and its current status in the supply chain • Enhanced traceability for the supply chain of the selected products • Increased security of the critical tracking events • Efficient communication of product related information • User friendly interfaces facilitating critical events tracking • Consumer: dDPP contributes to more informed decision making

2.2.7 Green accountability tool

Green accountability tool end-to-end scenario	
Hypothesis	The Green Accountability Tool (GAT) aims for effective monitoring and evaluation of agricultural practices by leveraging advanced technologies such as Earth Observation (EO) data, MEMS photonics, and blockchain. The GAT will empower farmers, policymakers, and stakeholders by integrating insights from environmental factors like carbon footprint and soil health, alongside insights from spectral analysis for product authenticity and blockchain-based supply chain traceability. This comprehensive approach facilitates producers, suppliers, certification bodies and other stakeholders with data-driven decision-making, promotes sustainable practices, and ensures transparency and accountability across the agricultural value chain.
Specific Goals	• Use EO-based services to track crop health, plot damage, and interventions for actionable insights. • Employ MEMS photonics to identify food adulteration and chemical use in organic products and soil.

	• Leverage blockchain and verification engines to manage and validate traceability documentation securely. • Present harmonised data through user-friendly maps, plots, and certification status indicators. • Simplify compliance checks for efficient certification processes with traffic light system. • Offer detailed product traceability data to verify authenticity and compliance.
Activity Description	**Deployment Sites**
	The Green Accountability Tool (GAT) will be deployed in Serbia and Greece as part of the THEROS pilot demonstrations. In both Serbia and Greece, the GAT will leverage blockchain systems for tracking products, MEMS photonics for soil and product authenticity assessments, and EO tools for compliance monitoring and agricultural optimisation.

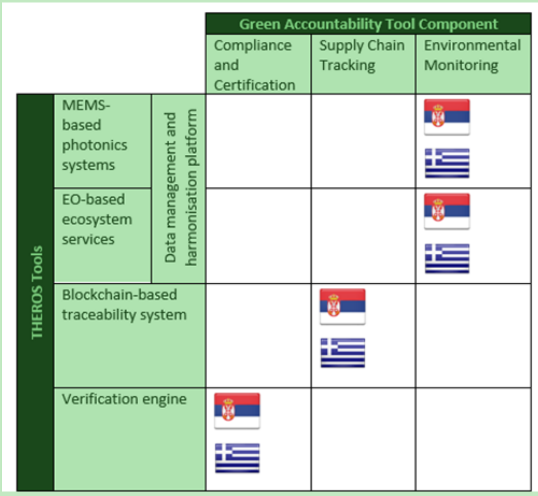


Figure 14 Use case mapping to components and tools.

	Experimental Procedures
	The experimental procedures for the Green Accountability Tool (GAT) involved the initial phase showcasing mockups and receiving feedback from pilots to design and refine the user interface. The current focus is demonstrating the alpha version of the tool to key stakeholders, including producers, certification bodies, and supply chain actors, for real-world evaluation. This demo showcases the tool's main functionalities, including compliance and certification, supply chain tracking, environmental monitoring, data visualisation, and reporting. Stakeholders will interact with the alpha version, explore its features, and provide feedback on its usability and effectiveness to guide further refinements.

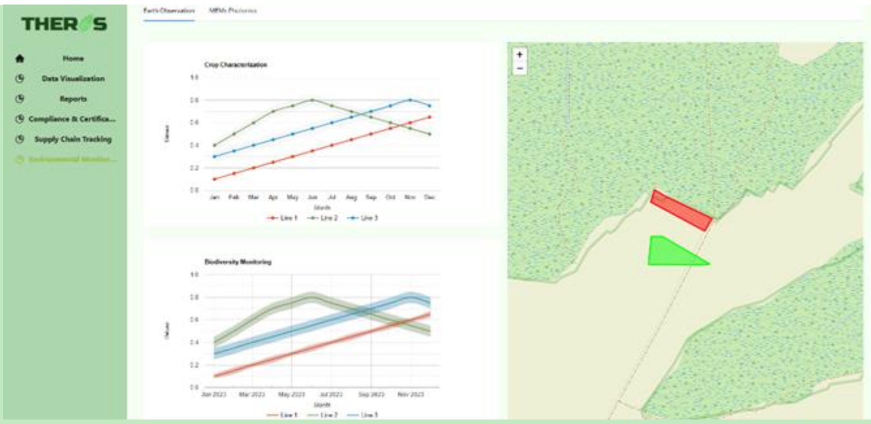


Figure 15 GAT EO page.

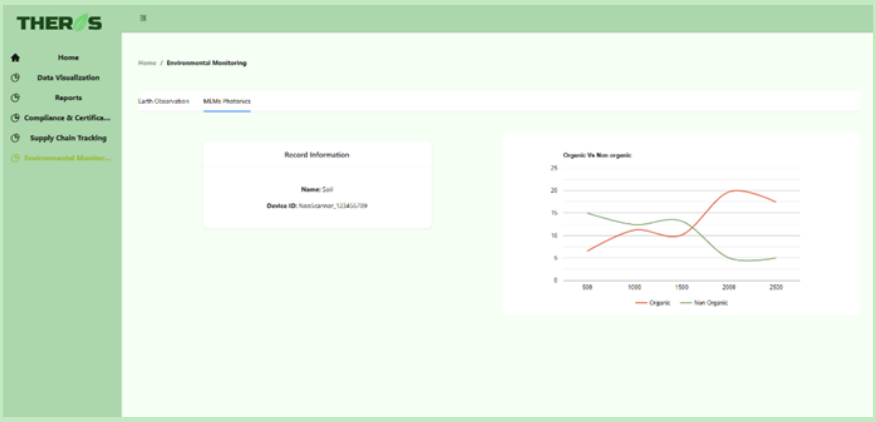


Figure 16 GAT MEMS page.

Tech Components

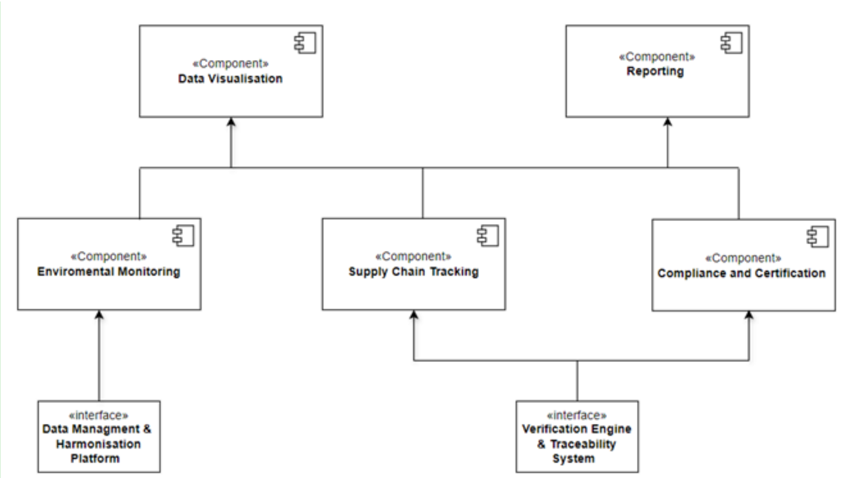


Figure 17 GAT components.

The GAT is built on an interconnected architecture comprising of the following components:

- Environmental monitoring, acquiring data from the Data Management and Harmonization Platform and leveraging inputs such as satellite imagery outputs from EO and spectral signatures form MEMS photonics.

