



D1.1 Uses cases and analysis report

June, 2025



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Work package	WP 1
Task	T1.1
Due date	30/06/2025
Submission date	30/06/2025
Type of deliverable	Report
Dissemination Level	Public
Deliverable lead	FBK
Version	1.0
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Keywords	Use cases, KPIs, User Requirements, Task analysis

Document Revision History

Version	Date	Description of change	List of contributor(s)
V0.1	12/03/2025	First draft from template	Paul Chippendale (FBK)
V0.2	28/05/2025	Restructuring the doc, pilots' information	Sara Sillaurren, Tatiana Bartolomé, Ana Belén Ruiz (TEC), David Erice (UPA), Aikaterini Kasimati, Georgios Ntakos (AUA), Annekatrin Hoppe (UBER), Lina Kasties (UBER), Linda Onnasch (TUB), Luca Morelli (IUV)
V0.3	11/06/2025	Removal of some tech detail	Paul Chippendale (FBK)
V0.4	22/06/2025	Internal peer review	Melisa Gómez (XYM), Pablo Malvido Fresnillo (TAU)
V0.9	23/06/2025	Final review by responsible	Paul Chippendale (FBK)
V1.0	30/06/2025	Final quality review ready for submission	Leire Bastida (TEC)

Partners Responsible for Deliverable

FBK, TEC

Funding



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Call: HORIZON-CL6-2024-GOVERNANCE-01

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Executive Summary

The document serves as a comprehensive analysis of the project's use cases and provides a first look at the requirements from stakeholders. As this deliverable is the first major contribution to the project, it is useful to provide a brief overall of the objectives of AgRimate and show which of these match D1.1. Below is a synthesis of these objectives:

1. Assess the Needs & define Specification of the solution (conducting a comprehensive assessment of human, technical, and business needs, focusing on well-being practices, to define functional and operational specifications for AgRimate and establish benchmarks for evaluation.)
2. Develop an AR solution for pruning (providing real-time guidance and training for pruning, including evaluative capabilities to assess tasks and facilitate continuous learning for farmers).
3. Develop AI-enhanced Advanced Robotics for Pruning (develop an autonomous pruning robot and labour-assistive exoskeletons, to optimize pruning tasks, augment worker capabilities (especially for women and older farmers), and improve well-being, while evaluating scalability and viability)
4. Develop an advanced AI-Powered Decision Support system for pruning (integrating diverse data streams to provide real-time insights and personalized recommendations, encompassing a Pruning Learning Processor, Scene Simulator, Skills Profiling Engine, and Well-being Analytics Engine)
5. Enhance Social Sustainability & Well-being (advanced AR and AI technologies, complemented by supportive peer networks and social media, to reduce job demands and foster community among smallholder farmers)

The work done in T1.1, "Use cases and KPI analysis," and reported in this deliverable primary defines the project's purpose and scope by thoroughly outlining use cases (see obj 1 above), analysing both functional and non-functional requirements, and developing a reference architecture. This will therefore serve as a crucial guide for the development and integration of various AgRimate modules.

Early work in T1.1 was instrumental in producing D1.1. This document focuses on an exhaustive delineation of use cases, analysing human-centric problems within these scenarios of olive groves and vineyards, and proposing solutions that will inform the technical and functional specifications for subsequent tasks (T.2 and T1.3).

Furthermore, T1.1 is responsible for establishing a robust suite of benchmarks and Key Performance Indicators (KPIs) to evaluate performance during the pilot phase (WP6). This aligns with WP5's focus on psychosocial and human-centred approaches. D1.1 also considers prominent industry standards and reference architectures to ensure interoperability to maximize the project's impact. Notably, a strategic collaboration with trade unions, facilitated by the UPA partner, will be integrated to ensure that workforce perspectives and welfare are central to AgRimate's development and assessment, reinforcing the human-centred objectives of WP5 (these matches closely obj5 above).

Finally, it should be noted that the task descriptions in the DoA are sometimes a little vague and high-level. In this deliverable more detail is being provided to enrich these descriptions, hence new research questions will be posed and solutions hypothesised.

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Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
ARPP	Autonomous Robotic Pruning Platform
CAP	Common Agricultural Policy
CTA	Cognitive Task Analysis
DDS	Data Distribution Service
DoA	Document of Action
EKF	Extended Kalman Filter
EU	European Union
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GOMS	Goals, Operators, Methods, Selection Rules
HCI	Human-Computer Interaction
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFAPA	Instituto de Investigación y Formación Agraria y Pesquera de Andalucía
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LiDAR	Light Detection and Ranging
MVS	Multi-View Stereo
NGO	Non-governmental organizations
OPC UA	Open Platform Communications Unified Architecture
PPE	Personal Protective Equipment
RGB	Red, Green, Blue (camera sensor)

ROS	Robot Operating System
RTK-GPS	Real-Time Kinematic Global Positioning System
SLAM	Simultaneous Localization and Mapping
TEO	Technological Enabling Object
TRL	Technology Readiness Level
UX	User Experience
VR	Virtual Reality
XR	Extended Reality

1 Introduction

Within WP1 (Technical and Operational Roadmap), Task 1.1 (Use cases and KPI analysis) focuses on the conducting of an exhaustive delineation of the use cases, including the activities related to the analysis of (functional and non-functional) requirements and the reference architecture, which will guide the development, and integration of the different AgRimate modules. A robust suite of benchmarks and pertinent KPIs will be established to gauge the performance throughout the pilot phase in WP6, aligning closely with WP5's objectives surrounding psychosocial and human-centred approaches. Prominent standards and reference architectures and related platforms will be considered to ensure interoperability and maximise impact. Additionally, this task will incorporate a strategic collaboration with trade unions, facilitated by the UPA partner, to ensure the perspectives and welfare of the workforce are integral to the development and assessment of AgRimate, thus aligning closely with the human- centred and psychosocial objectives outlined in WP5.

In more detail, with reference to the document sections:

- We begin in Section 1, Introduction, by detailing the aim and scope of this work and its relationships with other project tasks.
- In Section 2, Use cases and KPIs, dives into the core scenarios for our solutions, specifically the Olive tree pruning use case and the Grapevine pruning use case. For each, we provide a detailed description and define key performance indicators to measure success.
- Moving to Section 3, Stakeholders Identification, we define and identify the key individuals and groups who will be impacted by or contribute to the project.
- Section 4, Task Analysis, provides a comprehensive breakdown of the activities involved in pruning. This includes a thorough Context analysis for both olive tree and grapevine pruning, expert identification, and detailed Knowledge acquisition through pilot visits, questionnaires, and interviews. We then present a Data Analysis of tasks, decisions, cues, and cognitive strategies for both pruning scenarios, identify the Pain points of the process, and discuss the Results validation and application.
- Section 5, Requirements Elicitation, outlines our methodology for gathering requirements and presents the derived functional and non-functional needs for the AgRimate system.
- In Section 6, Prominent Standards, Reference Architectures and Enabling Platforms for Interoperability, we explore existing standards and architectures relevant to In-the-fields sensing for Agriculture, Robotic platforms and manipulators for Agriculture, and XR Human interfaces for Agriculture, ensuring our solutions are built on a foundation of interoperability and best practices.
- The document concludes with Section 7, Conclusion, summarizing our findings and looking ahead to future work. Supporting details, including questionnaires and categorized statements on technology perceptions, can be found in the Annexes.

1.1 Aim and the scope

The main objective of this document is to describe the purpose and scope of Task 1.1 (Use cases and KPI analysis) within WP1 (Technical and Operational Roadmap) of the AgRimate project. It outlines the task's focus on defining use cases, analysing requirements, developing a reference architecture, and establishing benchmarks and KPIs to guide the development and integration of AgRimate modules.

1.2 Relationships with other tasks

Task 1.1 (Use cases and KPI analysis) contributes to deliverable D1.1 (Uses cases and analysis report). The first step in this task is to analyse human problems found in the use-cases and suggest solutions. These insights form the foundation for developing the technical and functional specifications for Task 1.2 (Development of Functional and Operational Specifications) and Task 1.3 Technical Specification.

2 Use cases and KPIs

The AgRimate project is addressing two main application domains in the field of **traditional olives trees** and **grape vines** (vineyards), where the solutions will be demonstrated; with the first use-case looking at traditional olive tree pruning and the second addressing grape vine pruning.

For each of our application domains, the following technical components will be created:

TEO1 – AR Guide (Olive trees pilot only): This real-time Augmented Reality (AR) guidance system overlays strategic pruning instructions directly onto a farmer's field of view. It aims to significantly improve pruning accuracy and efficiency while reducing manual labour errors. By offering on-the-spot evaluation of pruning outcomes and suggesting actionable improvements, the AR Guide will ensure optimal tree health and crop productivity, fostering continuous skill enhancement for farmers.

TEO2 – AR Trainer (both pilots): An immersive, AR-based training platform, the AR Trainer provides personalized learning experiences for farmers. It considers individual factors like gender, immigrant background, and existing expertise to tailor content, creating a more inclusive and effective educational environment. This enables farmers to master diverse pruning strategies, optimally aligned with their crops' specific needs, ultimately enhancing overall crop management and yield.

TEO3 – Automatic Pruner (Vineyard pilot only): This AI-guided robotic pruning solution autonomously executes precision-based pruning tasks based on AI-generated plans. Equipped with two robotic arms and advanced tools, its planner module receives instructions from the Pruning Learning Processor, ensuring uniform, error-free pruning cuts. This technological solution not only optimizes the pruning process but also includes a planning tool for strategic agricultural decision-making, substantially reducing labour costs and elevating farming sustainability.

TEO4 – Assistive Exoskeleton (Olive trees pilot only): Engineered to support agricultural workers in physically demanding tasks like pruning, harvesting, and planting, this assistive exoskeleton could be a game-changer. It can be adapted to diverse physical requirements, including gender, size, and strength, providing a tailored ergonomic support system that reduces injury risk and fatigue. By augmenting human strength and endurance, the exoskeleton enables workers to operate with increased efficiency and comfort over extended periods, significantly improving overall agricultural productivity. This innovation not only boosts the physical well-being of farmers but also contributes to the sustainable scaling of agricultural operations by achieving more with less physical strain.

TEO5 – Assessing Tool (both pilots): This comprehensive evaluation tool utilizes data from AR, AI, and robotic technologies to conduct multidimensional analyses of the agricultural ecosystem. The Assessment Tool gauges economic benefits, productivity enhancements, and the social and well-being impacts of technology on the farming community. It acts as a crucial link between technological innovation and holistic community advancement, empowering stakeholders to make more enlightened decisions that are inclusive, sustainable, and enable progressive agricultural development.

2.1 Olive tree pruning use case

2.1.1 Description

Traditionally, olive pruning generates a high, and most notably seasonal, demand for manual labour. For example, in Spain there are over 2,788,084 hectares of olive groves across 350,000 farms. From January to April, a mix of permanent and seasonal labour is needed in this traditionally significant sector. For pruning, there is a strong dependence on farmer expertise, and as there is a growing shortage of such experts, this is leading to inconsistent outcomes and physical strain, spotlighting the necessity for innovation. Spain is attempting to transit to a higher density, mechanical-oriented grove, driven by issues like climate change and the need for competitiveness. This means that sustainable practices are desperately needed. The challenge of bringing AI and robotics to this domain is hindered by informal knowledge transfer barriers, making the labour-intensive care of olive groves and the scarcity of available workers a pivotal concern.

Olive tree pruning is key for shaping and rejuvenating an olive tree's crown for productivity. Pruning techniques varies throughout a tree's life, juvenile to adult, affecting everything from root growth to fruit production. The Picual olive tree's slow maturation process (up to 20 years for peak development) emphasizes the value of precise pruning.

The evolution of olive pruning can come from several emerging technologies, for example: AR Guidance, AR Training, exoskeletons for fatigue reduction, AI health care analysis, robotic scanning to create digital passports, etc. These technologies can offer benefits such as real-time guidance and advice that can be tailored to an individual tree – for example working towards structural growth in young trees and then maintaining productivity in adult trees.

To ensure optimal pruning techniques, the incorporation of health insights and ergonomic practices for farmer safety are needed. AR Trainer could facilitate efficient knowledge transfer, enhancing skills for efficient pruning, while exoskeletons could reduce worker strain, supporting longer work periods and preventing injuries. These approaches will not only improve farmers' well-being but also boost olive farming productivity and sustainability, promoting healthier trees and increased yields.

2.1.2 KPIs

It is difficult to establish detailed improvement estimates so these will be revised as the project progresses. The KPIs initially introduced in the proposal were:

- Increase in yields +15%
- Reduction in time spent pruning -5%
- Reduction of physical effort -25%
- AR Guide effectiveness >80%
- Increase in labour availability +10%
- Worker acceptance >80%

To advance KPI measurement and acquisition, it will be helpful to incorporate the following additional information:

Based on the assumption that a person has at least 10 years of olive pruning experience on a particular plot of land, and they are expert in the use of a chainsaw and in optimal conditions, it is estimated that the duration of the work should not exceed the following times in an ideal scenario, according to the type of case.

	Worker with 10 years of experience	Unskilled worker
Case 1 slopes less than 20%	5 minutes/tree	10 minutes/tree
Case 2 (slopes greater than 20%)	7-8 minutes/tree	15 minutes/tree

Table 1. Typical pruning times

It is also important to consider the orography of the plot, as this will affect the total duration of the work due to the time required to move from one tree to the next. In case 2, with slopes greater than 20%, an increase in time of 10% is expected.

There is a growing problem regarding the availability of workers in the agricultural sector. Official data shows a declining trend in the number of people employed in the agricultural sector in Jaén.

Year	Thousands of workers
2017	34,2
2018	26,1
2019	27,0
2020	27,1
2021	30,8
2022	28,8
2023	28,3
2024	27,9

Table 2. Availability of workers over time

The olive grove is certainly the most important agricultural crop in the province of Jaén, thereby influencing the entire agricultural sector. The number of people employed in the agricultural sector in Jaén in 2024 decreased by 18% compared to 2017.

2.2 Grapevine pruning use case

2.2.1 Description

Globally, vineyards cover nearly 7 million hectares, producing over 80.1 million metric tons of grapes each year. The European Union remains a dominant force in global viticulture, accounting for approximately 45% of total vineyard area and 58% of grape production, making it the largest producer, exporter, and consumer of grapes and wine. Within this landscape, Greece stands out as an important contributor, with over 10,308 hectares of vineyards spread

across 188,873 farms, many of which are small-scale, and family owned. The sector is deeply embedded in the country's agricultural economy, cultural heritage, and rural identity.

Grapevine pruning in Greece is carried out between November and March, during the vine's dormancy period, and remains a labour-intensive and skill-dependent process. This period marks one of the most crucial phases in vineyard management, as proper pruning determines the vine's structure, productivity, fruit quality, and long-term health. The complexity of the task lies in adapting pruning techniques to the physiological traits of each grape variety, regional microclimatic conditions, soil properties, and desired yield or wine profile.

Despite its importance, pruning is still performed manually in most Greek vineyards, relying heavily on the practical experience and tacit knowledge of seasoned workers. However, a shrinking rural workforce, lack of structured training, and a growing need for consistency and sustainability are exposing vulnerabilities in the current system. Mistakes in pruning, often made by seasonal or undertrained labourers, can have long-lasting negative impacts on vine vigour, disease susceptibility, and grape composition.

Given these challenges, the integration of emerging technologies such as Augmented Reality (AR), Artificial Intelligence (AI), and robotics offers a promising pathway for innovation. In the AgRimate project, the focus is on developing a blended technological approach to support, train, and partially automate the pruning process, particularly within the Greek vineyard pilot focused on the Savatiano variety.

- AR-based training systems can provide real-time visual guidance, helping users to identify correct cuts, bud selection, and canopy management strategies. These systems can be customised to the growth stage and training system (e.g., double Guyot) of each vine, facilitating skill transfer and reducing reliance on expert-only knowledge.
- Robotic pruners, equipped with AI-driven decision-making algorithms, are designed to analyse vine structure and execute precise cuts, enhancing consistency, accuracy, and operational speed. These robots can also capture data on vine health, structure, and phenology, contributing to digital vineyard records and decision support tools.

By combining these tools, AgRimate aims to relieve physical burden, reduce human error, increase operational efficiency, and enhance the resilience of viticultural practices in Greece. These innovations also align with the country's broader goals of climate-smart agriculture, rural development, and the digital transformation of traditional sectors.

The Greek viticulture sector, particularly small to mid-scale vineyards, is at a crossroads between tradition and innovation. While the artisanal knowledge of pruning remains invaluable, there is an urgent need to systematise training, attract younger generations, and digitalise critical processes to cope with environmental pressures and market demands.

The integration of AgRimate technologies in Greek vineyards:

- Promotes inclusive and knowledge-based innovation, ensuring even less experienced workers can contribute effectively.
- Supports the transition toward sustainable viticulture, with lower environmental footprints and improved worker well-being.
- Contributes to regional competitiveness, especially in areas where the wine economy is a cornerstone of local identity and tourism.