	• Supply Chain Tracking and Compliance and Certification obtain data through interfaces with the Blockchain-based Traceability System and the Verification Engine, ensuring accurate tracking of products and their certification status. • The Data Visualisation and Reporting modules are fed data from the other three components, which process and present integrated insights which are exportable.
	Time plan
	The time plan for the GAT spans three distinct phases. Phase 1: "Requirements Collection", completed by M13, Phase 2: "Wireframes and Mock-up Designs", finalized by M16, and he current phase, Phase 3: "Development, the alpha version" will be demonstrated by M24, and pilot feedback from the initial evaluation will be incorporated into the intermediate version, planned for M27.
Outcomes	• Enhanced monitoring and evaluation of environmental and compliance indicators. • Increased traceability and transparency in supply chains. • Actionable insights to support informed decision-making and sustainability goals.

2.2.8 Business model driven digital marketplace

Digital marketplace end-to-end scenario	
Hypothesis	The hypothesis driving the development of the THEROS Digital Marketplace is that integrating advanced digital technologies such as IoT sensors, blockchain, and data analytics into a unified platform can significantly enhance the traceability, authenticity, and accessibility of organic and GI (Geographical Indication) food products. By providing a transparent, efficient, and secure system for connecting organic producers with consumers, the marketplace aims to increase consumer trust and support for sustainable agricultural practices. It is anticipated that such a platform will not only facilitate the reduction of food adulteration but also promote shorter supply chains, thereby contributing to the environmental and economic sustainability of the food sector. The marketplace is expected to serve as a critical tool in empowering producers, particularly small and medium-sized enterprises, by providing them direct access to broader markets and enabling them to verify the quality and origin of their products in real-time.
Specific Goals	Enhance Traceability and Transparency: Develop and integrate a blockchain-based traceability system that records every transaction and movement of organic and GI food products. This system will provide consumers bodies with data on the lifecycle of selected products, increasing transparency and accountability across the supply chain. Improve Food Quality and Authenticity Verification: Implement IoT sensors to continuously monitor the conditions and verify the quality of food products during transportation and storage. This goal aims to

	minimize food fraud and ensure that all products sold through the marketplace meet established organic and GI standards. Support Small and Medium Producers: Design the marketplace to serve especially small and medium-sized enterprises (SMEs) by providing them with a cost-effective way to reach a wider market. This includes reducing barriers to market entry, such as high marketing costs and distribution challenges.
Activity Description	**Deployment Sites**
	The pilot deployment of the Digital Marketplace within the THEROS project is set in the Klatovy region of the Czech Republic. A key operational partner in this region is Šumavaprodukt, a local dealer of regional products. Šumavaprodukt is also a direct partner of the THEROS project, playing a crucial role in the deployment and integration of the marketplace. Objectives at the Deployment Site: • Local Integration: Leveraging Šumavaprodukt's established network and expertise, the marketplace will connect with local organic food producers, retailers, and consumers to foster a community centered around sustainable practices. • Real-World Testing: The deployment in the Klatovy region allows for practical testing in a real-world environment, assessing the marketplace's functionality, user interface, and integration of IoT sensors under authentic conditions. • Feedback and Iteration: With Šumavaprodukt's active involvement, the site will serve as a dynamic platform for gathering critical user feedback. Insights obtained will be instrumental in refining the marketplace to ensure it meets the local needs effectively. This regional focus, supported by a key local partner like Šumavaprodukt, underscores the project's commitment to enhancing the organic supply chain specifically tailored to the needs and characteristics of the Klatovy region. This approach ensures that the pilot's outcomes will be relevant and scalable, potentially extending to other regions globally.
	Experimental Procedures
	The experimental procedures for the Digital Marketplace within the THEROS project in the Klatovy region are designed to evaluate the integration and effectiveness of the platform across multiple dimensions. Here is an outline of the key procedures planned: Technology Deployment: • Digital Marketplace set up: We establish the core infrastructure of the Digital Marketplace. This involves configuring the server environments, setting up the database, and ensuring that the user interface and backend systems are fully functional and integrated. • IoT Sensor Integration: We deploy IoT sensors within the transportation infrastructure to monitor conditions such as temperature, humidity, and possible tampering. Sensors will be

	installed in transportation vehicles and packaging materials used by Šumavaprodukt (details in the IoT sensors task). • Blockchain Implementation: We set up the blockchain platform to ensure all transactions within the marketplace are recorded and can be traced back transparently, providing a reliable ledger of all activities. User Experience Testing: • We will conduct usability tests with real users, focusing on the ease of use, navigability, and overall user satisfaction with the digital marketplace interface. • We will run through complete purchase integrated communication with the THEROS platform to test the efficiency and reliability of all processes. Feedback Loops: • We engage with all stakeholders, including producers, consumers, and logistic partners, through interviews and surveys to collect qualitative feedback on their experiences and suggestions for improvement. Performance Evaluation: • We will perform tests to ensure that the products sold via the marketplace meet the claimed quality standards and are not subject to adulteration. Outcome Reporting: • We will document all findings and prepare a comprehensive report detailing the outcomes of the experimental procedures. This report will highlight successes, challenges, and provide a roadmap for future enhancements.
	Tech Components
	The digital marketplace developed within the THEROS project incorporates a range of advanced technologies and innovations. At its core is the PrestaShop-based Marketplace Builder - Multivendor, which facilitates independent access for multiple sellers while ensuring the platform's authenticity, transparency, and operational efficiency. Integration with the IoT sensor network enables monitoring of quality parameters during product delivery, while the connection to the THEROS toolbox ensures the verification and reliability of sensor data. Together, these components create a dynamic, secure, and efficient marketplace ecosystem. **PrestaShop's Marketplace Builder - Multivendor Module** At the core of the digital marketplace's e-commerce functionality is the Marketplace Builder - Multivendor module, designed to transform a standard PrestaShop site into a fully functional multi-vendor marketplace. This module supports the creation of individual seller profiles, product listings, and management tools, allowing organic food producers to directly upload and sell their products. It also includes features for managing commissions, pay-outs, and vendor subscriptions, ensuring

smooth operational processes. The module's flexibility and customization options make it possible to tailor the marketplace to the specific needs of the organic food sector, including integration with other technologies such as IoT sensors and the THEROS verification engine.

Internet of Things (IoT) Sensors Network

IoT sensors integrated into the marketplace offer real-time monitoring of organic products during transport, collecting data on environmental conditions that affect product quality. This IoT data enhances the marketplace's value proposition, providing sellers and buyers with critical information on product handling and storage conditions, directly accessible through the PrestaShop-based platform.

THEROS System Integration

A crucial element is the integration into the overall THEROS system, which will enable a verified connection with data from the IoT Sensor Network thanks to the Verification Engine. It complements the Marketplace Builder - Multivendor module by offering a decentralized verification system for product transport and supply chain critical events.

Integrating the Marketplace Builder - Multivendor module with these advanced technologies creates a comprehensive solution tailored to the organic food sector's needs. This strategic approach ensures the THEROS project's Digital Marketplace is not only a platform for buying and selling organic products but also a hub of trust, transparency, and innovation, fostering a sustainable and efficient organic food supply chain.

Time plan

Technology Integration and Testing (Months 17-27)
Objective: Integrate advanced technologies into the marketplace and conduct internal testing. It will be run in collaboration with the tasks T3.3 and T4.5
Activities:

- Implement IoT for transport monitoring, THEROS system integration;
- Conduct internal testing to ensure technical functionality and security compliance;
- Perform limited testing with a select group of producers and consumers to refine the platform.

Pilot demonstration (M25-M30)
Objective: Wider testing, marketing, and Pre-Launch Activities.
Activities:

- Perform testing with a wider group of producers and consumers to validate the platform;
- Create marketing materials and launch a promotional campaign targeting organic food producers, consumers, and retailers;
- Establish partnerships with industry influencers, organic certification bodies, and sustainable farming organizations;
- Open the marketplace for pre-registration, offering early access or incentives to initial users.

Official Launch and Operational Scaling (M31- M36)

	Objective: Officially launch the Digital Marketplace and begin operational scaling based on user feedback and market demand. Activities: ➢ Launch the marketplace with full functionality and begin onboarding producers, consumers, and retailers; ➢ Monitor platform performance, user engagement, and transaction volumes, adjusting operations as necessary; ➢ Implement a continuous improvement process, incorporating user feedback to refine and expand marketplace features.
Outcomes	Digital marketplace for organic food, which will enable the promotion of individual participating organic food producers and facilitate the availability of their organic products in the region. We expect: Enhanced Traceability and Transparency - a transparent supply chain, allowing consumers to verify the origin and journey of each product. This will enhance consumer trust and potentially increase market demand for verified organic and GI products. Improved Food Safety and Quality - integration of IoT sensors will provide real-time data on the transportation conditions of food products, significantly improving food safety and quality management. This will help in reducing food spoilage and ensuring products meet health standards upon arrival. Increased Market Access for Small Producers - the marketplace is designed to lower barriers to entry for small and medium-sized producers by providing them a platform to reach a broader audience without the need for significant marketing budgets or distribution networks. Economic Benefits - by facilitating direct transactions between producers and consumers, the marketplace will help reduce intermediaries, potentially increasing the profit margins for producers and reducing costs for consumers. Scalability and Replicability – we expect the scalability of the digital marketplace model, providing a blueprint that can be adapted and replicated in other regions or countries, enhancing the global organic and GI food market.

2.2.9 Fraud Alert Workflow - From Detection to Resolution

The end-to-end scenarios described in Sections 2.2.1 through 2.2.8 detail how each THEROS toolbox component detects potential non-compliances, adulterations, or fraudulent activities. However, a complete evaluation methodology must also address what happens after a potential fraud signal is generated. This section defines the standardised workflow that governs the lifecycle of a fraud alert within the THEROS system; from initial detection, through confirmation and escalation, to final resolution and recording. The THEROS fraud alert workflow is structured around four sequential phases: (1) Alert Generation, (2) Alert Confirmation via Complementary Tools, (3) Escalation or Dismissal, and (4) Recording and Audit.

Phase 1 - Alert Generation

A fraud alert is generated when a THEROS toolbox component produces an output that falls outside the defined compliance thresholds. Each tool generates alerts according to its specific detection logic:

- The **EO-based ecosystem services** component generates an alert when one or more monitoring markers (e.g., organic/non-organic classification score, homogeneity, crop-type prediction) fall below their defined classification thresholds for a given parcel, indicating a potential non-compliance in farming practices.
- The **MEMS-based photonics system** generates an alert when the purity index of a scanned product falls below the acceptable threshold, indicating a potentially adulterated or non-compliant product (e.g., talc adulteration in wheat flour, dilution in apple juice, or detection of herbicide residues in organic citrus).
- The **IoT sensor network** generates an alert when measured environmental parameters (temperature, humidity) during transport exceed the predefined acceptable ranges, indicating potential mishandling or tampering with the product.
- The **DNA-based authenticity kit** generates an alert when the High Resolution Melting (HRM) analysis of a sample produces a melting profile that does not correspond to the declared species, indicating potential species substitution or mislabelling.
- The **Blockchain-enhanced traceability system and Verification Engine** generate an alert when a product batch or parcel fails the automated business rule validation (i.e., when the data submitted by supply chain actors does not satisfy the compliance logic defined for that product type, pilot, or certification standard). In such cases, the product status is set to "rejected" and no further supply chain transactions can be recorded for that batch until the issue is resolved.

All alerts are automatically propagated to the THEROS Data Harmonisation Platform and are made accessible to authorised users through the Green Accountability Tool (GAT) and the Dynamic Digital Product Passport (dDPP).

Phase 2 - Alert Confirmation via Complementary Tools

A single alert from one tool is treated as a preliminary signal and must be confirmed before escalation to avoid false positive outcomes. The THEROS toolbox is designed to operate in an integrated manner, where multiple tools can cross-validate each other's outputs. The following cross-checking logic applies:

- An **EO marker alert** (e.g., detection of non-organic land management on a certified parcel) triggers a targeted on-site inspection request. During the inspection, certification body inspectors may additionally use the **MEMS-based photonics system** to scan produce or soil samples directly on site. A confirmed MEMS non-compliance finding alongside the EO alert constitutes a corroborated fraud signal.

- A **MEMS photonics alert** (e.g., purity index below threshold for wheat flour) triggers a confirmatory sampling procedure. The flagged sample is sent for laboratory analysis at an accredited facility (e.g., AUTH) to validate the MEMS result. Laboratory confirmation upgrades the alert status from "suspected" to "confirmed".
- A **DNA kit alert** (e.g., species mismatch in mussel samples) requires a second independent DNA analysis run on a different sub-sample from the same batch. Consistent results across both runs confirm the adulteration finding.
- An **IoT sensor alert** (e.g., temperature excursion during transport) is cross-validated against the delivery timeline and route data stored in the blockchain traceability system. If the excursion is verified as genuine (i.e., not a sensor malfunction), and if the affected product batch has already been recorded in the supply chain, the batch is flagged in the Verification Engine for further review.
- A **Verification Engine rejection** (i.e., a batch failing business rule validation) is communicated to the responsible supply chain actor, who is given the opportunity to submit corrected data or additional evidence within a defined timeframe. If no satisfactory response is received, the rejection is escalated.

In all cases, the tool responsible for the confirmatory check and the outcome of that check are recorded in the THEROS Data Harmonisation Platform as a linked event to the original alert.

<u>Phase 3 - Escalation or Dismissal</u>

Following the confirmation phase, the alert is either escalated to the responsible authority or dismissed as a false positive, based on the following criteria:

- *Escalation criteria:*
    - The alert has been confirmed by at least one complementary tool or an accredited laboratory analysis.
    - The Verification Engine has set the product batch to "rejected" status following failed business rule validation.
    - The same producer or supply chain actor has generated repeated alerts within a defined monitoring period.
    - The suspected fraud has implications for consumer safety (e.g., undeclared allergens due to species substitution in mussels).

Upon meeting the escalation criteria, the alert is formally communicated to the competent certification body (e.g., BIOH, OCS, KIWA) or relevant authority. Inspectors are notified through the GAT interface and receive a structured report including the original alert, confirmation findings, affected product batch identifiers, and the specific business rules or thresholds that were violated. The certification body then decides on the appropriate regulatory action in accordance with applicable EU organic or GI regulations.

- *Dismissal criteria (false positive):*
    - The confirmatory tool or laboratory analysis does not reproduce the initial alert finding.
    - The alert was generated due to a known sensor malfunction, calibration error, or data transmission issue (e.g., IoT sensor hardware failure).