This use-case aim to exemplifies how precision viticulture and human-centred technology design can address practical labour shortages while safeguarding grape quality and productivity—making pruning smarter, safer, and more sustainable.

2.2.2 KPIs

Quantifying improvements in viticulture through technological interventions can be challenging due to variability in environmental conditions, crop cycles, and human performance. However, to evaluate the effectiveness and added value of the AgRimate tools and systems, a set of initial Key Performance Indicators (KPIs) were defined in the proposal. These indicators aim to capture improvements in efficiency, quality, user satisfaction, and agronomic outcomes related to grapevine pruning:

- **Time spent pruning: -15%:** Reduction in average time required per vine due to AR-guided or robotic pruning interventions.
- **Increase in yields: +5% to +10%:** Measured as improvement in grape output per hectare, linked to improved canopy and fruiting balance resulting from more consistent pruning.
- **Improvement in pruning accuracy and quality: +15% to +25%:** Assessed via expert scoring of pruning conformity, uniformity of cuts, and correct bud selection according to the training system (e.g., double Guyot).
- **Reduction in pruning-related errors or corrective actions: -30%:** Based on the number of post-pruning corrections or mis-pruned vines flagged by supervisors.
- **Worker acceptance: >80%:** Evaluated via surveys and interviews with vineyard workers and managers, covering usability, perceived value, willingness to continue using the tools, and perceived impact on workload.

These KPIs are subject to refinement as the project progresses, and more baseline data becomes available through pilot site observations and end-user evaluations. It is expected that contextual factors, such as slope, vine age, training system, and weather, will influence the variability of results. Therefore, KPI assessment will be triangulated using multiple methods, including:

- Field time measurements (e.g., stopwatch assessments during manual vs. assisted pruning);
- Yield monitoring tools (e.g., weight/volume of harvested grapes per plot);
- Digital assessments (e.g., pruning maps, AR usage logs);
- Farmer and worker feedback (qualitative surveys and structured interviews).

As part of WP5 and WP6 activities, the KPIs will be tracked longitudinally, comparing pre- and post-intervention values across two growing seasons. Additionally, results will feed into the broader impact assessment framework, contributing to the understanding of AgRimate's technological, economic, and social value in the viticulture sector.

3 Stakeholders Identification

Stakeholders are individuals or groups who have an interest or investment in an organisation and may be affected by its decisions and activities. In the context of agriculture, stakeholders include different groups that play a crucial role in the agricultural supply chain.

Their importance lies in their ability to influence decisions and policies that affect food production and distribution. Their collaboration and engagement ensure a resilient and sustainable agricultural industry.

At this point the objective is to identify the roles and users that will be involved in the project and their level of influence. In order to do this, the following unknowns should be considered and analysed:

- Who are the people involved?
- What needs they have and what needs are unmet or could be improved?
- Who could be the drivers of these changes and who could be the consumers?
- What barriers can be identified to achieving the desired outcomes and who can help to overcome them?

By answering all these questions, we will be able to arrive at the broadest possible identification of the spectrum of stakeholders associated with the AgRimate project.

Initially, some stakeholders' entity groups have been identified as part of the AgRimate environment, in which we are going to focus on from the users' requirement perspective:

Demand Entities: Stakeholders who will directly use AgRimate solutions in their daily agricultural activities. They are essential for implementing and benefiting from the project's innovations in real-world farming contexts. Includes: Farm owner, Field supervisor, Agricultural workers, Farming communities, Cooperative member.

Supply Entities: Stakeholders who develop and provide the technologies and tools used in the project. They are responsible for designing, building, and delivering the core technological solutions of AgRimate. Includes: Technology developers, Innovative companies.

Impact Entities: Stakeholders who influence policy, funding, and social/environmental outcomes. They shape the regulatory, financial, and ethical environment in which AgRimate operates and scales. Includes: Policy makers, Investors and financiers, NGOs.

Early Adopters: Stakeholders who test and validate AgRimate solutions in real-world settings. They provide critical feedback and help demonstrate the feasibility and value of the technologies. Includes: Pilot Partners, Innovative companies.

3.1 Stakeholders' definition

The identified stakeholder groups in this section have been categorized into four main entity groups—Demand, Supply, Impact, and Early Adopters—based on their roles, responsibilities, and interactions within the AgRimate ecosystem (defined at the beginning of this section). This classification helps align each stakeholder group with the specific functions they fulfil in the project, from end-user engagement and technology development to policy influence and early-stage validation.

The major AgRimate stakeholders are further analysed in Table 3, where several aspects related to how the proposed solution affects their work are presented. These aspects are summarised below:

1. **Stakeholder Group:** This column identifies the specific group or type of actor involved in the AgRimate environment (e.g., farmers, technology providers, policymakers, etc.).
2. **Motivation and Goals:** A brief summary of what drives each stakeholder group—their main interests, needs, and objectives in relation to the AgRimate project.
3. **Expected Benefits:** An explanation of how the AgRimate project can support or enhance the stakeholder's goals, highlighting the potential value or improvements they may gain.
4. **Priority Level:** This section evaluates how much attention the project should give to each stakeholder group, based on two criteria:
 - **Influence:** The stakeholder's ability to affect project decisions, support its implementation, or create obstacles (rated as high, medium, or low).
 - **Importance:** The degree to which the stakeholder's needs and expectations should be prioritized, as perceived by the person providing the input (rated as high, medium, or low).
5. **Stakeholder Relationships:** Describes the nature of the interactions and connections between different stakeholder groups—whether they collaborate, depend on each other, or have conflicting interests.

Specifically, related to the two use cases, both olive pruning and vineyard pruning, the following stakeholder typology has been identified:

Stakeholder group	Definition & Motivation & goals	Benefits from solution	Influence (H/M/L)	Importance (H/M/L)	Relation to other ST
Farm owners	The owner of the company and responsible for strategic decision-making. Regarding pruning they make strategic decisions about when and how to prune to maximize yield and maintain tree health. This company may or may not be member of a cooperative.	Gaining access to advanced, easy-to-use technologies that improve the quality and efficiency of daily agricultural tasks.	H	H	-Field supervisors -Agricultural workers -Farming communities -Cooperative members -Pilot Partners - Investors and financiers -NGOs
Field supervisors	Responsible for coordinating and supervising the daily activities of workers in the field. A field supervisor plays a vital role in ensuring that farming operations are carried out efficiently and safely, contributing to the overall success of the farming enterprise.	Ensure that workers follow best practices in pruning. The training modules and well-being analytics help supervisors support worker development and safety, fostering a more skilled, motivated, and healthier workforce.	M	H	-Farm owners -Agricultural workers -Farming communities -Cooperative members -Pilot Partners
Agricultural workers	This includes labourers, tractor drivers, agricultural workers and pruners who perform the tasks of harvesting and maintaining the crops. Their workload and safety can be impacted by the pruning schedule and techniques used.	Receive real-time visual instructions and training adapted to their skill level, language, and physical abilities. This helps them perform tasks more accurately and safely, even without prior experience.	L	H	-Farm owners -Field supervisors -Farming communities -NGOs

Farming Communities	Organized groups of farmers involved in olive cultivation, managing agricultural production, and influencing sustainability and local socio-economic development.	Gain access to shared, scalable technologies that enhance collective productivity, sustainability, and knowledge exchange. Empower communities to strengthen their economic resilience and collective decision-making, reinforcing their role as key actors in rural development	H	M	-Farm owners -Agricultural workers -Cooperative member -Pilot Partners -Technology developers -Innovative companies -Policy makers -Investors and financiers -NGOs
Cooperative Members	Individual farmers in agricultural cooperatives dedicated to olive cultivation, participating in collective decision-making and sustainable pruning practices.	Gain access to standardized, sustainable pruning practices and shared technological resources that enhance both individual and collective productivity. By contributing to and benefiting from collective knowledge and innovation, cooperative members strengthen the efficiency, ecological impact, and economic resilience of their cooperative.	M	H	- Farm owner -Field supervisor -Agricultural workers -Farming communities -Pilot Partners -NGOs.

Pilot Partners	Entities participating in pilot projects to test and validate AgRimate solutions in real-life environments.	Early access to innovative solutions, improved practices, and valuable insights.	M	H	-Farm owners -Field supervisor -Farming communities -Cooperative member -Technology developers -Innovative companies -Policy makers -Investors and financiers -NGOs
Technology Developers	Creators of robotics, augmented reality tools, exoskeletons, and AI solutions for the AgRimate environment, enhancing efficiency and precision in pruning.	Market opportunities, feedback for improvement, and successful implementation of technologies.	H	M	-Farming communities -Cooperative member -Pilot Partners -Innovative companies -Policy makers -Investors and financiers -NGOs

Innovative Companies	Forward-thinking agricultural businesses in the olive and vineyard sectors, integrating cutting-edge technologies to enhance operations and worker well-being.	Gain early access to cutting-edge agricultural technologies. Shape the development of tools that meet market needs. Enhance their visibility and credibility within the agritech ecosystem, opens up new business opportunities. Foster valuable partnerships and accelerate the path to commercialization.	H	M	-Farming communities -Cooperative member -Pilot Partners -Technology developers -Policy makers -Investors and financiers -NGOs
Policy makers	Entities that establish and supervise agricultural, labour and environmental regulations, such as governments at various levels (regional, national, and European) and regulators. They ensure that pruning practices comply with agricultural, labour and environmental regulations.	Gain valuable insights and tools to support evidence-based agricultural, labour, and environmental policy development. Better understanding about how innovation affects productivity, social inclusion, and environmental outcomes. Enable to design more effective regulations, support programs, and funding mechanisms that foster smart, resilient, and equitable agricultural systems.	H	H	-Farming communities -Cooperative member -Pilot Partners -Technology developers -Innovative companies -Investors and financiers -NGOs

Investors and financiers	Individuals or institutions that provide capital for the operation and expansion of the agricultural company. They are interested in the profitability and sustainability of the company, which can be influenced by effective pruning practices. Their decisions can accelerate or hinder the transition toward smarter and more sustainable farming.	Support a high-impact, innovation-driven initiative that aligns with EU priorities on sustainability, digital transformation, and rural development. Identify a clear path to return on investment through the development of scalable technologies, such as AI, robotics, and AR, for the agricultural sector, which is increasingly in need of modernization.	H	M	-Farm owners -Farming communities -Pilot Partners -Technology developers -Innovative companies -Policy makers -NGOs
NGOs	Groups that can be involved in promoting sustainable agricultural practices, environmental protection and care for workers.	Amplify their impact, access real-world data and success stories, and support the adoption of technologies that empower vulnerable groups such as migrant workers, women, and smallholder farmers.	H	M	-Farm owner -Agricultural workers -Farming communities -Cooperative member -Pilot Partners -Technology developers -Innovative companies -Policy makers -Investors and financiers

Table 3. AgRimate Stakeholders

4 Task Analysis

Task analysis refers to a collection of methods for systematically examining how tasks are performed. It is widely used in human factors, industrial engineering, and UX design to break down activities, understand user goals, and identify the knowledge or skills required. Two different methodologies to task analysis have been had into consideration for AgRimate project: **Cognitive Task Analysis (CTA)** (Crandall & Hoffman, 2013) and **GOMS (Goals, Operators, Methods, Selection Rules)** (Card, Moran & Newell, 1983).

Cognitive Task Analysis (CTA) dives into the mental processes and knowledge requirements underlying task performance. CTA is “*a family of methods for uncovering and representing what people know and how they think*”, extending task analysis into decision-making, reasoning, memory, attention, and other cognitive aspects. In other words, CTA aims to capture the tasks “**that require a lot of cognitive activity from the user**” – the judgments, strategies, and mental steps experts take which may not be directly visible in their physical actions.

GOMS (Goals, Operators, Methods, Selection Rules) is a specialized task analysis technique originating from human computer interaction (HCI) research (Card, Moran & Newell, 1983). It provides a structured way to describe the procedural knowledge a user needs to **operate an interface** and is especially known for **predicting how long tasks will take**. In essence, a GOMS model breaks down a user’s interaction with a system into a series of low-level steps and decisions. It was one of the first formal methods to tie task analysis to quantitative predictions of user performance. GOMS is often used to evaluate and compare interface designs by estimating how efficiently typical tasks can be performed on each.

The **selection of Cognitive Task Analysis (CTA)** as the methodological framework for analysing olive pruning tasks on AgRimate project is grounded in the cognitive complexity and contextual variability inherent to this agricultural practice. Unlike procedural models such as GOMS, which are optimized for structured, repetitive tasks typically involving human-computer interaction, CTA is specifically designed to uncover the **tacit knowledge, decision-making processes, and mental strategies** employed by experts in dynamic environments. Olive pruning involves nuanced judgments—such as determining which branches to cut, when, and how—based on tree morphology, environmental conditions, and long-term cultivation goals. These decisions are not easily observable or reducible to simple action sequences, making **CTA the most suitable approach** for capturing the cognitive demands of the task.

Moreover, **the questionnaire data collected for this study** highlights several dimensions—such as physical and mental fatigue, tool usage, environmental adaptation, and the transmission of expert knowledge—that align closely with CTA’s strengths. Through techniques like critical decision interviews, think-aloud protocols, and concept mapping, CTA enables a rich, qualitative understanding of how experienced pruners navigate uncertainty, apply heuristics, and adapt their strategies across varying contexts. This depth of insight is essential not only for documenting expert performance but also for informing the design of training programs, ergonomic tools (e.g., exoskeletons), and augmented reality systems aimed at supporting novice workers in the field.

Cognitive Task Analysis (CTA) is typically conducted through a structured yet flexible sequence of phases. The process begins with **Context Analysis**, wherein the analyst acquires foundational knowledge of the domain and identifies the specific task or scenario to be examined, often through document review and consultation with **subject matter experts**.

The **Knowledge Acquisition** phase follows, employing techniques such as structured interviews (e.g., Critical Decision Method), think-aloud protocols, and concept mapping to uncover the tacit knowledge and cognitive strategies used by experienced practitioners. In the **Data Analysis** phase, qualitative data are systematically examined to extract key cognitive components, including decision points, cues, goals, and heuristics. These insights are then synthesized during the **Knowledge Representation** phase into formats such as cognitive flow diagrams, decision tables, or mental models, tailored to the study's objectives. Finally, the **Results Validation and Application** phase involves expert review to ensure accuracy and the integration of findings into practical interventions, such as training programs or interface designs, aimed at enhancing task performance and cognitive support.

4.1 Context analysis

The first phase of a Cognitive Task Analysis—**context analysis**—is essential for grounding the study in the realities of the domain and ensuring that subsequent data collection is both relevant and insightful. In the case of olive and vineyard pruning, this phase involves a comprehensive exploration of the agricultural environment, seasonal cycles, pruning objectives, and the socio-technical conditions under which the work is performed. Analysts begin by conducting background research, which may include reviewing agronomic manuals, training materials, and scientific literature on pruning techniques. This is complemented by field visits and informal conversations with practitioners to gain a preliminary understanding of the workflow, tools used, and environmental constraints such as terrain, weather, and plant variability.

Equally important is the identification and engagement of **subject matter experts**—typically experienced pruners—whose insights will shape the focus of the analysis. Through this process, the analyst defines the specific **cognitive aspects** of the task to be examined, such as **decision-making** under uncertainty, adaptation to plant morphology, or the mental strategies used to manage fatigue and optimize efficiency. In the context of olive and vineyard pruning, where expertise is often tacit and context-dependent, this initial phase ensures that the CTA captures not only what workers do, but also how and why they make critical decisions in the field. This foundation is crucial for designing effective elicitation methods in the next phase and for producing representations that reflect the true cognitive demands of the task.

4.1.1 Olive tree pruning

Spain has more than 2.5 million hectares spread across most of its territory, with three autonomous communities covering around 85% of the total area. Andalusia is the autonomous region with the largest olive grove area, with almost 1.7 million hectares.

4.1.1.1 Agricultural Environment and Socio-Technical Conditions

Olive tree pruning has a high demand for labour, usually between December and March. This labour force must have sufficient experience to carry out a job that has enormous consequences, both for the development of the trees and for the farm's economic profitability. Unfortunately, there is not widespread knowledge of the best techniques for carrying out the

task, which, combined with the ageing of the working population in the agricultural sector, makes it even more difficult to find trained workers. There is a need to improve the training of future generations in the use of new technologies.

4.1.1.2 Seasonal Cycles and Pruning Objectives

Pruning olive trees is key to shaping and regenerating the canopy for greater productivity. Pruning techniques vary throughout the tree's life, from the young to the adult stage, affecting everything from root growth to fruit production. The slow maturation process of the Picual olive tree (up to 20 years to reach full development) emphasizes the importance of precise pruning.

Pruning achieves a balance between leaves and wood, keeping the canopy perfectly lit and well-ventilated for good production. In older olive trees, renewal pruning is recommended to remove old wood, balance the leaf-to-wood ratio and allow canopy regeneration in later years.

There is a range of tools used in pruning, mainly depending on the size of the branches. The most commonly used tool is the chainsaw, especially for mature olive groves, due to its high performance. For thinner branches, usually less than 5 cm wide, handsaws or shears are used, some of which are pneumatic or electric to make the work easier. The use of heavy tools such as chainsaws and the different working positions required for this type of work are associated with muscle and skeletal problems.