- On-site inspection by a certification body inspector finds no evidence of non-compliance.

When an alert is dismissed as a false positive, this decision is documented, and the alert is closed with a "false positive - dismissed" status in the system. The false positive outcome is logged and fed back into the model improvement cycle for the relevant tool (e.g., recalibration of MEMS models, adjustment of EO classification thresholds).

Phase 4 - Recording and Audit

All fraud alert events, including the initial detection, confirmation activities, escalation or dismissal decision, and final resolution outcome, are recorded as immutable events in the THEROS blockchain-based traceability system. This ensures a complete and tamper-proof audit trail that is accessible to competent authorities, certification bodies, and; where appropriate; supply chain actors. Specifically:

- Each alert is assigned a unique identifier linked to the relevant product batch or parcel identifier.
- The alert status (generated, under confirmation, confirmed, escalated, dismissed, resolved) is updated in real time and visible through the GAT and dDPP interfaces.
- All alert decisions are time-stamped and linked to the user or system that made the decision, ensuring accountability and traceability of the response process.
- The complete alert history for each product batch is accessible during audits by certification bodies and competent authorities, supporting compliance verification and regulatory reporting.

This structured approach ensures that fraud alert management within the THEROS system is transparent, auditable, evidence-based, and aligned with the regulatory requirements applicable to organic and geographical indication food products across all four demonstration pilots.

2.3 Definition of the evaluation framework

The purpose of THEROS's evaluation framework is to answer questions on project's progress, whether the deployment of THEROS toolbox components is having the expected results, to allow for the outcomes assessment and whether something can be performed in a different way to achieve the overarching objectives of the project. Figure 18 illustrates the connection between the THEROS's need and objectives and the evaluation process, through the simultaneous implementation of a monitoring phase.

In addition to evaluating the performance of individual toolbox components, the evaluation framework explicitly incorporates the assessment of the fraud alert workflow described in Section 2.2.9. This includes evaluating the efficiency and reliability of the multi-tool cross-checking logic, the appropriateness of escalation decisions, the rate of false positives generated across pilots, and the completeness of alert recording in the blockchain-based traceability system. These dimensions are reflected in the KPI framework presented in Chapter 3, particularly in the technological KPIs related to fraud detection accuracy, compliance report accuracy, traceability completeness, and verification engine precision, as well as in the user-acceptance KPIs related to fraud detection trust and data transparency. The evaluation of the fraud alert workflow across the four demonstration pilots will contribute to the lessons learnt and impact assessment report (D5.3), with particular attention to the practical functioning of the cross-tool confirmation logic and the response times of certification bodies following escalation.

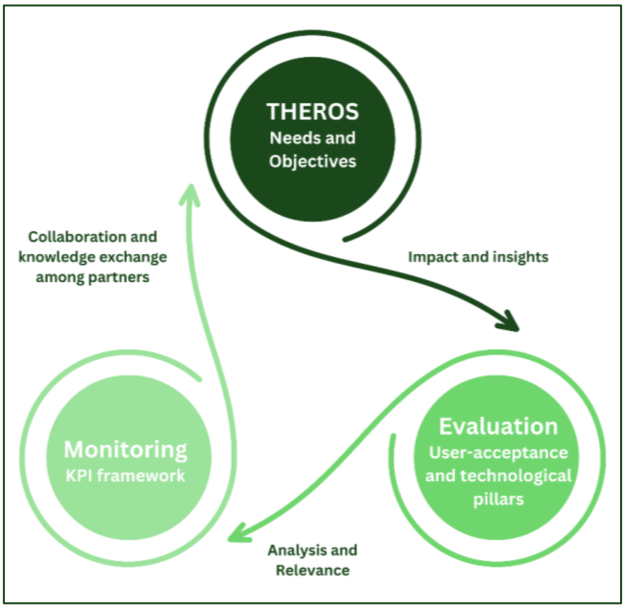


Figure 18 Connection between THEROS and monitoring and evaluation processes.

In this context, this task is designed to present a structured framework for executing the evaluation process. Given that the THEROS demonstration pilots are deployed across various countries and diverse agro-climatic regions, a standardized approach to evaluation is essential to ensure consistent, reliable, and comparable collection and reporting of project monitoring data generated through planned activities. This standardization enables the collection of similar data sets from multiple sources, supporting the comprehensive «Lessons learnt and impact assessment report (D5.3)».

To facilitate the evaluation process, a standardized monitoring approach will be implemented using a KPI Framework specifically developed to assess the performance and success of THEROS applications in achieving desired outcomes. Establishing THEROS KPIs requires a solid foundation for evaluation to guide the development of specific, targeted indicators. To achieve this, a literature review has been carried out to inform and shape the evaluation framework. The analysis of this framework encompasses the demonstration pilots, focusing on both user perspectives (**user-acceptance**) and the technological aspects (**technological acceptance**) of the THEROS toolbox components.

The "User-Acceptance Evaluation Pillar" gathers feedback from end-users specifically regarding the THEROS toolbox components (Section 2.2), addressing all tools and the operational aspects of the integrated toolbox for organic and GI food supply chains. This evaluation includes indicators such as ease of use, perceived usefulness, improved efficiency, effort reduction, and the quality of visualization and interaction. A summary of these user-acceptance indicators is presented in Table 6.

Table 6 Evaluation indicators for user-acceptance evaluation.

Evaluation	Example Questions
Ease of Use	How straightforward is it to apply the THEROS components?
Usefulness	How does the use of THEROS components and tools compare to the current hardware and software used in...
Increased Efficiency	Do the THEROS components and tools enhance efficiency in...
Time Reduction	Do the THEROS components and tools allow for time savings in...
Effort Reduction	Do the THEROS components and tools contribute to effort reduction in...
Level of Satisfaction	What is your overall satisfaction with the THEROS components and tools in terms of...
Visualisation	How satisfied are you overall with the THEROS components and tools regarding...

The "Technological Evaluation Pillar" focuses on assessing the technical solutions proposed within the THEROS demonstration pilots for their effectiveness. During the real-life operational demonstrations, the THEROS toolbox and its components will be evaluated in alignment with specific end-user requirements. The methodologies and tools developed within THEROS advance beyond the current state-of-the-art in data acquisition and processing for agricultural monitoring. This section, therefore, includes inquiries related to in situ data collection, data analytics, processing, and data modeling visualization. General questions are structured to evaluate scalability, resource optimization, openness and flexibility, and reliability across the pilot cases.

Table 7 Evaluation indicators for technological evaluation.

Evaluation	Example Questions
Resource Optimisation	Do the THEROS demonstration pilots enable management capabilities and resource optimization (such as for security and compute resource management)?
Openess-flexibility	Do the THEROS demonstration pilots permit the addition of new data? Do they promote replicability by using open-standards? Do they promote flexibility through the integration of open-source data and libraries?

Reliability	Are the THEROS toolbox components developed for the demonstration pilots reliable enough for daily operational use?
Conformity	Are results from the pilots conforming to user expectations and quality standards?
Collaboration	How do relevant stakeholders are trained by experts on the THEROS toolbox solutions?
Data Analytics and Processing	Regarding EO data analysis, do the THEROS demonstration pilots allow for a reduction in time? Contribute to effort reduction? Enable enhanced performance?
Data Visualization and end-user interaction	Data Visualization and end-user interaction are adequate to support end-user needs?