4.1.1.3 Pruning Systems and Pilot Approach

Olive growing has a number of characteristics that make it difficult to homogenize. In first place, it is necessary to differentiate between traditional olive groves and the new intensive or super-intensive olive groves, which have the following planting structures:

- Traditional olive grove. Wide planting frames, 10x10 – 8 x10.
- Intensive olive grove, where the most common planting frames are 7x7 metres, 8x4 metres and 7x5 metres.
- Super-intensive olive grove, with a hedge-like layout and planting frames between 1,500 and 3,000 trees per hectare.

The following pictures show the three types of olive groves:



Figure 1. Traditional olive groves.



Figure 2. Intensive olive groves.



Figure 3. Super-intensive olive groves.

Traditional olive groves, covering around 70% of Spain's olive-growing area, have a number of characteristics that vary from region to region, which generally include the density of trees per hectare, the slope of the plot, its age and whether or not it is irrigated.

In Andalusia, and specifically in Jaén, traditional olive groves consist of low-density olive trees (less than 150-180 trees/ha) and face orographic difficulties due to the slope of the plots. These olive groves were usually established before the beginning of the 21st century, and in recent decades they have been transformed into irrigated groves, although the majority are still non-irrigated (approximately 30% may be irrigated).

Another important factor to consider is the morphology of the trees. Traditional olive groves have generally been characterised by trees with 2 or 3 trunks, or even 4. This factor is extremely important when it comes to pruning.



Figure 4. Olive grove with 3-foot trees.

Although there is no specific data on the ratio of traditional olive groves based on the number of trees, there is a general trend to reduce the number of trees from 3 to 2. This tendency is also related to changes in olive harvesting practices.



Figure 5. Olive grove with 2-foot trees.

Olive trees can be divided into two different phases: young and adult. The difference between these stages is evident, in terms of reproductive capacity (only in the adult phase), rooting potential (greater in the young phase) and morphological differences in leaves and branches.

The Picual olive tree grows slowly and, in optimal conditions, takes between five and ten years to reach its full development. During the first few years, the plant will dedicate most of its energy to developing its root system, which is essential for its subsequent growth and production.

The trunk of the Picual olive tree will gradually become thicker and taller. As the tree grows, the main and secondary branches will start to develop, forming the tree's canopy. The first fruits will start to look visible around the fourth or fifth year, although production will be low compared to later years.

From the seventh year onwards, the Picual olive tree leaves behind its growth phase and starts producing fruit. Between fifteen and twenty years, the trees will have reached their maximum growth and optimal leaf volume per hectare. Regarding the lifetime of the Picual olive tree, it can easily exceed 100 years in full production if properly pruned and managed.



Figure 6. Young stage (formative pruning) 8 years approximately.



Figure 7. Adult stage, in full production (production pruning) 20 years approximately.



Figure 8. Adult stage (50 years approximately).



Figure 9. Adult stage.

It is very difficult to analyse all the different scenarios that can be found in traditional olive groves, so it is necessary to focus on a couple of models that can serve as a basis for the other options. Both are two-foot olive groves, currently the most common traditional olive groves in Jaén.

- CASE 1. The first model consists of a 2-foot olive grove aged between 20 and 50 years, with a moderate slope of less than 20%.
- CASE 2. The second model consists of a 2-foot olive grove aged around 100 years, with a steep slope of more than 20%.

For this purpose, the olive grove pilot project will use the following plots for data collection in each case:

Case 1¹: Description:

- Age of the trees: 40 year
- Planting frame: 8 * 8
- Plot slope: 12%
- Number of feet/tree: 2
- Number of workers on the plot: 2. Other workers will be contacted to expand the results (10-15 workers in total)

Case 2²: Description:

- Age of trees: 100 years
- Planting frame: 8 * 8
- Slope of the plot: 44%
- Number of feet/tree: 2
- Workers on the plot: 2. Other workers will be contacted to expand the results (10-15 workers in total)

¹ <https://maps.app.goo.gl/oBxMqCgNVZfAKyK37>

² <https://maps.app.goo.gl/5W8e2YehTaUWztVd9>

4.1.2 Grape vine pruning

Greece cultivates more than 10,000 hectares of vineyards, a sector that is not only economically significant but also deeply embedded in the country's cultural and agricultural heritage. Viticulture extends across a wide range of agro-climatic zones, with major vineyard areas located in Central Greece, the Peloponnese, and Northern Greece, while Crete and the Aegean Islands also play key roles in the diversity of production. Each region brings its own microclimatic conditions, topographic challenges, and soil types (ranging from limestone to volcanic and alluvial soils), contributing to the remarkable variability in grapevine physiology, training systems, and pruning practices.

Among the most cultivated varieties, Savatiano dominates Central Greece and is the focus of the AgRimate pilot in Spata (Attica). This variety is known for its drought tolerance and is traditionally managed with minimal irrigation and manual interventions, making it ideal for exploring the integration of digital and robotic tools in a real-world, semi-intensive context.

4.1.2.1 Agricultural Environment and Socio-Technical Conditions

The vineyards in the pilot area are situated on gently sloping terrain (0–15%), with a planting frame of 1.5m x 2m, enabling machine access but still requiring high levels of manual work. At the time of the first pilot visit there was considerable debris in the grass between the rows and the grass was long. This situation is realistic of a real-world vineyard. The age of the vines ranges between 20 and 30 years, and annual yields average around 10 tonnes per hectare, depending on the weather conditions and pruning quality. Vineyard management is carried out primarily by small-scale farm owners and cooperative members, with labour provided either by experienced vineyard workers or, in the case of training sessions, by agriculture students under supervision. Note: There were many vines that had not been pruned well in recent years, in the words of the experts, which means that pruning techniques had been inconsistent. This is another real-world challenge to face. The limited availability of trained labour and ageing rural workforce pose critical barriers to ensuring pruning consistency and quality, especially given the narrow seasonal window.

In the AgRimate pilot plot, 4–5 professional pruners can manage the winter pruning operation. However, when educational groups are involved (e.g., student training sessions), the number rises to 10–15 persons, with considerable variation in performance. The time needed to prune a vine ranges between 30 to 60 seconds for an experienced worker and up to 90 seconds for an untrained or novice worker.

4.1.2.2 Seasonal Cycles and Pruning Objectives

Pruning is a foundational task in viticulture, determining vine architecture, fruit quality, and future yield. In Greece, winter pruning is typically conducted from December to March, during vine dormancy. This operation shapes the vegetative-reproductive balance and removes non-productive or damaged wood.



Figure 10. The pruning process.

Pruning in Greek vineyards serves several interconnected objectives:

- To maintain structural form, ensuring sunlight penetration and airflow;
- To manage bud load and prevent overcropping or under-cropping;
- To prepare fruit-bearing canes for the current season and renewal spurs for the next;
- To support long-term vine health and resilience to stress, including drought and disease;
- To reduce labour costs and simplify subsequent operations such as canopy management and harvesting.

Depending on vine age and training needs, pruning is classified into:

- Canopy-formation pruning: Applied during the juvenile phase (first 4–6 years) to establish a productive framework. Occasionally repeated in older vines if re-training is needed.
- Fruit-production pruning: Performed on mature vines annually, focused on maintaining balanced growth and consistent yield.

4.1.2.3 Pruning Systems and Pilot Approach

Across Greek vineyards, three primary training systems are commonly used:

1. Goblet (cup-shaped): Used in dryland, bush-trained vineyards (mostly in Aegean islands);
2. Linear systems, which include:
 1. Royat (cordon spur-pruned);
 2. Guyot (cane-pruned);
3. Pergola system (Krevattina): Used in Northern Greece and some parts of Crete, to avoid sunburn and humidity.

In the AgRimate pilot in Spata, the bilateral Royat with 2-node spurs system is applied to Savatiano vines. In this system:

- A trunk up to 50 cm tall is maintained;
- At its top, two cordons (double Royat) are retained;
- The cordons are bent horizontally along the support wire (in opposite directions);
- Over time, these cordons become woody and function like permanent horizontal structures;
- Short spurs with 2 buds each are maintained along the cordons;

This system offers a good balance between yield potential, canopy control, and suitability for partial mechanisation. It also aligns well with robotic pruning logic, as it involves predictable node placement and clearly defined cane positioning.

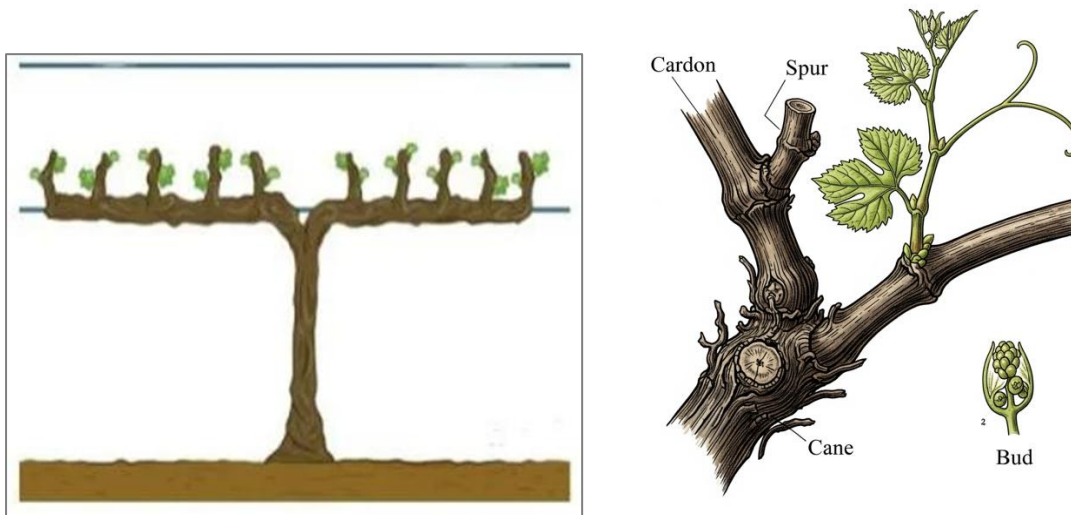


Figure 11. The bilateral Royat system (image taken from: www.agroclica.gr), and the terminology used (image generated by Gemini)



Figure 12. A vineyard formed in lines.

Case 1: AUA-Experimental Vineyard – Spata, Attica

Parameter	Details
Location	Spata, Attica
Vineyard Ownership	Agricultural University of Athens (AUA)
Variety	Savatiano
Vine Age	20–30 years
Planting Frame	1.5m x 2m
Terrain Slope	0–15%
Total Size	~10 hectares
Average Yield	~10 tonnes/hectare
Number of Workers (professionals)	4–5
Number of Workers (students)	10–15
Time per Vine (skilled)	30–60 seconds

This pilot provides a representative case of traditional Greek viticulture where manual precision, biological variability, and knowledge asymmetry (between experts and seasonal workers) are significant. The deployment of AgRimate's AR-based guidance, robotic pruners, and training modules is expected to improve task efficiency, pruning uniformity, and worker safety, while enabling data collection for precision management and long-term vine monitoring.

Case 2: Commercial Vineyard – Spata, Attica (TBA)

While the AUA-owned vineyard described in Case 1 offers a controlled and research-oriented environment, it is important to note that it also serves as an educational and experimental field,

frequently used by students for hands-on learning in viticultural practices, including manual pruning, canopy management, and phenological monitoring. As a result, pruning quality and consistency may vary due to the differing skill levels and training objectives associated with student involvement. This introduces variability that, while valuable for educational purposes, may not be ideal for training or validating machine learning algorithms or robotic models requiring precise and repeatable patterns.

To complement this setting and support more robust technological development, a second case vineyard has been selected in the same viticultural zone in Spata. This is a commercially managed vineyard where pruning is carried out exclusively by experienced fieldworkers, following professional agricultural standards and schedules optimised for yield and grape quality.

The rationale for this second case includes:

- Higher consistency in pruning practices, ideal for robotic data collection and validation;
- Real-world operational conditions, reflecting typical labour constraints and commercial productivity goals;
- Fewer confounding variables, such as student training interruptions or varied tool use;
- Benchmarking AgRimate tools in both experimental and commercial contexts.

Details of this Case 2 vineyard will be provided in the next iteration of the deliverable once field measurements and interviews are completed. However, it will be located across the AUA site, share similar soil and climate conditions, and use the same Savatiano variety under a double Guyot training system.

This dual-site approach enhances the overall robustness of the AgRimate pilot by allowing:

- Comparison of lab-like and field-like pruning environments;
- Validation of AR guidance systems and robotic tools across skill levels;
- Collection of high-quality data from commercial settings for AI model training and pruning automation.

4.2 Expert identification

From among the previously defined stakeholders, a subgroup of them was identified for their expertise in order **to acquire the necessary knowledge** for the task definition and requirements identification processes. These initially identified stakeholders are:

- Farm owners
- Field supervisors
- Agricultural workers
- Farming Communities
- Cooperative Members
- Pilot Partners

These groups were chosen because of their direct contact with the pruning process, their extensive experience and their in-depth knowledge of the different tasks related to pruning.

The rest of the stakeholders identified in section 3.1 Stakeholders' definition will be of interest in later phases of the project.

4.3 Knowledge acquisition

To ensure a correct identification of requirements, it is essential to be able to understand the full context of the use cases.

Within the AgRimate project this knowledge task has been developed in two stages.

In these pilots this process, or context knowledge task has been performed in two times or levels. The first one can be considered as a **high-level or initial approach**. And the second one, a **low level or detailed approximation**.

In addition, the **documentation provided by the pilot partners** has been taken into account. Theoretical pruning guides for each pilot:

- Viticulture Notes (Technological Educational Institute (TEI) of Peloponnese.)
- Vine Training Techniques (Viticulture Laboratory Department of Agriculture University of the Peloponnese)
- Vine Fruit Pruning (Dimitrios G. Tsilianos, Viticulture Laboratory Department of Agriculture University of the Peloponnese)
- Training manual. Olive Pruning. (Instituto Andaluz De Investigación Y Formación Agraria, Pesquera, Alimentaria Y De La Producción Ecológica)

4.3.1 Initial approach: Pilot visits

This initial approach was carried out through the execution of two activities, each one focused on a specific use case. The first was centred on vineyard pruning in Greece, and the second on olive tree pruning in Spain.

Activity 1: Visit to Sparta vineyards (Greece)

The visit took place on February 5–6, 2025, during the Kick-off Meeting. Agenda, Athens, Greece).

During the visit:

- AUA's vineyards were visited, and the pruning process was explained



Figure 13. Sparta region (Greece)

Activity 2: Visit to Sociedad Cooperativa Andaluza San Vicente de Mogón (Jaén, Spain)

The visit took place on March 5, 2025, with a total of 24 attendees, including project partners and representatives from UPA Jaén and olive farmers.



Figure 14. Jaen region (Spain)

The cooperative was founded in 1966 by 100 pioneering members in cooperative work, whose strong beliefs in the agricultural traditions of Jaén are still reflected today in the production process. This is ensured through the Governing Council of the Cooperative, which is composed exclusively of member farmers. This structure has fostered a strong commitment to excellence in the production of Extra Virgin Olive Oil.

During the visit:

- The project concept was explained to all attendees.
- A set of interviews were performed during the day by UBER to some farmers.
- Provision of a live demo of how the pruning process is performed. Details about how the pruning is done were provided.
- Video footage and images about pruning, and olive trees were collected by FBK and TAU.
- The pruning was done wearing the exoskeleton to test it.

These visits laid the foundation for gaining an initial understanding of the terrain and the work carried out in the field, allowing for the design of the next phase of information gathering with a more detailed approach.

4.3.2 Detailed approach: questionnaires and interviews

After an initial approach with the first field visits, it is deemed necessary to get to know in more detail the pruning process in both pilots, i.e. to deepen the actions carried out, the reasons, the working conditions. For this reason, the best way of extracting this knowledge has been sought.

There are different strategies for knowledge acquisition, and their applicability varies depending on the stage of the knowledge-gathering process.

The following illustration provides an overview of the groups of techniques, including the level of prior knowledge required and the knowledge gain they offer based on the outcomes (Luftensteiner et al., 2022).