Example questions from the two evaluation pillars will guide the development of a set of KPIs, considering the outputs derived from the analysis of various THEROS tools. Questions related to the sustainability and business aspects of THEROS have been more challenging to define and will be further refined as KPIs are established, and will be reported in D5.3.

3. THEROS KPIs framework

This chapter defines the THEROS KPIs, their goals, the methodology for their formulation, and the measurement methods. The KPIs are designed to address both technological and socio-economic dimensions, ensuring they comprehensively reflect the outcomes of the THEROS toolbox components and their impact. They are based on the analysis of the THEROS demonstration pilots, aligning with example questions that evaluate both user-acceptance (Table 6) and technological performance (Table 7). These KPIs serve as a foundation for monitoring and evaluating the project's progress, as depicted in the evaluation-monitoring relationship framework.

It is important to note that the KPIs initially described in the project proposal required refinement to effectively capture the impact of the THEROS toolbox, which integrates all components. During the startup phase of the pilot demonstrations, baseline values for many KPIs were not fully established. As a result, these values needed to be defined collaboratively by the pilot teams and end-users during the development and validation phases of the project.

To prepare the KPI framework, the THEROS team, conducted a thorough literature review, desk studies of pilot descriptions, and meetings with use case partners. This effort led to the development of an initial KPI catalogue and measurement methods. In particular, the team reviewed the descriptions of the demonstration pilots (Section 2.1: THEROS Demonstration Pilots Overview) and the end-to-end deployment scenarios (Section 2.2: End-to-End Scenarios for THEROS). From this analysis, a catalogue of revised and potential new KPIs was created, focusing on technological, socio-economic, and business case dimensions.

Building on this catalog, specific KPI sets were created for each use case, incorporating extensive input and feedback from the respective partners. An iterative review process ensured that the selected KPIs aligned with the needs and objectives of the use case teams. The finalized and validated KPI list provides a robust framework for evaluating the performance, impact, and contributions of the THEROS project.

3.1 Why KPIs?

Key Performance Indicators (KPIs) are essential metrics that provide a detailed understanding of the performance and impact of THEROS's advanced tools and services. Within the framework of the THEROS project, KPIs are designed to measure the extent to which the project achieves its overarching objectives, while identifying areas requiring improvement. These metrics are particularly significant for monitoring the implementation and effectiveness of THEROS solutions across its diverse pilot demonstrations. By employing KPIs, the project ensures alignment with stakeholders' expectations and fosters evidence-based evaluation and decision-making.

It is important to recognize the diversity of stakeholders involved in THEROS, including farmers, certification bodies, policymakers, technical developers, and end-users such as consumers. Each stakeholder group operates within unique contexts and regulatory frameworks, which means there is no one-size-fits-all set of KPIs. Instead, KPIs must be carefully tailored to each use case to reflect the specific needs and operational realities of the stakeholders. Poorly defined or overly complex KPIs could hinder progress, divert resources, and detract from the project's overall impact. For example, setting an unrealistic target for a KPI may lead the consortium to prioritize achieving that target at the expense of optimizing the scientific and technological aspects of THEROS's tools.

To address these challenges, THEROS has adopted the European Commission's "RACER" criteria[1] (Relevant, Accepted, Credible, Easy to monitor, and Robust) for developing robust and actionable KPIs. Building on these principles, the project has defined two primary categories of KPIs: Technological KPIs and User-Acceptance KPIs. These are tailored to evaluate both the technical performance of the tools and the satisfaction of end-users, respectively. These categories form the foundation for assessing THEROS's tools, ensuring their scalability, interoperability, and long-term sustainability.

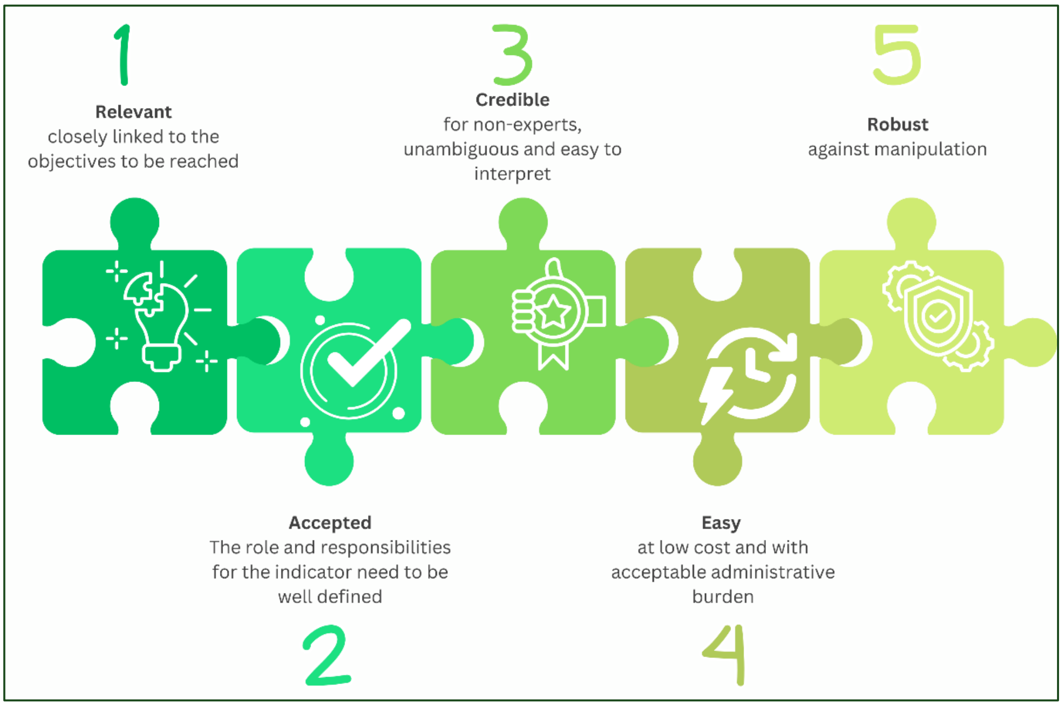


Figure 19 The "RACER" set of general principles for identifying good KPIS in the THEROS project.

[1] "Better regulation Toolbox", produced by the European Commission complementing the "Better Regulation Guideline" SWD(2021) 305 final. Accessed from https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en on 18 November 2024.

This systematic approach ensures that the KPIs are not only aligned with the objectives of the THEROS project but are also practical and relevant to the real-world contexts in which the tools are deployed. The KPI framework thus serves as a dynamic mechanism for monitoring progress, evaluating impact, and driving the successful implementation and adoption of THEROS solutions, ultimately contributing to sustainable, safe, and transparent food systems.

3.2 Development of THEROS KPI framework

To ensure the establishment of a comprehensive and objective KPI framework for the THEROS project, the RACER approach has been adopted to guide the selection of a focused and practical list of recommended KPIs. These KPIs are specifically tailored to support the validation and evaluation of THEROS's tools in addressing food fraud prevention, supply chain traceability, and compliance monitoring challenges. This approach builds upon a thorough review of existing methodologies and stakeholder feedback to ensure relevance, robustness, and alignment with project objectives.

In addition, input was gathered from end-users and stakeholders to understand existing levels of KPI usage and their perspectives on applying advanced tools for supply chain transparency, fraud detection, and environmental impact monitoring. Insights from stakeholders, documented in prior THEROS deliverables, were instrumental in shaping the framework to reflect real-world challenges and opportunities. The THEROS KPI framework has been structured to evaluate the performance, effectiveness, and impact of all THEROS toolbox components. To align with the two evaluation pillars—user-acceptance and technological evaluation—the KPIs are divided into corresponding categories. Each category focuses on assessing outcomes in accordance with the specific goals of THEROS's tools, ensuring a comprehensive evaluation approach.

Figure 20 illustrates how the KPI framework is designed to measure performance across both evaluation pillars. Each outcome of THEROS's tools is analyzed based on specific indicators, categorized as either user-acceptance or technological. This process ensures that each KPI is directly tied to the objectives of the THEROS tools and their practical application in diverse supply chain scenarios.

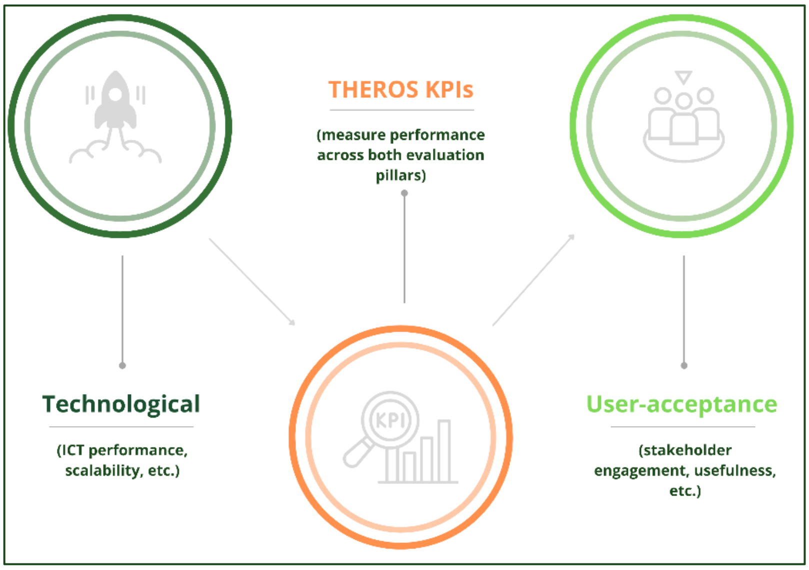


Figure 20 The two primary categories of the THEROS KPI framework.

To support the development of the KPIs, a detailed preliminary activity was undertaken. This included defining each of the KPIs in greater detail, specifying what each KPI measures, and outlining approaches for their calculation and application. This step-by-step methodology ensures that the KPIs are not only comprehensive but also actionable and measurable. The iterative review and refinement of these KPIs, as illustrated in Figure 21, ensure that the framework remains aligned with the overarching goals of the THEROS project, providing an objective basis for monitoring and assessing the project's success.

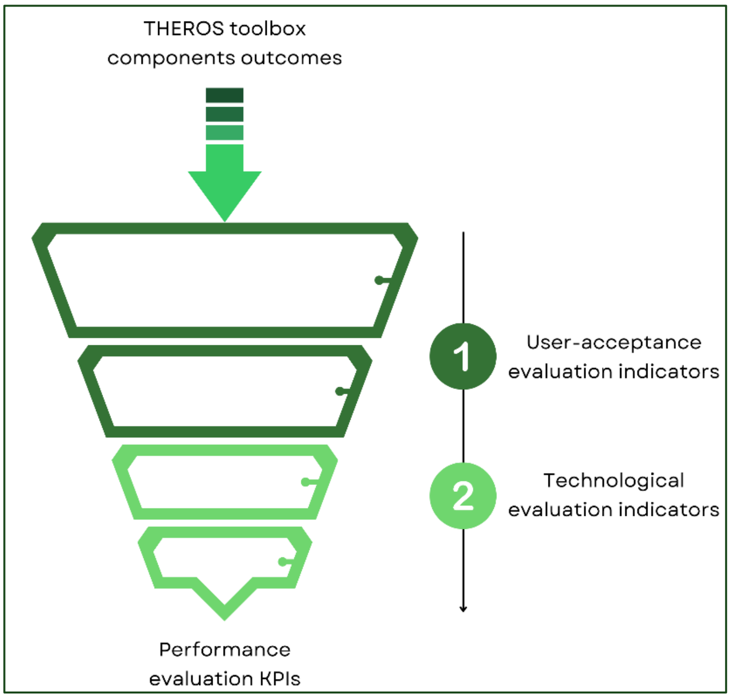


Figure 21 The Tiered Evaluation Framework of THEROS is used to filter component outcomes through predefined evaluation indicators to establish KPIs.

By combining state-of-the-art methodologies, stakeholder feedback, and project-specific insights, the THEROS KPI framework establishes a robust and effective evaluation system. This ensures the project's outcomes are measurable, impactful, and aligned with its commitment to creating transparent, sustainable, and trustworthy food supply chains.

3.3 THEROS defined KPIs

As previously mentioned, the THEROS team has developed individual KPI catalogues for each use case and invited partners involved in the use cases to review and discuss the proposed themes and indicators. A panel of experts from the THEROS consortium created the project-defined KPIs. Below, we analytically present the KPIs categorised by theme and use case. The corresponding metrics (measurement units) for each KPI are also detailed in the catalogues provided below.

3.3.1 Technological KPIs

A critical step in the validation and testing of the THEROS toolbox involves establishing a clear methodology, tools, and procedures to ensure alignment with the expected functionalities and outcomes of THEROS's fraud prevention, traceability, and compliance monitoring applications. Scalability is also a key consideration, focusing on the ability of THEROS solutions to adapt to additional end-users and diverse pilot scenarios, including the integration of field-based tools that complement blockchain, IoT, MEMS system, DNA authenticity, and EO data.

KPIs also address the seamless integration of THEROS technologies and services into various applications, such as supply chain traceability, fraud detection, and compliance monitoring. This includes leveraging both new and existing infrastructure to ensure efficient deployment, sustainability, and long-term impact. Furthermore, the technological KPIs (as detailed in Table 8) are directly tied to the project's primary objectives, offering measurable indicators to assess progress and impact across all pilot activities.

Table 8 THEROS technological KPIs.

ID	KPI Name Identifier	Description	Metric	Method of collection and measurement	Project target
TC-001	Fraud Detection Accuracy	Measures the effectiveness of fraud detection in the supply chain. This KPI encompasses both the initial	% Accuracy	Comparison of detected fraud cases vs. total fraud instances in pilot tests.	≥ 95%

		detection accuracy of individual tools and the confirmed detection accuracy following the cross-checking confirmation phase.			
TC-002	Blockchain Transaction Speed	Time taken to process a transaction in the blockchain system.	Seconds	System logs and transaction timestamps.	≤ 5 seconds per transaction
TC-003	IoT Sensor Data Reliability	Reliability of data collected by IoT sensors during transport and storage.	% Valid Data	Comparison of valid vs. invalid data points from IoT sensors in pilot deployments.	≥ 90%
TC-004	EO Marker Precision	Accuracy of EO markers for compliance detection.	% Accuracy	Validation against ground truth data in pilot areas.	≥ 85%
TC-005	DNA Kit Sensitivity	Sensitivity of DNA tools in detecting food authenticity.	% Sensitivity	Lab testing on known samples across pilots.	≥ 95%
TC-006	Data Harmonization Success	Successful integration of data from multiple sources using harmonization tools.	% Successful	Validation of harmonized datasets across pilots.	≥ 95%
TC-007	Traceability Completeness	Degree to which product lifecycle is tracked via blockchain. This includes the completeness of fraud alert event recording - all	% Completion	Analysis of blockchain records across pilot scenarios.	≥ 98%