Although this methodology was originally designed for the industrial sector, it has been reviewed to assess its suitability for the agricultural domain

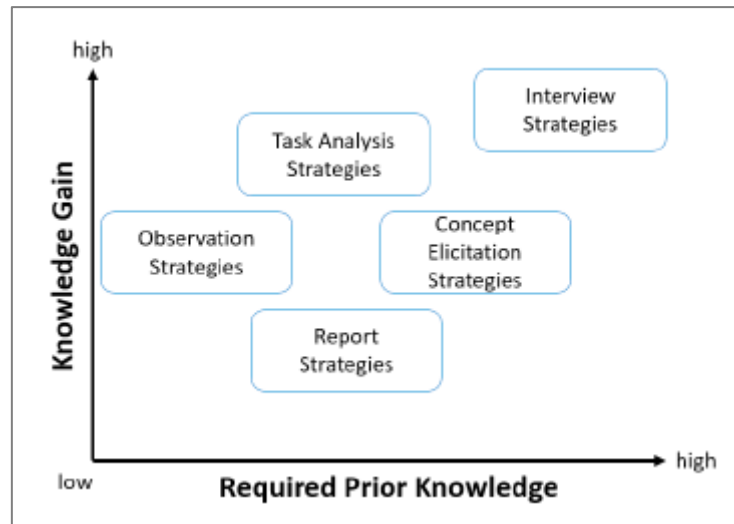


Figure 15. Classification of different knowledge elicitation techniques according to prior knowledge and information gain (Luftensteiner et al., 2022)

Report Strategies: These should be used when there is already a knowledge base that allows focusing on the beneficial parts of the process and providing useful information. They can be verbal or non-verbal.

Observation Strategies: Observation is one of the most powerful tools for gathering knowledge about unknown processes, especially because verbal reports from those involved can vary significantly.

Interview Strategies: This is a frequently used technique for knowledge extraction. Interviews can be conducted directly or indirectly, and the questions asked may be explicit or implicit, depending on the planned structure and the objective of the interview. Generally, they involve a retrospective view of the operators' work, asking them to recall information based on their experience, for example, in machine handling or service missions. Like observation strategies, interviews should also be recorded in written, audio, and/or visual formats.

Interview techniques can be divided into unstructured and structured interviews.

- Unstructured interviews do not follow a predefined structure for the sequence of topics or the content in general. They are considered suitable as a first step in knowledge gathering to obtain a broad overview of the domain and an initial idea of relevant topics.
- Structured interviews follow a predefined format or systematic structure, allowing for more comprehensive knowledge collection. The level of structure defines how the content and sequence of events are organized.

Task Analysis Strategies: These focus more on the behavioural level of a specific task. The emphasis is on what the operator does compared to what they know and reveal. The outcome of these task analysis techniques often involves the assumption of structures or components—such as rules or functions—and their interrelationships.

Concept Elicitation Strategies: At the beginning of conceptual techniques, there is a set of concepts—such as objects or parts of the process—that are central to understanding the domain or task. The idea is to identify this set of concepts and encourage the operator to verbally present their problem-solving domain.

In this project, due to its nature, **interviews were chosen as the primary method, using structured questionnaires**. Those are main reasons why this technique has been chosen

1. In-depth exploration of tacit knowledge:

- Olive tree pruning involves practical knowledge, often undocumented, which experts have acquired through experience.
- Interviews allow for the exploration of this tacit knowledge, which is not usually available in manuals or academic articles.

2. Flexibility and adaptability

- Questions can be adapted in real time according to the expert's responses.
- This enables deeper exploration of relevant topics that arise spontaneously, something not possible with structured surveys.

3. Immediate clarification

- If something is unclear, the expert can be asked to clarify or provide an example.
- This improves the accuracy and understanding of the knowledge gathered.

4. Contextualisation of knowledge

- Experts can explain why they carry out certain practices, when they apply them, and how they vary depending on the context (climate, age of the olive tree, type of cultivation, etc.).
- This allows for capturing not only the “what” but also the “why” and the “how”.

5. Building trust and collaboration

- Face-to-face or even virtual interviews foster a relationship of trust, which may lead the expert to share more detailed and valuable information.
- It also enables the collection of insights into beliefs, values, and attitudes that influence their decisions.

6. Possibility of immediate validation

- Interviewer can check whether is interpreting the expert's input correctly, which reduces the risk of misinterpretation.

The interviewer provides questionnaires with open-ended questions about concepts, values, approaches, and relationships. These interviews involve pre-prepared questions, while maintaining enough flexibility to introduce new questions if necessary or if new relevant factors were identified.

These questionnaires have been designed as follows: Structurally, the questionnaire begins with a section on “Demographic Data”, followed by a second section with “Open Questions” covering the following topics: 'General questions', 'Environment', 'Work organisation', 'Tools used', 'Pruning process', and 'Knowledge acquisition'. And then two sections, one for each technology presented. For each of them, a list of statements was designed, about which the interviewee had to say whether he/she agreed or disagreed, and then a series of open questions.

The questionnaires are available in the annexes section: “Annex A: Questionnaire on olive pruning” and “Annex B: Questionnaire on vineyard pruning for detailed approach”

4.3.2.1 Olive pruning pilot results (Jaén, Spain)

In order to carry out the interviews according to the above-mentioned questionnaires, it was thought that a good option would be to attend the EXPOLIVA2025³ fair that took place on 14-17 May 2025, in “IFEJA Palacio de Ferias y Congresos de Jaén”, the trade fair of the city of Jaen.

Some figures:

14 interviews were conducted, representing the following positions:



Figure 16. Positions of interviewees.

(Other: Pensioner, Student Agricultural Engineer, Technician, Forest firefighter, Technician in Occupational Risk Prevention)

These jobs were not exclusive, as most of them were olive tree owners and workers at the same time, as they were mainly family farms.

In terms of age, the majority were in the 40-49 age group, but there was representation from university students to retirees.

³ <https://expoliva.com/expoliva25/>

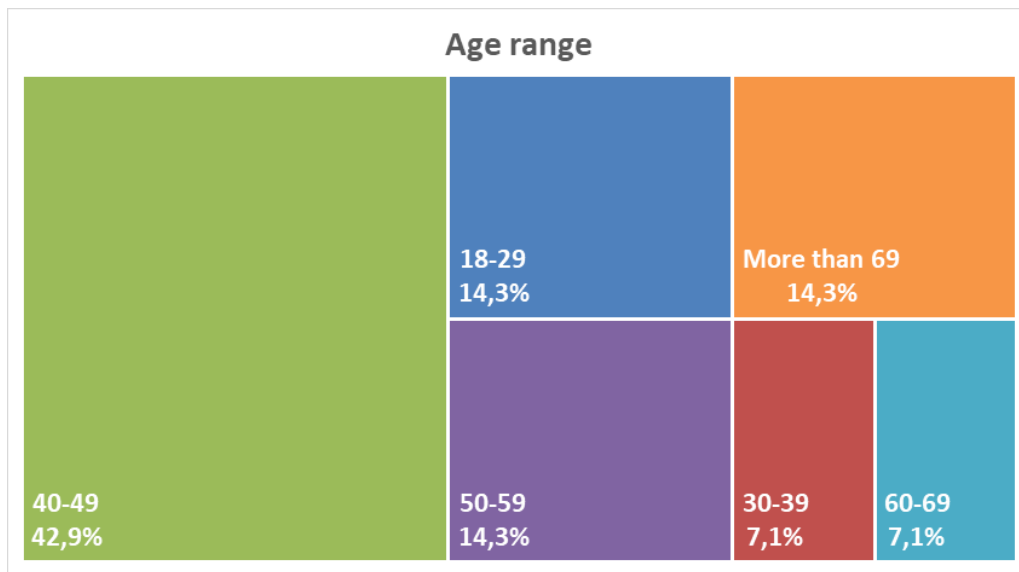


Figure 17. Age range of interviewees.

Reaching between them a high number of years of experience:

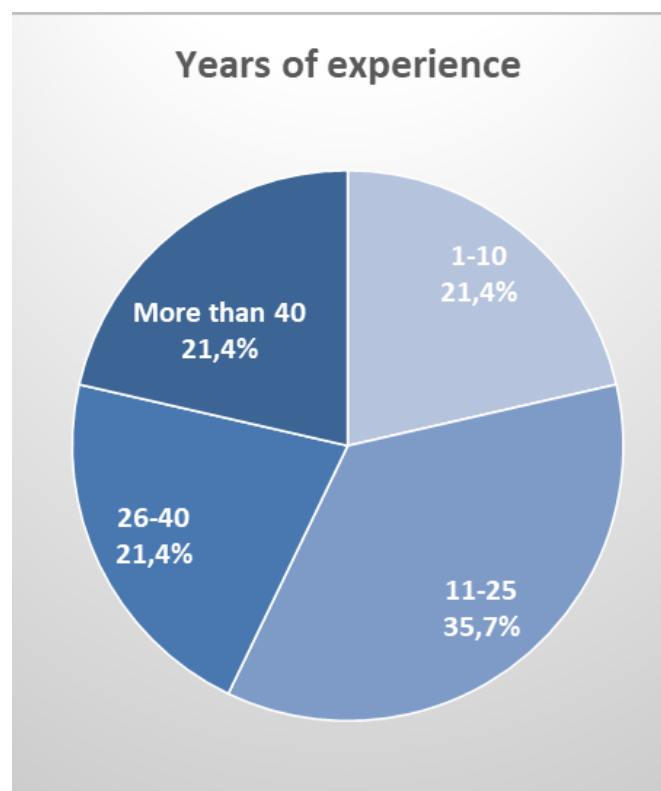


Figure 18. Years of experience of interviewees.

Regarding gender issue, although the majority of the interviewees are male, there is also a considerable representation of the female gender, which is not usually so well represented in jobs in the field:

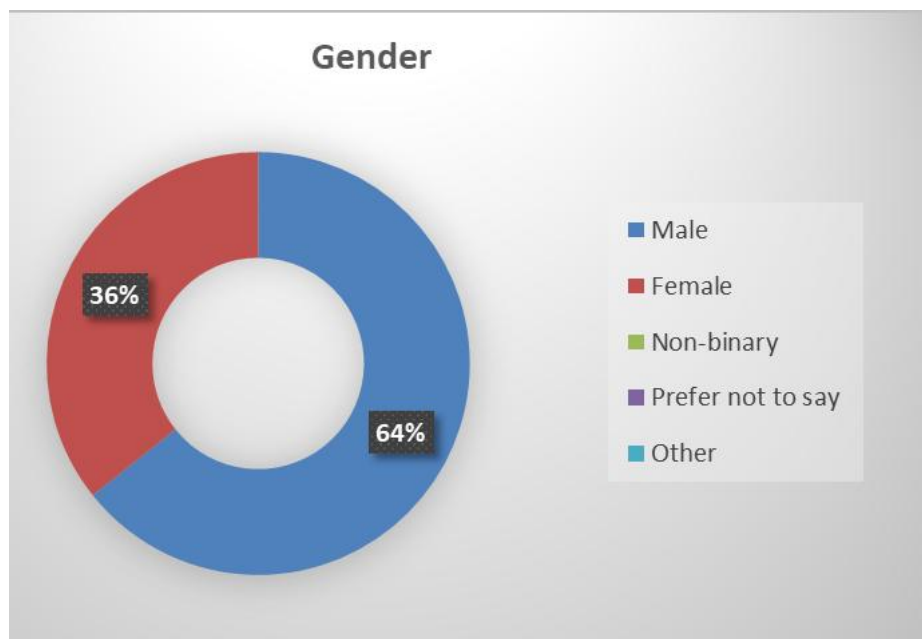


Figure 19. Gender interviewees.

Lessons learned about olive trees pruning process:

After having carried out the interviews, very relevant information is available to know more in depth the work of pruning, as follows.

General context:

Most of the interviewees have family-run farms, where they primarily carry out the full cycle of olive cultivation: observing the trees, pruning, spraying, fertilizing, ploughing, phytosanitary treatment (olive tree care), sowing, “desvareado”⁴ de “chupones”⁵, harvesting, cover crop maintenance, encarrar⁶, collection of “ramón”⁷, shredding of “ramon” (putting it in order) ... In addition to all of the above, landowners also handle the economic and commercial management of the farm.

Among all the tasks they perform, the most important ones are pruning and harvesting. Pruning is key because it connects the two main objectives: profitability and improving the land. Harvesting is crucial because its direct results generate economic benefits.

These two main tasks in the field are usually carried out by family members. Pruning requires fewer people than harvesting and is typically done individually or in small groups of two or three. For harvesting, however, it is sometimes necessary to hire additional labour. These are usually seasonal workers from the same town or province and of Spanish origin. However, some interviewees mentioned that they hire workers from Senegal, whom they have known for years and trust

⁴ Desvaterar: Remove shoots or twigs appearing at the base of the trunk and on the main branches.

⁵ Chupón: an unwanted shoot or stem emerging from the trunk or main branches of a tree or shrub.

⁶ Encarrar: Branch gathering

⁷ Ramón: Refers to the part of the plant that is cut off during pruning of the olive tree, such as dry branches and leaves.

When forming these work groups, what is most lacking is 'labour force.' It is difficult to find experienced and qualified workers. In many cases, the available workforce is not sufficient because people are unwilling to work in the fields, as it is hard labour. There are even cases where workers prefer to collect unemployment benefits because it is more worthwhile for them.

It also identifies the need for machinery and technology to help in these hard tasks in the field. And the need to improve the conditions of the Common Agricultural Policy (CAP)⁸, as it imposes guidelines and regulations from Brussels that make the work difficult, for example: you are not allowed to plough, you cannot mix the twigs ("ramón"), you often have to leave it until it rots...

Land:

The terrain used for olive cultivation in the province of Jaén, in Andalusia (Spain), is predominantly hilly or mountainous, although there are also flatter areas, especially in plains and valleys. The mountainous zones and hills are found on land with moderate to steep slopes, particularly in areas such as the Sierra de Cazorla, Sierra Mágina, and Sierra Morena. These terrains make mechanization difficult (with slopes of 40% or more, crawler tractors are required), but they are ideal for olive cultivation, as the olive tree adapts well to poor soils and sloped land.

Working conditions:

The pruning process on the farms of the interviewees is carried out by one person or, at most, two, usually family members.

For this type of work, labourers spend about 70% of their working day walking, covering an average distance of 8 to 15 kilometres and pruning up to 100 trees.

The official working day is set at six and a half hours, starting early in the morning and ending around midday, with scheduled breaks approximately every two hours. On large farms, these conditions are strictly followed, but on smaller farms, working hours can vary—sometimes shorter, sometimes longer—as the rules are not strictly enforced. In reality, the length of the workday depends on the family and the size of the farm, and it can extend up to 10 hours, with breaks taken when it's necessary to refuel the chainsaw used for cutting.

Regarding the weather conditions during the pruning process, temperatures are usually cold, below 10 degrees Celsius, depending on the month it is carried out, typically from January to March. It is worth noting that the main pruning takes place in winter, but there is also a second pruning phase (removal of suckers ("chupones") at ground level), which is done in summer at around 40 degrees Celsius. This is the most common schedule, although it can vary depending on when the harvest ends. Additionally, field maintenance activities may be carried out throughout the year.

Main Aspects of Pruning:

In pruning, the key is to identify the objective, following the rule of the "3 Rs": Reduce (remove the tallest branches), Redistribute (ensure branches are evenly distributed), and Rejuvenate (cut off the oldest parts). It is also important to note that in many cases pruning is done with the type of harvesting to be done in mind. Pruning also differs depending on whether the olive grove is irrigated or rainfed, and whether it is in a shaded area or one exposed to full sun.

The main action is choosing the right branch to cut, but there is no universal consensus—each farmer may follow different criteria. It's important to note that pruning practices can vary from

⁸ https://agriculture.ec.europa.eu/common-agricultural-policy_en

one municipality to another. Within each town, the method tends to be similar due to the similarity of the terrain and the tendency of neighbours to imitate each other.

For pruning to be effective, the temperature in the field should not drop below 4–5°C.

As for tools, the chainsaw is by far the most commonly used. Chainsaws have become lighter over time, going from 6 kg to the current 2–3 kg models. In some cases, for smaller branches or suckers (less than 2–3 cm in diameter), pruning shears are used. Over the past two years, battery-powered electric shears have become increasingly popular due to their ease of use.

The use of machinery and technology is one of the improvements identified by interviewees as a key factor that could help them in their work. Special vehicles are not required to transport these tools. The type of vehicle needed to access the farms is mainly determined by the terrain and the condition of the access roads.

Pruning Process:

Most of the interviewees base their pruning process and the selection of branches to cut on their own experience, usually learned from childhood within their family environment. However, there are also cases where individuals have attended specialized courses.

The actions they carry out during pruning include:

- Analysing the olive tree, often walking around it and observing it from both the inside and outside.
- Deciding on the shape to give the tree, always aiming for airflow and light penetration, while also considering wind exposure.
- Identifying the branch to cut, removing the least productive ones. It is important to avoid sunburn on younger branches.
- Making the cut.
- Collecting the pruned branches, removing them from the tree. These can be arranged in lines (“acordonar”) or in piles.
- Shredding the branches.
- Incorporating the shredded material into the soil if used as ground cover. In the past, branches were burned, but now they are shredded and left on the ground as fertilizer.

The selection of the right branch is based on experience. In most cases, learning first comes through the transmission of knowledge within the family. Later on, in some cases, more structured training is undertaken, such as courses organized by the Junta de Andalucía, UPA, the School of Agricultural Engineering, or IFAPA (Institute of Agricultural and Fisheries Research and Training).

When both steps are taken, people often begin to understand the connection between what their family taught them and the formal knowledge.

As for pruning standards, there is no official one. The Junta de Andalucía provides a pruning manual and other documents, but in practice, as mentioned earlier, everything is based on experience and the specific location of the land.