		alert generation, confirmation, escalation, and resolution events must be traceable as immutable blockchain records.			
TC-008	Compliance Report Accuracy	Accuracy of compliance reports generated by the verification engine. Reports are generated both at the tool level and following the completion of the fraud alert workflow, including escalation outcomes and false positive decisions.	% Accuracy	Cross-validation of reports against pilot data.	≥ 90%
TC-009	System Scalability	Number of users or devices supported without performance degradation.	Number of Users	Load testing under varying conditions.	≥ 500 Users
TC-010	Green Accountability Metrics	Accuracy of metrics generated for environmental accountability.	% Accuracy	Validation of reports against environmental benchmarks.	≥ 90%
TC-011	MEMS Data Accuracy	Precision of MEMS spectrometer readings.	% Accuracy	Calibration tests against known standards.	≥ 90%
TC-012	Blockchain Energy Usage	Average energy consumption	kWh	Monitoring of blockchain operations.	≤ 0.01 kWh/transaction

		of blockchain transactions.			
TC-013	Digital Passport Integration	Percentage of successfully integrated product passports.	% Integration	System validation logs from DPP pilots.	≥ 95%
TC-014	API Response Time	Average response time of toolbox APIs under pilot conditions.	Seconds	Monitoring API performance in real-time.	≤ 2 seconds
TC-015	Training Data Accuracy	Accuracy of training datasets used in AI models.	% Accuracy	Dataset validation and cleaning before deployment.	≥ 95%
TC-016	Environmental Monitoring Coverage	Total area monitored using EO and IoT tools.	Hectares	Analysis of monitored areas across pilot regions.	≥ 500 Hectares
TC-017	Multilingual Interface Usability	Number of languages supported in the user interface.	Number of Lang.	Functional testing of multilingual interfaces.	≥ 5 Languages
TC-018	Product Recall Efficiency	Time taken to trace and recall non-compliant products.	Hours	Simulated recall exercises during pilots.	≤ 24 Hours
TC-019	User Data Security	Number of security breaches in the system.	Count	Continuous monitoring of system logs.	Zero breaches
TC-020	Verification Engine Precision	Accuracy of verification checks against organic and GI standards. Precision is assessed both in terms of initial rule-based rejection accuracy and in the context of the	% Accuracy	Cross-validation with manual compliance checks.	≥ 95%

	confirmatory cross-checking logic, ensuring that rejected batches are consistently associated with genuine non-compliance events.	

3.3.2 User-acceptance KPIs

Stakeholder engagement for the THEROS project emphasizes the ability to effectively reach and involve key stakeholders, including farmers, certification bodies, policymakers, and consumers engaged in the pilot activities. This involves fostering active participation, motivation, and collaboration across these groups, thereby establishing a robust and adaptive operational framework. Additionally, the flexibility and scalability of the system are evaluated, focusing on its ability to address both specific end-user needs (e.g., individual stakeholders) and broader cross-sectoral applications. Several of the User-Acceptance KPIs detailed in the framework are directly tied to the objectives and initial business model framework established for THEROS, ensuring alignment with the project's goals and long-term sustainability.

Table 9 THEROS user-acceptance KPIs.

ID	KPI Name Identifier	Description	Metric	Method of collection and measurement	Project target
UR-001	Ease of Use	Stakeholders' perception of ease of use for THEROS tools.	1-5 Scale	User surveys and interviews post-deployment.	≥ 4/5 Rating
UR-002	User Satisfaction	Overall satisfaction of stakeholders using the THEROS toolbox.	1-5 Scale	Feedback collection during pilot demonstrations.	≥ 4/5 Rating
UR-003	Usefulness of Outputs	Perceived usefulness of outputs provided by THEROS tools.	1-5 Scale	Stakeholder feedback and focus groups.	≥ 4/5 Rating
UR-004	Training Effectiveness	Efficiency of training programs provided for	% Satisfaction	Surveys conducted after training sessions.	≥ 85%

		THEROS toolbox users.			
UR-005	Visual Presentation Quality	Quality of visualizations in the Green Accountability and Blockchain tools.	1-5 Scale	Stakeholder rating based on pilot outputs.	≥ 4/5 Rating
UR-006	Stakeholder Engagement	Level of stakeholder engagement during pilot implementation.	% Engagement	Attendance and participation rates during sessions.	≥ 80%
UR-007	Efficiency Improvements	Stakeholder-perceived efficiency improvements from using THEROS tools.	1-5 Scale	Surveys comparing baseline vs. post-deployment perceptions.	≥ 4/5 Rating
UR-008	Clarity of Guidelines	Clarity and comprehensiveness of user manuals and documentation.	1-5 Scale	Feedback collected after pilot sessions.	≥ 4/5 Rating
UR-009	Integration Success	Ease of integration of THEROS tools into existing workflows.	1-5 Scale	Stakeholder feedback on integration experiences.	≥ 4/5 Rating
UR-010	Data Transparency	Perception of data transparency in supply chain monitoring.	1-5 Scale	User surveys and case study reviews.	≥ 4/5 Rating
UR-011	Fraud Detection Trust	Stakeholder trust in fraud detection capabilities of the toolbox.	1-5 Scale	Feedback from certifiers and inspectors.	≥ 4/5 Rating
UR-012	Sustainability Awareness	Stakeholder awareness of sustainability metrics provided by THEROS tools.	% Awareness	Surveys measuring understanding of Green Accountability outputs.	≥ 80%

It is important to note that several user-acceptance KPIs are directly linked to the functioning of the fraud alert workflow defined in Section 2.2.9. KPI UR-011 (Fraud Detection Trust) captures stakeholder confidence not only in the detection capabilities of individual tools but also in the clarity and reliability of the escalation and dismissal process. KPI UR-010 (Data Transparency) assesses whether supply chain actors and certification bodies perceive the alert recording and audit trail as sufficiently transparent and accessible. KPI UR-008 (Clarity of Guidelines) will also be used to evaluate whether end-users find the fraud alert workflow; including confirmation steps, escalation criteria, and false positive handling; sufficiently documented and easy to follow in practice. Feedback on these dimensions will be collected through the dedicated post-pilot surveys and workshops described in the evaluation framework (Section 2.3).

As follow-up step, we identified the specific KPIs per use case, and which partners play a critical role, to ensure that there are no existing roles that are not fulfilled yet (Table 10).