Worker fatigue can be both physical and mental. Physical fatigue depends on the number of trees pruned, the terrain, etc. Mental fatigue arises during the branch selection process, due to doubts about whether the work is being done correctly. Stress can also occur when working on a piece-rate basis, as wages are tied to the number of trees pruned.

To find out the perception of the effort required in a working day, a direct question was asked about it and these were the responses:

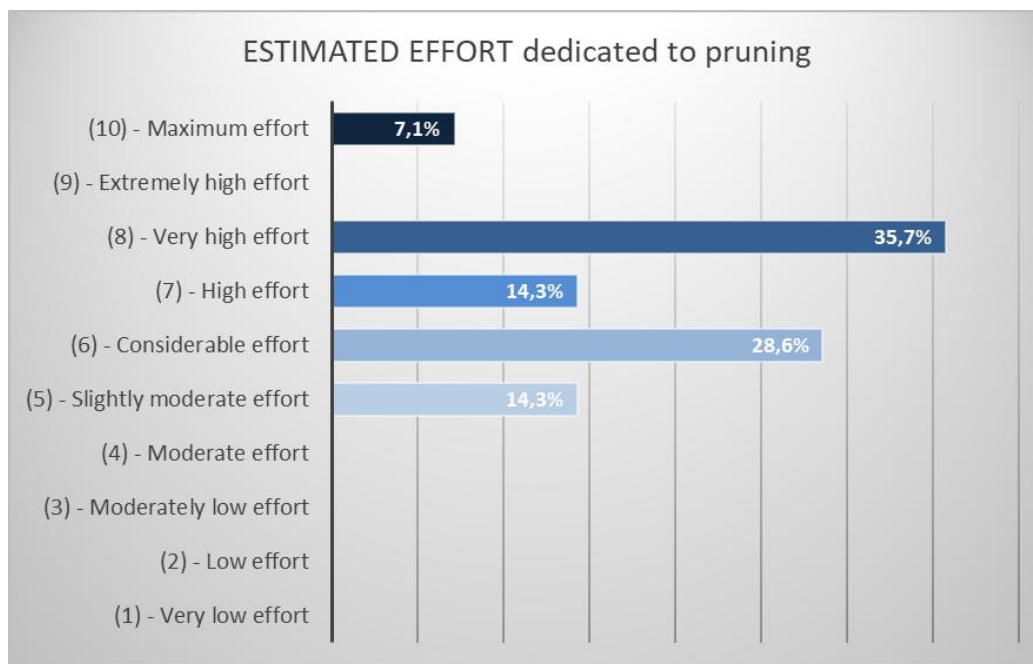


Figure 20. Estimated effort dedicated to pruning.

The chart reflects a general perception that pruning requires a significant amount of effort. Most responses are concentrated in the higher effort categories, indicating that people tend to view pruning as a demanding task. There is also a small group that considers it to be very easy, but these are in the minority.

Perception of the use of exoskeleton technology in olive trees pruning process:

The key benefit identified with the potential use of exoskeletons during pruning is the improvement of physical conditions, as it reduces fatigue by lowering the physical effort required to handle tools.

Unexpectedly, another possible use of the exoskeleton has also been identified: during the olive harvesting process. In this phase, vibrating machines and combs are used to shake the branches. These machines can weigh around 15 kilograms, and the vibration is transmitted to the worker's body.

On the other hand, the potential issues identified with using exoskeletons include their high cost, which is a significant barrier to their daily use, as well as safety concerns in case of falls and possible restrictions on freedom of movement, especially when working inside the tree canopy.

In addition to these general questions, they have been asked specifically about some topics to evaluate a series of concepts explained below:

- **Acceptance.** The willingness of olive pruning workers to integrate the exoskeleton into their daily tasks. It reflects whether they perceive the device as compatible with their routines, beneficial for their work, and worth adopting in the long term.
- **Adaptability.** The exoskeleton's ability to adjust to the specific demands of olive pruning, which often involves irregular terrain, varied tree shapes, and different pruning techniques. It also includes how well it fits different body types and user preferences.

- **Ease of Use.** How simple and intuitive the exoskeleton is to operate in the context of olive pruning. This includes how easily it can be put on and taken off, adjusted in the field, and used without interfering with tools or movement among branches.
- **Reliability.** Consistency of the exoskeleton's performance during olive tree pruning. A reliable device functions correctly and as expected throughout the entire working day.
- **Safety.** The extent to which the exoskeleton protects the user from physical strain or injury during olive pruning, without introducing new risks. This includes ergonomic support for repetitive overhead movements and stability on uneven ground.
- **Trust.** The confidence that workers have in the exoskeleton to support them effectively and safely while pruning olive trees. Trust is built through positive experiences, consistent performance, and the absence of unexpected failures or discomfort.
- **Utility.** The practical usefulness of the exoskeleton in improving the olive pruning process. This includes reducing fatigue, increasing efficiency, and enabling workers to maintain productivity over longer periods with less physical strain.

These concepts have been transparent to the users, without knowing exactly which of them they were being asked about. The way this was done was by means of a series of statements to which the interviewees had to answer with a check mark (from totally disagree to totally agree). Information available in “[Annex C: Categorisation of statements about perceptions of the use of exoskeletons](#)”

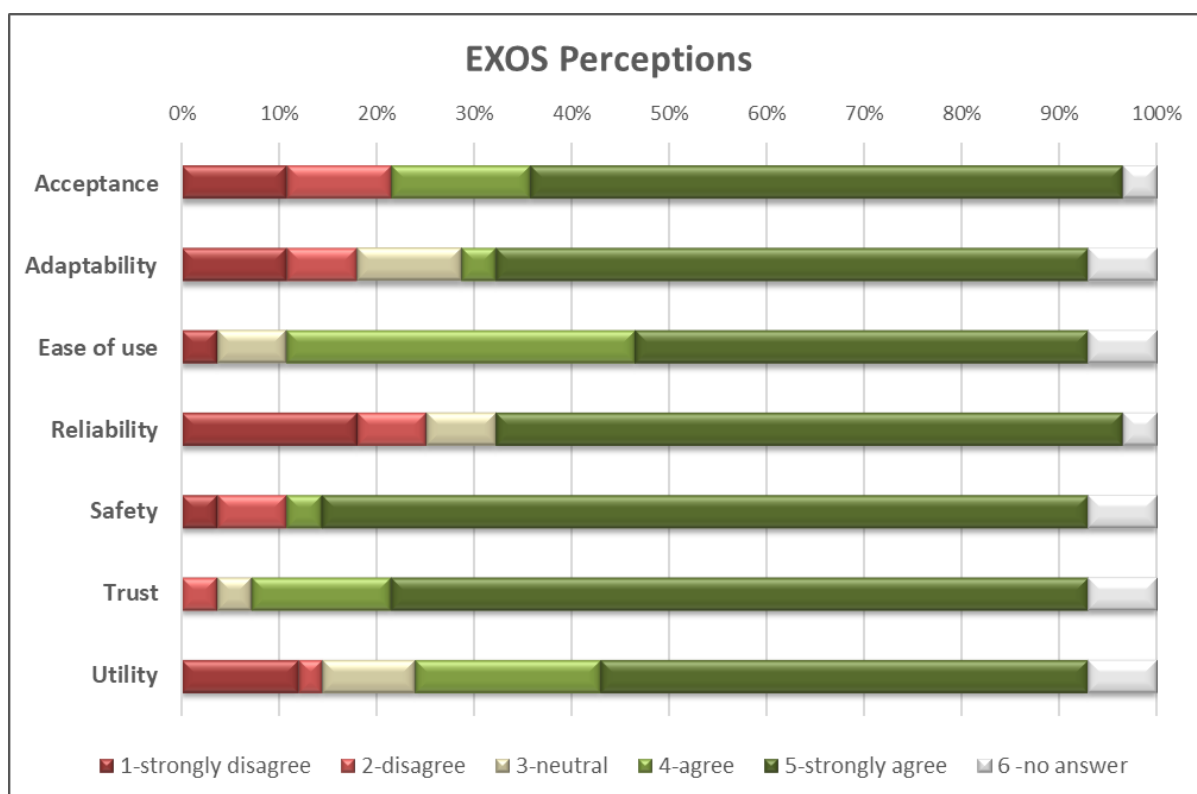


Figure 21. Perceptions of the use of Exoskeletons Technology during the olive tree process.

As a qualitative summary of the results shown in the preview chart, the following ideas can be extracted:

The overall perception of the exoskeleton is generally positive. Most categories, such as **Ease of Use**, **Safety**, and **Trust**, show a strong tendency toward agreement, with many users

selecting either "agree" or "strongly agree." This suggests that users find the exoskeleton beneficial, safe, and practical for their tasks.

The category in which there was the most disagreement, although those related to agreement were clearly higher, was **Reliability**. This data comes from the perception that the use of the exoskeleton could hinder the agility of the worker's movements during pruning.

In summary, users generally view the exoskeleton positively, especially in terms of usefulness, safety, and ease of use, though there is room for improvement in perceived reliability.

Perception of the use of Augmented Reality technology in olive trees pruning process:

The use of this technology has received both positive and negative feedback. On the positive side, it can help reduce errors. On the negative side, experienced workers often do not see its usefulness in their daily routines. However, both groups agree that AR technology could be very beneficial for training purposes, especially for those with little or no experience who want to learn.

When it comes to the preferred device for using AR, smart glasses are clearly favoured. Mobile phones and tablets are strongly rejected due to their impracticality and lack of agility during pruning tasks.

The benefits of AR are seen in the long term, particularly in training and education. However, potential issues include dust, sawdust, sweat, and glare, which could affect the usability of the devices. It's also important to note the lack of generational replacement in the agricultural workforce, and older workers may be more resistant to adopting new technologies.

A key point to highlight is that if there is a disagreement between the pruner's judgment and the AR system's suggestion on which branch to cut, the pruner's personal decision, based on their experience and criteria, will always take precedence.

Beyond the general questions, participants were also asked to reflect on specific topics in order to assess a set of key concepts described below:

- **Acceptance**: Measures the openness and willingness of users to adopt AR technology in their daily work. It includes preferences for comfort, clarity of system feedback, and the perceived feasibility of using AR devices during active pruning tasks.
- **Adaptability**: Refers to the system's ability to be customized to individual user needs and physical characteristics. This includes visual adjustments and ergonomic design features that ensure comfort and usability across different users.
- **Ease of Use**: Describes how intuitive and simple the AR technology is to operate. It includes how easily users can learn to handle the device and understand its functions without needing extensive training or technical knowledge.
- **Reliability**: Describes the consistency and dependability of AR technology in supporting pruning tasks. It includes the system's ability to provide accurate guidance, assist in training, and improve task precision without failure.
- **Safety**: Captures users' concerns about potential hazards or discomforts associated with using AR devices during pruning. This includes physical risks, operational errors, and the need for breaks to avoid fatigue or strain.
- **Trust**: Reflects the confidence users have in the AR system's recommendations and its ability to communicate information clearly. It also includes the willingness to rely on the system even when its suggestions differ from the user's own judgment.

- **Utility:** Refers to the perceived usefulness and practical benefits of AR technology in supporting pruning tasks. This includes how well the technology enhances productivity, task performance, and overall work efficiency, whether used through glasses or mobile devices.

Participants were not explicitly informed about the specific concepts being evaluated. Instead, their perceptions were gathered indirectly through a series of statements, to which they responded using a scale ranging from 'strongly disagree' to 'strongly agree'. The detailed information is available in “Annex D: Categorisation of statements about perceptions of the use of Augmented Reality Technology in olive tree and vineyard pruning”

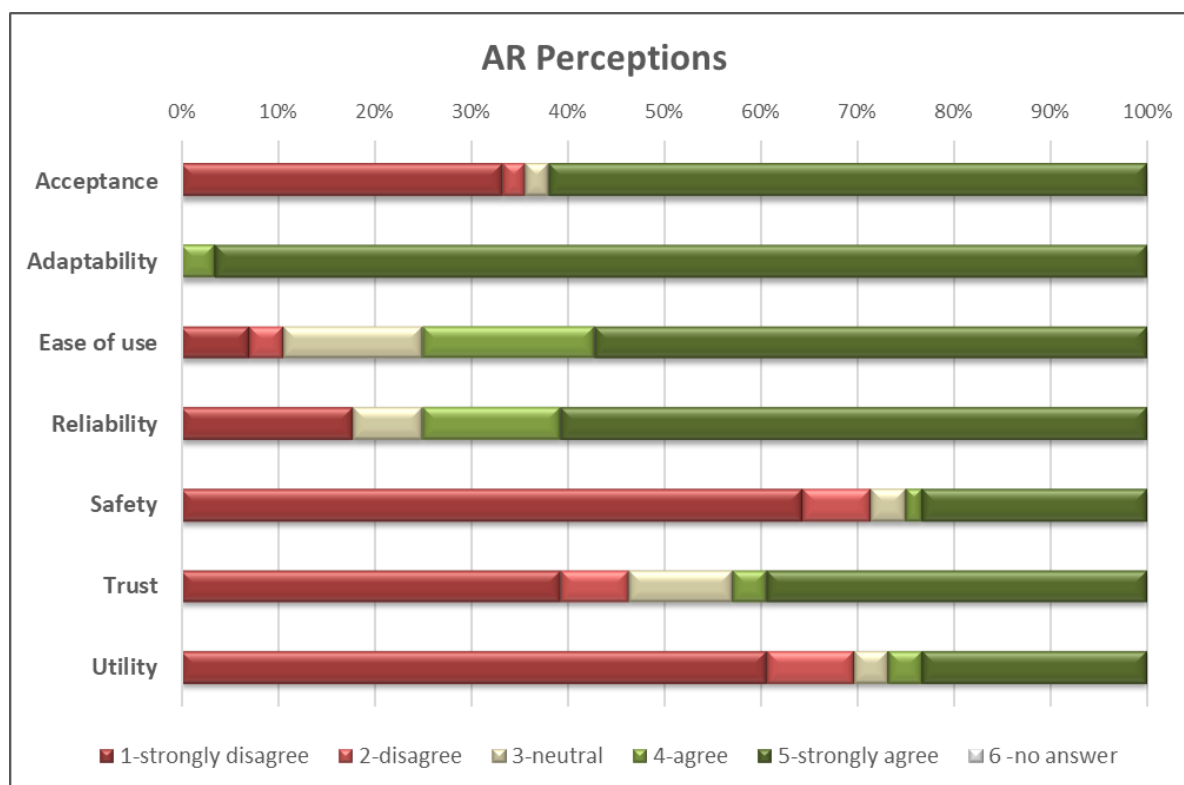


Figure 22. Perceptions of the use of Augmented Reality Technology during the olive tree process.

Based on the survey results shown in the "AR Perceptions" chart and the categorization of the associated statements, we can observe the categories of **Adaptability**, **Ease of Use** continue to stand out with a strong concentration of responses in the "agree" and "strongly agree" segments. This indicates that users generally recognize the value of AR technology in supporting their training process, find it easy to learn and operate, and appreciate its ability to adapt to their visual and ergonomic needs.

The category of **Safety** reveals the most critical stance. A considerable share of responses is negative, indicating ongoing concerns about the potential risks of using AR glasses or mobile devices during pruning. These concerns may relate to physical discomfort, distraction, or the need for breaks during extended use.

In terms of **Utility**, the clear negative result is given by the majority rejection of the use of mobile devices (phone and tablet) compared to the use of glasses, which are considered to support their task, clearly seeing their potential as training on the job for olive tree pruning.

4.3.2.2 Vineyard pruning pilot results (Spata, Greece)

We conducted a series of interviews with individuals we regularly collaborate with. Most of the interviews took place in person, either locally or at their location, as the respondents are part of our working network, while some interviews were held over the phone due to distance. In a few cases, we first had an introductory discussion to explain the purpose and scope of our inquiry, after which, at their request, we sent them the questionnaires by email. They reviewed and completed the forms independently before returning them with their responses.

Some figures:

8 interviews were conducted, representing the following positions:



Figure 23. Positions of interviewees.

Other: Researcher; Advisor of Agronomy, precision agriculture/viticulture; Advisor of Viticulture, Clonal/Varietal Selection; Owner of a vineyard nursery)

Most of the interviewees were owners of a vineyard, but as the jobs were not exclusive, some of them had other positions at the same time as advisor, researcher, etc.

In terms of age, the majority were in the 30-39 age group, and none were older than 69.

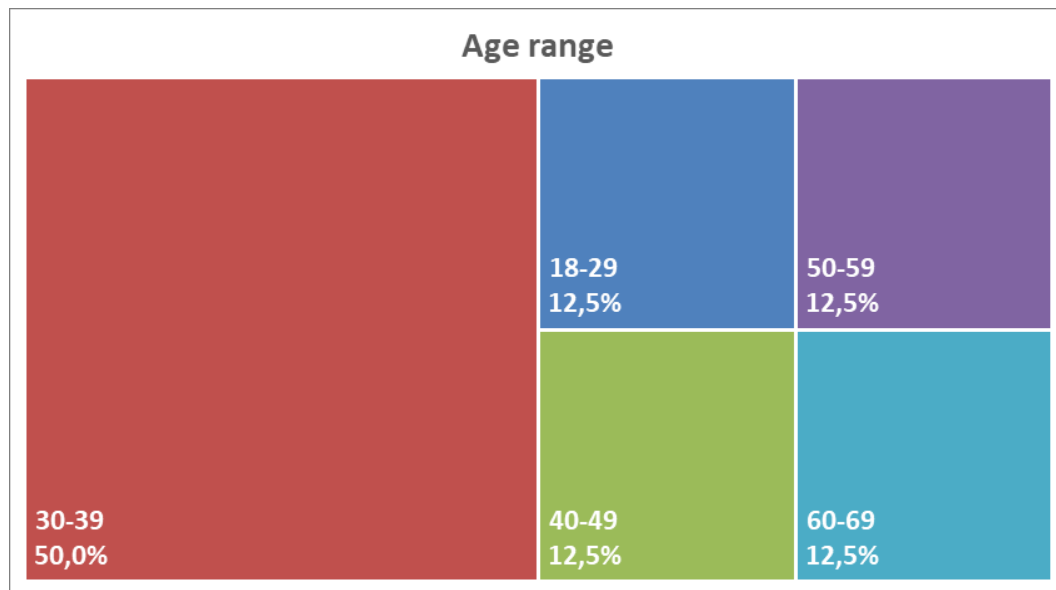


Figure 24. Age range of interviewees.

Reaching between them a high number of years of experience:

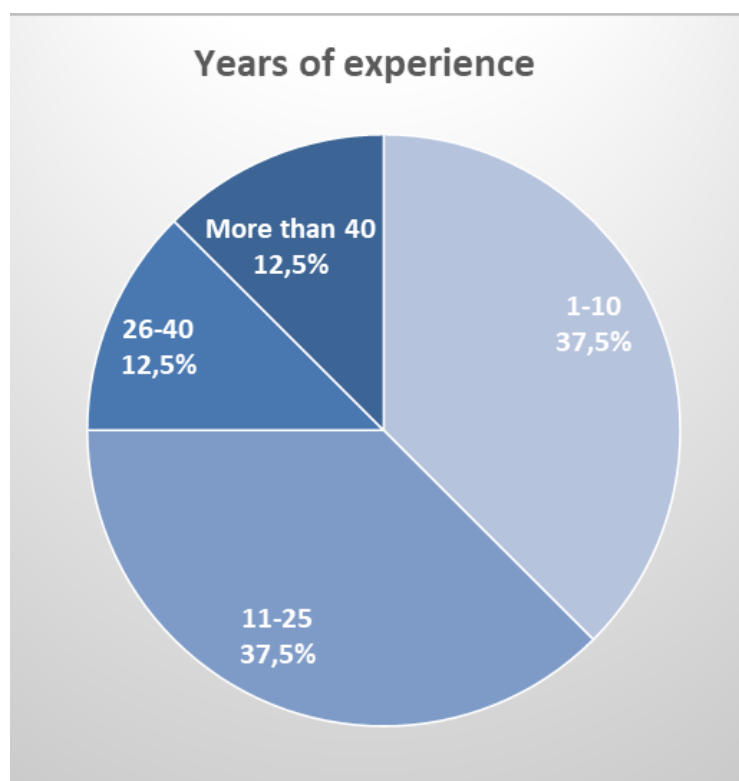


Figure 25. Years of experience of interviewees.

Regarding gender issue, although the majority of the interviewees are male, there is also a representation of the female gender, which is not usually so well represented in jobs in the field:

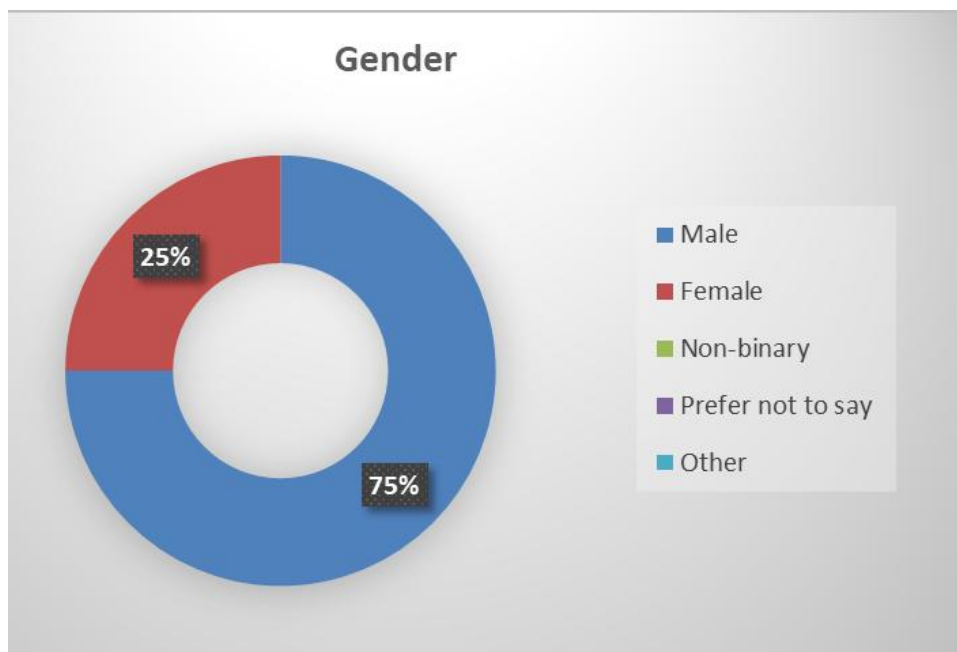


Figure 26. Gender interviewees.

Lessons learned about vineyards pruning process:

After having carried out the interviews, very relevant information is available to know more in depth the work of pruning, as follows.

General context:

The individuals interviewed play a key role in vineyard management, both in academic and family-run settings. Some supervise experimental vineyards at universities, organizing daily tasks and coordinating seasonal workers during activities like pruning and harvesting. Others manage small family vineyards where they not only grow grapes for winemaking but also advise fellow growers on improving their agricultural practices, focusing on soil health, pest control, and precision farming techniques to boost yield and quality. Additionally, some run traditional nurseries that produce certified, disease-free grapevine plants, ensuring new vineyards start with high-quality material.

There are also those who oversee the entire production process in family wineries, from vineyard care to winemaking and sales, including promoting wine tourism. These individuals carry out essential farming practices such as pruning, fertilizing, and pest management, ensuring that every stage of grape growing and wine production is done properly, whether on small plots or larger estates.

Several key vineyard management tasks that require careful attention and planning has been identified. One of the most critical aspects is timing—certain operations, such as preventive crop protection spraying (e.g., with copper or sulphur) and harvesting, must be carried out within strict time windows. Harvesting, in particular, is described as the most intensive period of the year, demanding meticulous organization to ensure everything is completed on time.

Pruning is universally regarded as a fundamental practice—without proper pruning, there are no grapes. Interviewees also emphasized the importance of soil health management, weed control, and the precise planning of agricultural inputs. Some also work on the selection of certified, disease-free propagation material, advising growers on the best clones and varieties to ensure productive, resilient, and long-lasting vineyards.

In summary, the most valued actions across the interviews are pruning, timely execution of critical tasks such as spraying and harvesting, sustainable soil and weed management, and careful planning of field inputs. All these practices aim to ensure healthy vines, high-quality grape production, and the long-term sustainability of viticultural businesses.

Land:

The vineyards described by the interviewees are mostly flat, with some areas featuring gentle slopes and, in a few cases, steeper inclines that require more careful planning and effort. Flat terrain generally makes vineyard work more manageable, while sloped areas, especially in larger estates, can increase the physical demands of tasks like pruning. *Note: There were also areas mentioned that were soft, unstable, not uniform, (note: such terrain could be challenging for the stability of the robotic platform)*

During pruning days, workers typically walk between 2 and 8 kilometres per day, depending on the size of the vineyard and the terrain. Some estimate their movement in steps, ranging from 5,000 to as many as 50,000 steps daily, reflecting the physically intensive nature of the work. On average, pruning involves 4 to 6 hours of walking per day, with walking making up a significant portion, sometimes up to 80%, of the workday.

Working conditions:

It is important to highlight the essential role of seasonal workers in vineyard operations, particularly during labour-intensive periods such as pruning and harvesting. While some vineyard owners manage most tasks themselves or with a small family team, they rely on additional help when the workload increases, especially in autumn during the harvest. Most seasonal workers come from Albania, but also from Pakistan, India, and other parts of Eastern Europe and the Balkans. These workers are often organized by community leaders and move from region to region across Greece, following the agricultural calendar. In smaller, family-run businesses, seasonal workers are valued for their skills in tasks like grafting and fieldwork, and they form a crucial part of the workforce during peak times.

There is a clear need for more manpower, particularly skilled and trained workers for critical tasks such as pruning, grafting, and applying phytosanitary standards. Seasonal labour is essential, but there is a shortage of available and adequately trained workers, especially in semi-rural areas. Many also emphasized the importance of better training for seasonal workers to improve efficiency and quality.

In addition to human resources, several respondents highlighted the need for advanced tools and technologies. These include ergonomic and lighter equipment, precision agriculture tools like sensors and decision-support systems, and machinery capable of handling large-scale operations. Some also mentioned the potential of emerging technologies, such as spraying drones, which could significantly reduce workload, though current regulations in Greece limit their use. Also, a few interviewees noted the need for more breaks and personalized technical guidance, reflecting the physical and mental demands of vineyard work.

Regarding weather conditions during pruning, they can vary, but it is generally carried out in the cooler months, typically in winter. Interviewees agree that pruning is done in cool, damp, foggy, or windy conditions, but they avoid working in extreme weather such as heavy rain, snow, or strong winds. In some areas, like Spata, wind is common, especially in the afternoon. On sloped terrain, wind exposure can be an added challenge. Dry and sunny days are also mentioned, though they are less frequent. Overall, pruning is performed under a wide range of conditions, as long as the weather does not pose a safety risk.

And if the timetable is studied, pruning is typically done in the morning, starting between 6:00 and 9:00 a.m., and usually continues until noon or early afternoon, depending on the location and workload. Daily pruning sessions range from 4 to 8 hours, with 6 to 7 hours per day being the most common. Regarding breaks, most interviewees mention taking two breaks, usually one in the mid-morning and another for lunch, which can last around 40 to 45 minutes. In some cases, breaks are more flexible and taken “as needed” or every 2-3 hours.

Main Aspects of Pruning:

Interviewees identified several key challenges related to pruning. One of the most common issues is the difficulty in finding workers, especially for small plots, where labourers often prefer more profitable jobs. Technical challenges include making the correct cuts to ensure optimal yield and quality, and adapting pruning techniques to the specific physiological traits of each grape variety.

Other major concerns involve weather conditions, which significantly impact planning and execution, and managing physical fatigue, particularly on sloped terrain or when working with large, inexperienced teams. In nurseries, maintaining strict hygiene protocols, selecting the right plant material, and preserving genetic integrity are also critical. Overall, pruning requires precision, physical endurance, and effective coordination of labour and timing.

Focused on the calendar, most interviewees confirmed that there is an established pruning schedule, though it is often adapted each year based on specific seasonal conditions. Pruning typically takes place in January or February, aligning with the dormancy period of the vines. However, adjustments are made depending on factors such as weather, labour availability, and the physiological state of the plant (e.g., when “the sap starts to flow”).

In mother plantations or nurseries, pruning follows a strict schedule to ensure disease control and the health of propagation material. Some also organize pruning by block, starting with younger vines and progressing through the estate based on dormancy and workforce logistics. One exception mentioned pruning starting as early as September, though without a fixed schedule, depending on weather and labour conditions.

Pruning is carried out through a combination of solo work and team support. Some interviewees mentioned that they mainly prune alone, while others are supported by family members (such as brothers, fathers, or uncles) or seasonal workers. In nurseries or larger operations, pruning is done with the help of a core team, trusted seasonal labourers, and migrant workers. Overall, support during pruning comes from a mix of family, permanent staff, seasonal labour, and even neighbouring farmers, depending on the size of the vineyard and available resources.

Most interviewees learned how to prune through family-based training, passed down from parents, grandparents, or other experienced farmers, often informal and unstructured. Hands-on fieldwork and direct observation played a key role in developing their skills. Some complemented this traditional foundation with academic education, including university studies or PhDs in precision agriculture or viticulture, as well as scientific collaboration with research institutes. Other sources of learning mentioned include agronomists, equipment manuals, and mentorship from experienced growers. In short, pruning knowledge is primarily passed down through tradition, but it is also enriched by technical and scientific training.

Regarding tool used, primarily manual pruning shears (cutters) for pruning tasks. Some also use electric pruning shears and small hand saws, especially for more demanding work or in larger vineyards. In nurseries, in addition to shears, they use grafting knives and sanitation materials such as alcohol and disinfectants to maintain plant hygiene.

To make pruning easier and more efficient, interviewees primarily emphasized the need for better tools, especially those that are more ergonomic, precise, and suitable for sloped vineyards. Warmer gear helps too. There is also interest in practical technologies, such as autonomous robots, digital decision-support systems, and tools for plant traceability and monitoring.

The pruning tools used are not bulky, and their weight is suitable for daily use, although prolonged use can lead to fatigue, especially if the tools are not ergonomically designed or with very cold weather. Pruning shears weigh between 200 and 800 grams, depending on whether they are manual or electric. Small saws can weigh up to 1 or 1.5 kg, and battery-powered tools may reach around 2 kg. So, no special transport is required.

Pruning Process:

The pruning process begins with a visual inspection of each vine, assessing its structure, health, and specific needs based on the variety. After this evaluation, the next step is to remove old, diseased, or unproductive wood, and to select the canes or spurs that will bear fruit in the upcoming season.

Cuts are made precisely, considering the training system (e.g., Guyot, Cordon, Goblet), the vine's vigour, and the balance between vegetative and reproductive growth. In nurseries, the process is even more meticulous, using sanitized tools and tracking each plant by clone and variety to ensure traceability and plant health. Finally, the area is cleaned up, and a final check is done to ensure uniformity and quality.

Process step by step:

- Visually inspect each vine.
- Assess the vine's structure, health, and vigour.
- Remove old, diseased, or unproductive wood.
- Select fruiting canes or spurs based on the training system.
- Make precise cuts to guide future growth.
- Adjust the number of buds per cane/spur according to vigour and variety.
- Sanitize tools (especially in nurseries).
- Clean up pruning debris from the field.
- Perform a final check to ensure uniformity and balance.

Interviewees agree that several key aspects must be considered during the pruning process. Among the most important are the age and vigour of the vine, as well as its overall health. Choosing the right timing is also essential, considering weather conditions and worker availability.

Other critical factors include disease prevention, optimal bud placement, and maintaining a balance between yield and vine health. In nurseries or with specific varieties like Agiorgitiko, it is important to follow certification standards and ensure genetic purity. Additionally, the slope of the land and planning the pruning route across vineyard blocks can impact the efficiency of the task.

Decision-making combines tradition, direct observation of the vineyard, and, in some cases, technical and commercial criteria. Decisions related to pruning are primarily based on accumulated experience, both personal and passed down through generations of grape growers. In addition to experience, factors such as the condition of the vines, the timing of pruning (especially during dormancy), weather conditions, and vineyard-specific practices are

also considered. In more technical settings, such as nurseries, decisions are also guided by certification standards, phytosanitary status, clonal characteristics, and market demand.

There is no universal manual or single standard for pruning, although there are established methods considered “proper,” often based on experience and the training system chosen early in the vine’s life, which typically remains consistent over time and pruning practices are adapted depending on the grape variety, region, and weather conditions. In nurseries, strict certification protocols are followed according to Greek and EU regulations. Others also adhere to organic or biodynamic principles, tailoring their approach to each block and variety.