Table 10: KPIs per use case and the corresponding partner for their evaluation

Use case	KPI ID	Actors
EO-Based Ecosystem Services Monitoring	TC-004, TC-006, TC-008, TC-009, TC-010, TC-016, UR-001, UR-002, UR-003, UR-004, UR-005, UR-006, UR-007, UR-008, UR-009, UR-011, UR-012	SIN, OCS, BIONET
MEMS Photonics and Mobile Application and dDPP application	TC-001, TC-007, TC-008, TC-009, TC-011, TC-013, TC-014, TC-015, TC-016, TC-017, TC-018, TC-019, UR-001, UR-002, UR-003, UR-004, UR-005, UR-007, UR-008, UR-009, UR-010, UR-011, UR-012	AUTH, ICCS, ELGO, OCS, UNIVER, BIONET, BIOH, MEXILLON, KIWA
IoT Sensor Network for Supply Chain Monitoring	TC-003, TC-006, TC-009, TC-014, TC-016, TC-018, TC-019, UR-001, UR-002, UR-003, UR-004, UR-007, UR-008, UR-009, UR-010	WRLS, SUMAVA
DNA-Based Authenticity Verification	TC-001, TC-005, TC-007, TC-008, TC-009, TC-015, TC-018, TC-020, UR-001, UR-002, UR-003, UR-004, UR-007, UR-008, UR-009, UR-011	CERTH, MEXILLON, KIWA, ICCS, eBOS
Blockchain and Traceability Implementation	TC-002, TC-007, TC-009, TC-012, TC-013, TC-014, TC-017, TC-018, TC-019, UR-001, UR-002, UR-003, UR-005, UR-007, UR-008, UR-009, UR-010, UR-011	EVERIS, ALL
Digital Marketplace Deployment	TC-007, TC-009, TC-014, TC-018, TC-019, UR-001, UR-002, UR-003, UR-006, UR-007, UR-008, UR-009, UR-010	WRLS
Green Accountability Tool Deployment	TC-006, TC-008, TC-009, TC-015, TC-016, TC-019, TC-020, UR-001, UR-002, UR-003, UR-005, UR-006, UR-007, UR-008, UR-012	eBOS, OCS, UNIVER, BIONET, BIOH, AUTH, SIN

3.4KPI lifecycle

The KPI development lifecycle in the THEROS project has been carefully designed to ensure that Key Performance Indicators (KPIs) effectively capture the performance, impact, and scalability of THEROS tools and services. This iterative process ensures alignment with the project's overarching objectives of fraud prevention, traceability, and sustainability while allowing for continuous improvement and refinement.

The life cycle involves five distinct stages to guide the definition, implementation, and evaluation of KPIs:

- **Define Preliminary KPIs:** Preliminary KPIs are identified based on an in-depth analysis of project goals, stakeholder requirements, and the operational context of each pilot activity. These initial indicators establish a foundation for assessing performance and addressing specific areas of interest within organic and GI supply chains.
- **Collect and Refine Relevant KPIs:** The most relevant KPIs are selected through consultations with stakeholders, technical partners, and pilot teams. This ensures the indicators are practical, actionable, and tailored to address the challenges and opportunities of each use case.
- **Group KPIs by Use Cases:** KPIs are grouped according to their relevance to specific pilot demonstrations. This facilitates targeted monitoring and evaluation, ensuring that each KPI addresses the unique goals and operational needs of the respective pilot activities.
- **Implement KPIs in a Feasible and Clear Way:** A standardized methodology is applied for the implementation of KPIs. Clear guidelines are established for data collection, measurement, and reporting to maintain consistency and accuracy across all pilot sites.
- **Assess Functionality and Adjust:** During the implementation phase, the functionality and relevance of KPIs are continuously evaluated. If discrepancies or inefficiencies are identified, corrective actions are taken, and the lifecycle re-enters the appropriate stage to refine and enhance the indicators.

A core objective of THEROS's KPI framework is to establish realistic and well-justified target values for each indicator. These targets act as benchmarks to evaluate project performance and identify areas for improvement. The framework acknowledges that target values may evolve over the project's lifecycle to incorporate new insights, changing conditions, or stakeholder feedback. Care is taken to avoid setting overly ambitious or unrealistic targets that might misalign project efforts or priorities. The KPIs are designed to account for external factors, such as seasonal variations or market fluctuations, that could influence the outcomes of pilot activities. By isolating these variables, the framework ensures that measured outcomes are directly attributable to the implementation of THEROS tools and methodologies.

To enhance the evaluation process further, feedback is actively collected from stakeholders through surveys, workshops, and pilot reviews. This input informs iterative improvements to the KPI framework and contributes to the continuous enhancement of THEROS tools and methodologies.

By adopting this lifecycle approach, THEROS establishes a robust and adaptive KPI framework that aligns with project objectives, supports effective monitoring, and ensures the tools deliver measurable benefits to stakeholders. This structured process enables the project to maximize its impact on fraud prevention, traceability, and environmental accountability while maintaining the flexibility to adapt to emerging challenges and opportunities.

4. Conclusions and recommendations

This deliverable is an outcome of Task 5.1 within WP5 of the THEROS project. It outlines the methods and approaches which will be used to analyze the demonstration pilots and specific use cases, develop comprehensive end-to-end deployment scenarios, define KPIs, and establish robust measurement methodologies. Additionally, the roles of key partners in each use case were identified to determine which stakeholders play critical roles in the evaluation and implementation processes.

This report proposes the use of KPIs categorized under five main themes: THEROS toolbox components, scalability, integration with existing systems, stakeholder engagement, and the transparency and accountability of the supply chain. These KPIs are designed to evaluate the pilot demonstrations across diverse geographies, including Greece, Spain, and other pilot regions. Each KPI is defined with specific reference to the factors being monitored, the frequency of reporting, and the units of measurement. To ensure consistency, an agreed-upon calculation method and relevant parameters are assigned to each KPI, facilitating the accurate monitoring and evaluation of data. This consistency is crucial to assessing the success, scalability, and replicability of THEROS activities.

In defining the KPIs, the THEROS team prioritized the development of practical, targeted indicators tailored to the project's specific needs. These KPIs are narrower in scope than those proposed in external guidelines or literature, reflecting the project's operational realities. It is also recognized that external factors, such as seasonal variations or supply chain disruptions, can significantly influence the outcomes of the pilot demonstrations. To address this, the KPIs are designed to measure the direct impact attributable to THEROS components, isolating the influence of external factors. Additionally, user feedback will be collected through dedicated surveys conducted as part of the pilot activities to evaluate satisfaction levels among end-users and stakeholders.

The final KPI catalogue is treated as a dynamic, "living" document for each use case, allowing iterative updates and adjustments during pilot implementation to support a comprehensive evaluation of the THEROS toolbox. To achieve this, several key actions are recommended:

- Conduct brainstorming sessions with WP5 pilot leaders and technical partners to refine KPIs and align them with pilot objectives.
- Identify all stakeholders involved in each use case, detailing their roles and interdependencies.
- Recognize potential obstacles and risks and implement timely remedial actions to minimize their impact on pilot outcomes.

- Facilitate user input of KPIs into an integrated KPI measurement system, providing a user-friendly interface for data collection. This system will support the clear and consistent measurement of results for each THEROS toolbox component, contributing to D5.3 ‘’ Lessons learnt and impact assessment report’’.
- Use KPI evaluation outcomes to review and adapt the initial business models, ensuring alignment with pilot results and stakeholder feedback.
- Document and standardise the fraud alert workflow across all pilots: The fraud alert workflow will be operationally tested and refined during the demonstration pilots (Task 5.2-5.5). Pilot leaders are recommended to record the number and type of alerts generated, the tools used for confirmation, the escalation decisions made, and the response times of certification bodies. This data will be essential for evaluating KPIs TC-001, TC-021, and TC-007, and will provide the empirical basis for the cross-tool cross-checking logic assessment reported in D5.3.

Through these structured steps, this deliverable provides a robust foundation for evaluating the performance, scalability, and impact of the THEROS project. The defined KPIs and measurement methodologies enable the project to assess progress effectively while adapting to challenges and maximizing the value of its outcomes for diverse stakeholders, including farmers, certification bodies, policymakers, and consumers.

References

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