And finally, to understand how workers perceive the level of effort involved in a typical workday, a direct question was posed, and the following were their responses:

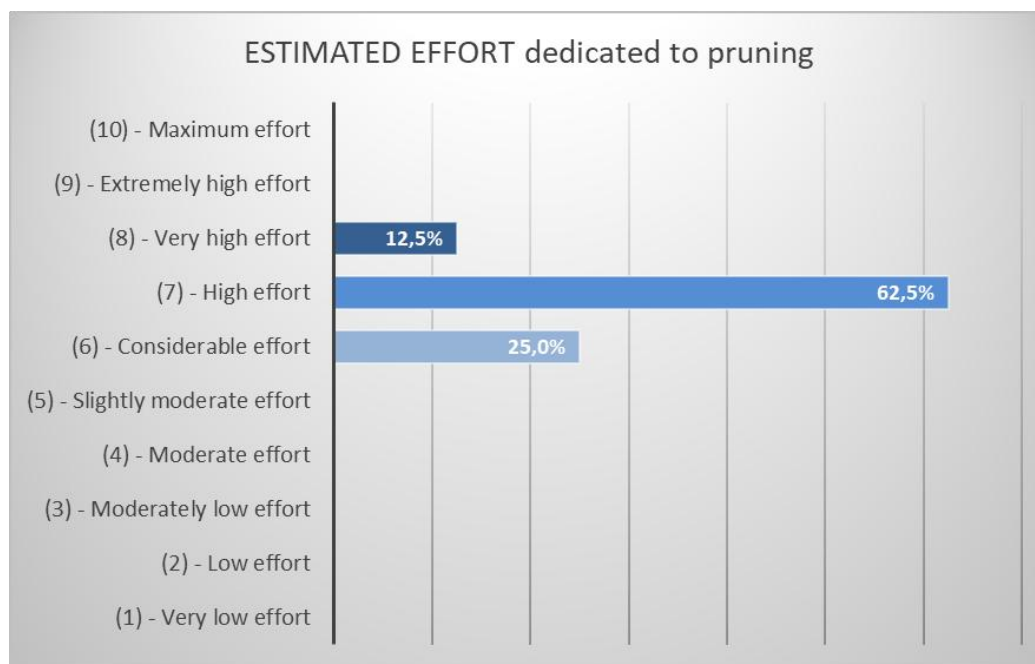


Figure 27. Estimated effort dedicated to pruning.

The chart indicates that most interviewees perceive vineyard pruning as a task that demands a high level of physical effort. Most responses fall within levels 6 and 7, corresponding to “considerable effort” and “high effort,” respectively. Additionally, one person rated it as an 8, indicating a very high effort. This trend suggests that pruning is widely regarded as a demanding activity, both physically and in terms of the focus and precision it requires.

Pruning and other vineyard tasks cause significant fatigue, both physical and mental. Physical fatigue is mainly linked to demanding postures (such as working close to the ground), repetitive movements, and muscle strain in the arms, back, and legs, especially on sloped terrain. Mental fatigue stems from the constant need to make precise decisions for each vine, maintain focus under challenging weather conditions, and, in nurseries, ensure traceability and disease control. Additionally, it is noted that the monotony of working across large fields contributes to mental exhaustion.

Perception of the use of Autonomous robotic pruning platform (ARPP) technology

The key benefit identified with the potential use of ARPP during pruning is the significant reduction in physical strain and fatigue for workers, alongside increased efficiency and speed

in the pruning process. Interviewees also highlighted the potential for improved accuracy, standardisation of cuts, and the ability to manage larger vineyard areas without the need for additional labour. Some also noted the opportunity for better vine management and data-driven insights, particularly if the system proves reliable and adaptable to different vineyard conditions.

On the other hand, the potential issues identified with using ARPP include concerns about high initial costs, ongoing maintenance, sensor calibration, and the robot's ability to navigate complex terrains such as steep slopes or narrow rows. Several interviewees expressed doubts about the system's reliability in early stages, the risk of damaging vines or buds, and the need for training seasonal workers. Adaptability to different pruning techniques and vineyard types, especially in smaller or biodynamic operations, was also seen as a critical factor for successful implementation.

Relating to the communication interface "human-robot", the following question was presented:

Regarding the interface for the monitoring or presentation of information by the ARPP, if the ARPP has to communicate a problem or alert to you, what system would you prefer to use for that communication?

The results of the survey indicate a clear preference among interviewees for receiving alerts from the ARPP via an app with a dashboard-style interface. This method received the highest positive feedback. Audio communication was also generally well received, though with slightly more varied responses, including some neutral opinions. In contrast, the use of lights as a communication method was met with a predominantly neutral stance, suggesting it may be less effective or less preferred for conveying important information.

These findings suggest that a visual, information-rich interface is the most favoured option for user interaction with the ARPP.

In addition to the predefined options, several interviewees suggested alternative communication methods that they would find convenient or effective. These included: Text or email notifications for immediate awareness, email summaries to ensure traceability and record-keeping, and SMS or phone alerts for urgent issues requiring prompt attention (taking into account language issue). These preferences highlight the importance of flexibility and personalisation in communication channels, particularly in field-based contexts such as vineyard management.

In addition to these general questions, the interviewees have been asked specifically about some topics to evaluate a series of concepts explained below:

- Adaptability: Refers to the ARPP's ability to adjust to the user's preferences and respond appropriately to unexpected situations (e.g., falls, rain). It reflects how well the system can adapt to dynamic environments and user-specific needs.
- Ease of Use: Assesses how intuitive and accessible the ARPP is for users. This includes how easy it is to learn to operate and whether its functions are self-explanatory without requiring extensive training.
- Reliability: Measures the user's confidence that the ARPP will operate correctly across various vineyard terrains and conditions. It also includes the usefulness of receiving task reports and the feasibility of setting up supporting infrastructure like ground stations.
- Safety: Relates to the perception that using the ARPP does not pose physical risks to the operator, even in the event of errors or stability issues. It emphasizes the system's ability to prevent harm.

- **Trust:** Concerns the user's sense of control over the ARPP, the belief that it will improve physical well-being during work, and confidence that it will prune accurately without damaging the vines.
- **Utility:** Evaluates the practical value of the ARPP in the pruning process, including its ability to assist the user and enhance productivity.

These concepts have been transparent to the users, without knowing exactly which of them they were being asked about. The way this was done was by means of a series of statements to which the interviewees had to answer with a check mark (from totally disagree to totally agree). Information available in “Annex E: Categorisation of statements about perceptions of the use of Autonomous Robotic Pruning Platform (ARPP) Technology in vineyards pruning”

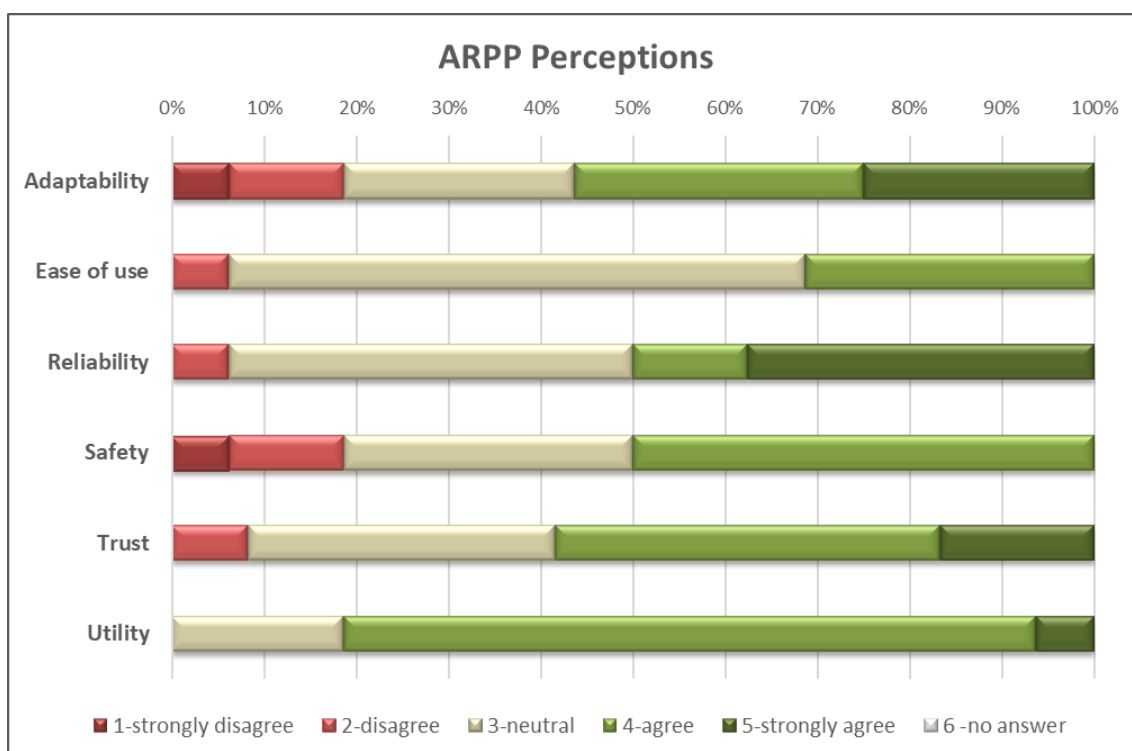


Figure 28. Perceptions of the use of ARPP Technology during the vineyard process.

As a qualitative summary of the results shown in the preview chart, the following ideas can be extracted:

The overall perception of the ARPP is generally positive. Categories such as **Trust** and **Utility**, show a tendency toward agreement, with many users selecting either "agree" or "strongly agree". Respondents highlighted the potential of the robot to assist in pruning tasks, reduce physical strain, and improve overall productivity.

The categories in which there was the most disagreement, although those related to agreement were clearly higher, were **Adaptability** and **Safety**. This data may come from the perception that the ARPP might not respond appropriately to certain situations (such as uneven terrain or adverse weather), and there were also doubts about whether the ARPP could consistently prune accurately without damaging vines, and whether users would feel fully in control of the system.

It is worth noting that there is a high percentage of "neutral" responses, which indicates that the user rates the issues related to the ARPP in a medium range (neither agree nor disagree), especially in the categories of **Ease of use** and **Reliability**.

These insights suggest that while the ARPP is viewed as a valuable tool, its success will depend on building user confidence and ensuring robust, safe performance in real-world conditions.

Perception of the use of Augmented Reality technology in vineyards pruning process:

The key benefit identified with the potential use of AR during pruning is its ability to enhance decision-making, improve training for less experienced workers, and increase the precision and consistency of cuts. Respondents noted that AR could help standardise pruning practices across different vineyard sizes and systems, reduce decision fatigue, and accelerate the learning curve for seasonal workers. Glasses were generally preferred over mobile devices due to their hands-free nature, which allows uninterrupted workflow and better integration into field tasks.

On the other hand, the potential issues identified with using AR include concerns about comfort, weight, glare, and battery life of AR glasses, especially during prolonged use in outdoor conditions. Some participants expressed scepticism about the practicality of using mobile devices while pruning, citing risks of dropping, damage, and interference with manual tools. There were also concerns about training requirements, system errors, and the potential for AR to suggest incorrect actions, which could lead to mistakes or safety hazards. Ensuring usability, adaptability to vineyard conditions, and user acceptance (reliance on the system over personal judgment) were seen as critical for successful implementation.

Beyond the general questions, participants were also asked to reflect on specific topics in order to assess a set of key concepts described below:

- **Acceptance**: Measures the openness and willingness of users to adopt AR technology in their daily work. It includes preferences for comfort, clarity of system feedback, and the perceived feasibility of using AR devices during active pruning tasks.
- **Adaptability**: Refers to the system's ability to be customized to individual user needs and physical characteristics. This includes visual adjustments and ergonomic design features that ensure comfort and usability across different users.
- **Ease of Use**: Describes how intuitive and simple the AR technology is to operate. It includes how easily users can learn to handle the device and understand its functions without needing extensive training or technical knowledge.
- **Reliability**: Describes the consistency and dependability of AR technology in supporting pruning tasks. It includes the system's ability to provide accurate guidance, assist in training, and improve task precision without failure.
- **Safety**: Captures users' concerns about potential hazards or discomforts associated with using AR devices during pruning. This includes physical risks, operational errors, and the need for breaks to avoid fatigue or strain.
- **Trust**: Reflects the confidence users have in the AR system's recommendations and its ability to communicate information clearly. It also includes the willingness to rely on the system even when its suggestions differ from the user's own judgment.
- **Utility**: Refers to the perceived usefulness and practical benefits of AR technology in supporting pruning tasks. This includes how well the technology enhances productivity, task performance, and overall work efficiency, whether used through glasses or mobile devices.

Participants were not explicitly informed about the specific concepts being evaluated. Instead, their perceptions were gathered indirectly through a series of statements, to which they

responded using a scale ranging from 'strongly disagree' to 'strongly agree'. The detailed information is available in “Annex D: Categorisation of statements about perceptions of the use of Augmented Reality Technology in olive tree and vineyard pruning”

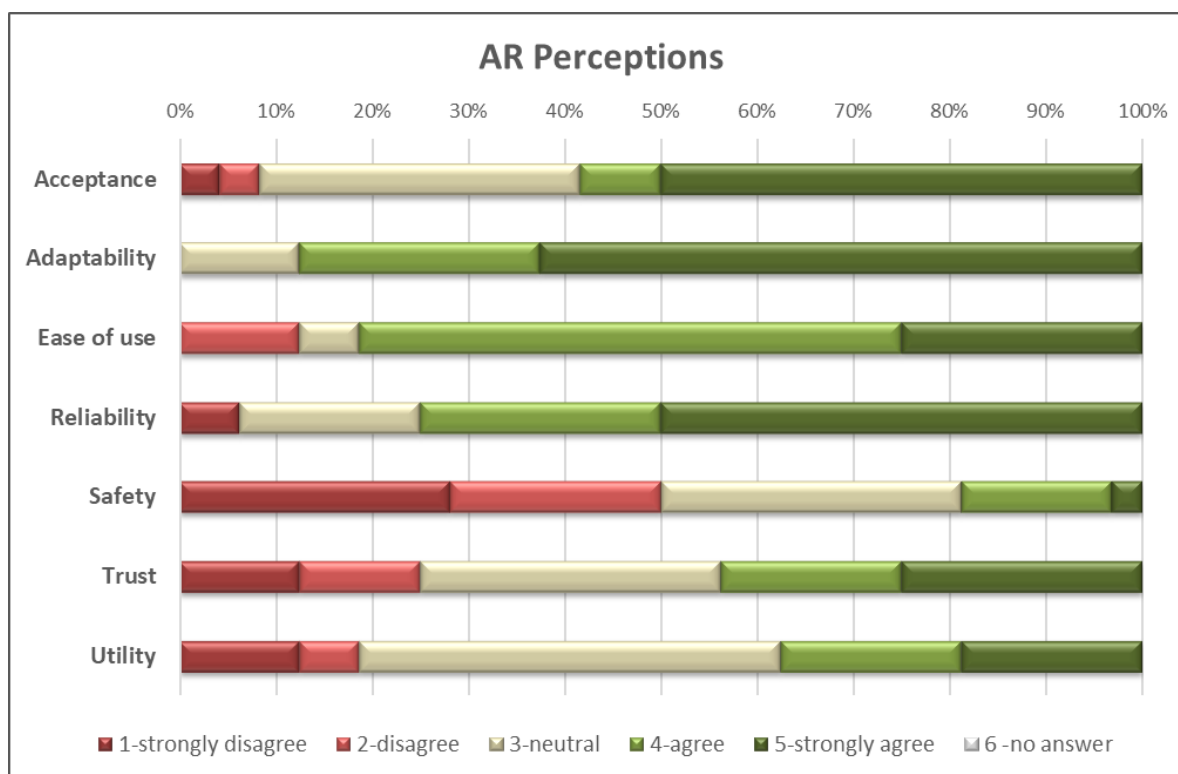


Figure 29. Perceptions of the use of AR Technology during the vineyard process.

Based on the survey results shown in the "AR Perceptions" chart and the categorization of the associated statements, we can observe the categories of **Adaptability**, **Ease of Use** and **Reliability** continue to stand out with a strong concentration of responses in the "agree" and "strongly agree" segments. This indicates that users generally recognise the practical benefits of AR in decision-making and training efficiency, particularly when the system is intuitive and requires minimal technical knowledge and consider AR tools are comfortable and can be tailored to individual needs.

On the other hand, the categories of **Safety** and **Trust** appear to raise more concerns among users. Participants expressed apprehension about physical discomfort, potential hazards during pruning, and the reliability of AR recommendations, especially when they conflict with personal judgement.

These insights suggest that while AR is seen as a promising tool for vineyard tasks, its successful implementation will depend on addressing ergonomic, safety, and trust-related challenges.

4.4 Data Analysis

In this section, we analyse the tasks, decisions, cues, and cognitive strategies used by experts during pruning. We identify key decision points, the cues they use to make decisions, and the strategies they employ to perform the task effectively.

4.4.1 Tasks, decisions, cues and cognitive strategies for Olive tree pruning

Pruning an olive tree is not merely a mechanical task, it is a thoughtful, knowledge-driven process that requires observation, decision-making, and skilled execution. Each step in the process is influenced by environmental, biological, and human factors, and each decision can have long-term consequences for the tree's health and productivity.

The following are the main steps and the keys to carry them out, for pruning the olive tree.

Choosing the Right Moment. The first and perhaps one of the most strategic decisions in olive pruning is determining the optimal time to begin. This is not a fixed date on the calendar but a window that depends on several variables. The type of olive production, whether for table olives or oil, can influence timing, as can the local climate and terrain. Pruning typically takes place after the harvest, during the tree's vegetative dormancy, when it is least vulnerable to stress. In general terms, it can be said that If the olive is harvested as **table olives**, it is usual to prune the tree between November and December. This may vary depending on the weather and ensuring there is no risk of frost. And If the goal is to produce **olive oil**, the pruning period is delayed to February, March, and April. However, sudden changes in weather, especially the risk of frost, can delay or complicate this decision. A pruner must weigh these factors carefully to avoid compromising the tree's recovery and future yield.

Observing and Diagnosing the Tree. Once the timing is right, the pruner must engage in a close and deliberate observation of the tree. This involves walking around and even inside the canopy to assess its structure, vigour, and health. The pruner must identify the tree's age, variety, and any signs of disease or pest infestation. These observations inform the choice of pruning type: formative pruning for young trees to shape their growth. The key at this point is to prevent secondary shoots from growing, which could harm the main shoots in olive production; maintenance pruning for mature trees to sustain productivity. The goal of which is to prolong the life of the olive tree as much as possible; or regenerative pruning for older trees that need revitalization. When the tree is already considered old, it is necessary to remove unproductive branches more frequently, as they multiply as the tree ages. In some older olive trees, it may be necessary to cut several branches in the same pruning, when the most common practice is to cut one branch and wait for it to grow back.

A misdiagnosis at this stage, such as overlooking disease or misjudging the tree's age, can lead to inappropriate cuts and long-term damage.

Defining the Desired Shape. Pruning is as much about what is removed as what is left behind. The pruner must envision the ideal shape of the tree, one that balances productivity with resilience. This shape is influenced by the tree's variety (arbequina, Picual...), the type of harvesting, the local climate (especially wind and sun exposure), and the pruner's own experience. The goal is to create a structure that allows light and air to penetrate the canopy, reducing the risk of disease and promoting even fruit development. A poorly shaped tree may suffer from sunburned branches or become unstable in strong winds. There are two main shapes: "Vase" (open centre), which is popular in traditional systems. And "Central leader", used in high-density or super-intensive systems

Selecting the Branches to Remove. With a clear vision of the desired structure, the pruner must now decide which branches to cut. This is a nuanced task that requires understanding the tree's growth patterns and production goals. The "3 Rs" rule: Reduce, Redistribute, Rejuvenate, guides this process. The pruner removes overly tall or dominant branches (Reduce), ensures an even distribution of remaining branches (Redistribute), and eliminates

old, unproductive wood (Rejuvenate). The age and position of each branch is critical considerations. Mistakes here, such as removing productive branches or leaving diseased ones, can affect not just the current season but the next two harvests.

Choosing the Right Tools. The effectiveness and safety of pruning depend heavily on the tools used. The pruner must select appropriate equipment based on the tree's age, the thickness of the branches, and the terrain. Young trees with thinner branches (less than 3 cm diameter) may require only hand shears or electric pruners, while older trees with thicker limbs may necessitate chainsaws. The condition of the tools is equally important, dull or poorly maintained blades can cause ragged cuts that heal poorly and increase the risk of infection. And Personal protective equipment (PPE) is essential to prevent injuries, especially when using power tools.

Executing the Cut. This is the moment where planning meets action. The pruner must make clean, precise cuts that align with the objectives defined earlier. This involves selecting the correct cutting position, whether to remove a branch entirely, reduce its length, or thin the canopy, and applying the right angle and technique. A well-executed cut promotes rapid healing and minimizes stress to the tree. Conversely, poor technique can result in bark tearing, exposed wounds, and even structural damage. The pruner's experience and attention to detail are critical at this stage.

It is important to emphasise that pruning must be done at the exact point of the branch, as there are different types of cut depending on their location, in order to achieve different objectives.

- **Blind cut:** This is usually the most common and involves completely severing the branch to redirect the sap to the adjacent branch. In other words, this type of cut is performed when you "sacrifice" a branch.
- **Shedding cut:** In this case, the goal is to replace an already old branch with a new one, for which it is necessary to leave a small stump and not cut it completely. This allows the branch to continue receiving sap, allowing it to renew itself.
- **Thinning cut:** This type of cut is performed to reduce the height of a particular branch, but not so much for regeneration purposes.

What is important, in all cases, is to make clean cuts, avoiding tears, as this could affect the quality of the olives and, therefore, the quality of the olive oil.

Evaluating the Outcome. Pruning does not end with the last cut. The pruner must step back and assess the overall result. Has the canopy been opened sufficiently? Are the remaining branches well distributed? Is the tree balanced and structurally sound? This evaluation may lead to additional adjustments, especially if the initial cuts did not achieve the desired effect. Failure to properly assess the outcome can lead to reduced tree health, increased workload in future seasons, and diminished yields. That is the reason why additional cuts may be needed to fine-tune the structure.

Managing the Pruned Material. Finally, the removed branches must be collected and processed. This is not just a matter of tidiness, it has implications for pest control, soil health, and labour efficiency. Branches can be shredded and used as mulch, contributing organic matter back to the soil. Alternatively, they may be burned or removed, depending on local regulations and available equipment. The use of qualified personnel is important here, as improper handling of tools or machinery can lead to injuries or inefficient work.

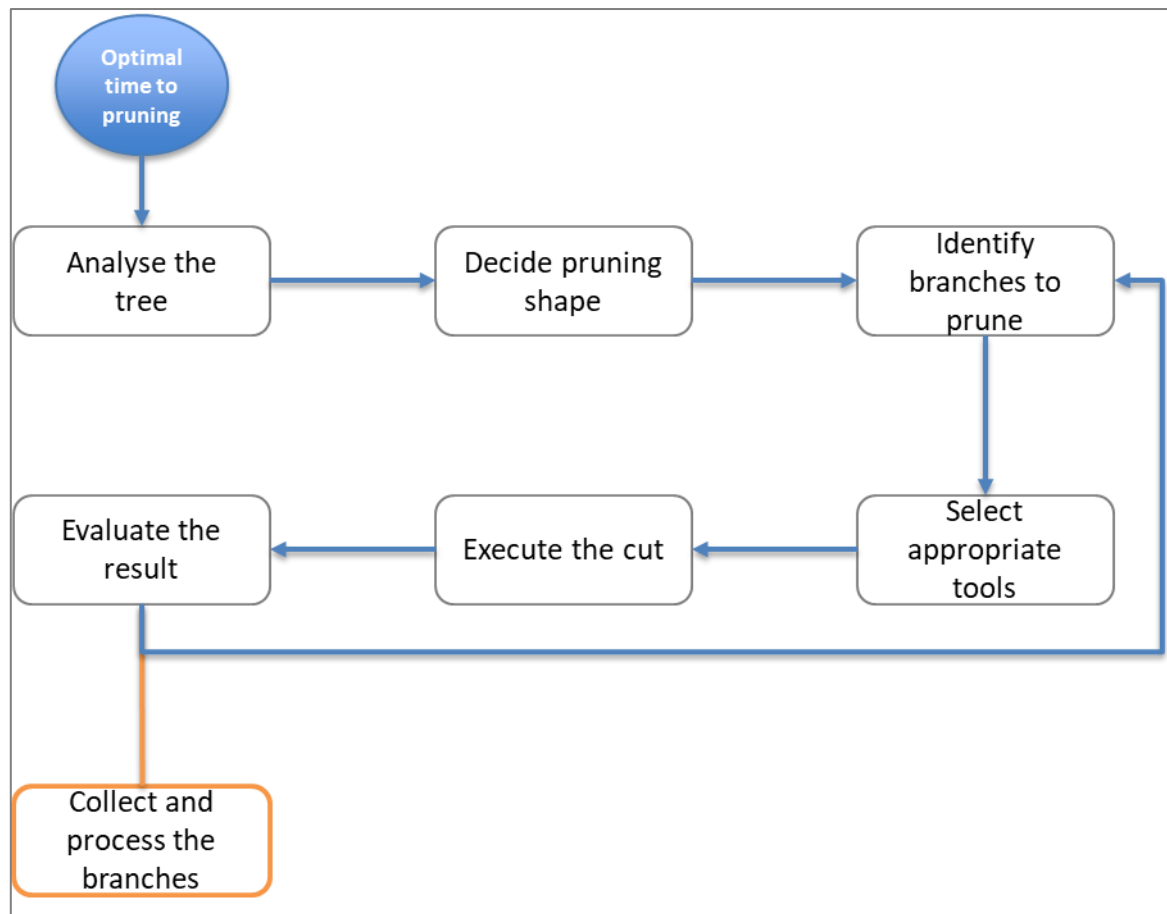


Figure 30. Olive tree pruning process flowchart.

This description captures the complexity and craftsmanship involved in olive pruning. It is a process that blends observation, decision-making, and manual skill, all guided by a deep understanding of the tree and its environment. The following section attempts to compile all this information in table format.

Pruning tasks	Subtasks	Contributing factors /cues	Key decision points and alternatives	Common risks
Select the optimal time to pruning	- Decision-making on the appropriate time for pruning	• Type of production (table olives/ olive oil) • Climate • Weather conditions • Terrain (sunny or shadow; flat or slope)	Start pruning after harvesting the fruit (period of "vegetative dormancy")	• Change of weather conditions (risk of frost)
Analyse the tree	- Observation of the tree (around and inside) - Identify tree characteristics - Select type of pruning	• Type of olive tree • Tree's structure • Age of the tree • Health of tree	Select type of pruning: - <u>Formative pruning</u> (young trees) - <u>Maintenance pruning</u>, focuses on sustaining (mature trees) - <u>Regenerative pruning</u> to enhance productivity and health (old trees)	• Incorrect evaluation • Ignoring signs of disease
Decide pruning shape	- Identify the factors that affect - Determine the shape the tree should have	• Variety (Picual, Arbequina...) • Type of harvesting • Weather conditions (wind, sun) • Pruner's experience and knowledge	Ensure: - Ventilation - Light - Prevention of young branches from burning out	• Not considering strong wind or sun • Burning out possibility

Pruning tasks	Subtasks	Contributing factors /cues	Key decision points and alternatives	Common risks
Identify branches to prune	- Identify the objective ("3Rs", etc.) - Selecting branches to cut - Determining the extent of pruning	• Agronomic criteria: - Type of pruning (formative, maintenance, regeneration) - Age of branches - Position of branch - Tree health - Production goals • Pruner's experience and knowledge • Geographical area or municipality	Rule of the "3 Rs": - <u>Reduce</u> (remove the highest branches) - <u>Redistribute</u> (ensure branches are evenly distributed) and - <u>Rejuvenate</u> (remove the oldest parts). Age of tree: - <u>Young trees</u>: prevent secondary shoots from growing. - <u>Mature trees</u>: branches older than 3-4 years should be removed - <u>Old trees</u>: This pruning can be the most aggressive (more unproductive branches in the same pruning).	• Incorrect branch selection can have repercussions on the next two harvests. • Not considering production goals
Select appropriate tools	- Select tools and EPI for pruning - Determine the appropriate maintenance of tools	• Tools availability • Status of the tools • Safety (EPI) • Age of the tree • Branch size and thickness • Pruning type • Terrain (vehicles for tools transportation)	Age of tree: - <u>Young trees</u>: Pruning shears, Electric shears, saws, chainsaws. - <u>Mature/Old trees</u>: Chainsaws. Branch size and thickness: - <u>Thicker branches</u>: Chainsaws. - <u>Thinner</u> (younger growth, less than 3cm thick): Pruning shears, Electric shears.	• Inadequate or poorly maintained tools • Not making clean cuts • Damage to the tree • Personal injuries

Pruning tasks	Subtasks	Contributing factors /cues	Key decision points and alternatives	Common risks
Execute the cut	- Remove the appropriate branches based on the objectives	• Tool status • Safety (EPI and tool) • Pruner's experience and knowledge (precision and quality of the cut)	Select appropriate cutting position (Blind, Shedding, Thinning). Select cutting angle and accuracy.	• Damage to the tree for using no appropriated techniques (Ragged cuts that don't heal well, bark stripping or tearing) • Increase risk of the worker injury
Evaluate the result	- Verify pruning effect - Make necessary adjustments	• Tree health • Pruner's experience and knowledge	Identify pruning adjustments needs	• Reduce tree health • Impacts on future harvests • Increase workload for the pruner
Collect and process the branches	- Collect the branches - Shred and chop the branches - Incorporating them into the soil as mulch	• Existing Regulations • Available tools and machinery	Arrange the branches in a line (cordoning off) or in a pile. Use shredded branches as ground cover or not. Select qualified or unqualified personnel for task execution	• Cut branches are not used and may rot. • No appropriate tools or machinery available • Increase worker injury for unqualified personnel

Table 4. Cognitive task analysis on olive tree pruning summarize.

4.4.2 Tasks, decisions, cues and cognitive strategies for grape vine pruning

Pruning grapevines is a complex and knowledge-intensive task that goes far beyond simply cutting branches. It requires a deep understanding of the vine's biology, the production goals, and the environmental context. Each decision made during pruning has a direct impact on the vine's health, fruit quality, and long-term productivity. The process involves a sequence of cognitive tasks, each influenced by specific cues and requiring careful judgment.

Selecting the Optimal Time for Pruning. Choosing the right moment to prune is a strategic decision that sets the tone for the entire vineyard management cycle. This choice hinges on whether to perform winter pruning, during the vine's dormancy in January or February, or summer pruning, also known as green pruning. Factors such as grape variety, climate, sap flow dynamics, terrain, canopy structure and labour availability influence pruning decisions. Winter pruning is the primary method used to establish vine structure and prepare the vines for the vine growth, while summer pruning is employed to improve canopy microclimate, and balance vegetative/generative growth. However, mistiming this step can disrupt vine growth, making it essential to adapt to seasonal conditions and anticipate labour constraints. In nurseries, pruning follows stricter schedules to ensure plant health and certification standards.

Planning the Pruning Route. Once the timing is defined, the next step is to plan the pruning route across the vineyard. This involves organizing the work by blocks, considering vine age, dormancy stage, terrain because in sloped vineyards physical demands increase, and logistical aspects such as labour availability and weather forecasts. Typically, younger vines or those that enter dormancy earlier are prioritized. A well-structured plan reduces physical strain on workers and improves efficiency, while poor planning can lead to delays, fatigue, and inconsistent pruning quality.

Analysing the Vine. Before making any cuts, the pruner must carefully analyse each vine. This includes observing its structure, vigour, age, and health, as well as identifying the pruning system in use, such as Guyot or Royat. The previous year's growth and the slope of the terrain also play a role in this assessment. This diagnostic step is critical, as it informs the pruning strategy and ensures that the vine's shape and productivity are maintained. Misjudging the vine's condition or pruning system can lead to inappropriate cuts and long-term damage. In nurseries, this step is even more meticulous, involving clone identification and strict hygiene protocols to preserve genetic integrity and plant health.

Choosing the Pruning Method. The pruning method must be selected based on the vine's characteristics and production goals. The two main approaches are spur pruning (used in the Royat system) and cane pruning (used in the Guyot system). Spur pruning involves leaving short spurs with one or two buds, while cane pruning retains longer canes with multiple buds. The choice depends on the grape variety, terrain, and desired yield. In some cases, a mixed method may be appropriate. Some growers also adapt their pruning method based on organic or biodynamic principles, or to meet certification standards in nurseries. Selecting the wrong method can compromise vine performance and fruit quality.

Identifying Canes or Spurs to Prune. This step requires a detailed evaluation of the vine's canes or spurs to determine which ones are most fruitful. The pruner must assess latent bud fertility, cane thickness, node count, and overall vine vigour. Buds are typically located at leaf axils, and their fertility can vary by variety (for example, Sultanina), show higher fertility from the base to the middle of the cane. In Guyot pruning, one or two canes with 6–10 buds are left, while Royat pruning retains 2–3 spurs with 2 buds each. Mistakes here can significantly

reduce yield. It is important to balance between vegetative and reproductive growth, especially in varieties like Agiorgitiko, where precision is key to maintaining quality and yield.

Selecting and Maintaining Tools. Tool selection is essential for both efficiency and safety. Depending on cane thickness, vine age, terrain slope, and ergonomic needs, pruners may use manual or electric shears, or saws for thicker wood. In nurseries, tool hygiene is especially important to prevent disease transmission. Poorly maintained or inappropriate tools can lead to fatigue, injury, and inefficient cuts, all of which compromise the quality of the pruning and the health of the vine. High ergonomic and lightweight tools requirements, especially for sloped terrain.

Executing the Cut. Executing the cut is where planning meets action. Before the main pruning, unproductive canes are removed to clean up the vine. Cuts must be clean and angled, made just above the last bud, and adapted to the vine's vigour and training system. The direction of sap flow must be considered to promote healing and prevent disease. Poor cutting techniques can result in bark tearing, exposed wounds, and reduced regrowth, making precision and experience essential at this stage.

Evaluating the Pruning Result. After pruning, the vine must be evaluated to ensure that the desired structure and balance have been achieved. This includes checking for symmetry, proper bud distribution, and alignment with the training system. If the result is not satisfactory, adjustments may be necessary. This final check is especially important in nurseries to ensure uniformity and compliance with certification standards. Unbalanced pruning can negatively affect vine health, reduce yield, and increase the need for corrective actions in future seasons.

Collecting and Disposing of Pruned Material. The final step involves managing the pruned material. Depending on local regulations and vineyard hygiene protocols, canes may be shredded for mulching or removed entirely to avoid pest buildup from the field. Terrain accessibility can influence the disposal method chosen. In nurseries, strict sanitation is required to prevent the spread of pests and diseases. Proper disposal not only maintains cleanliness but also contributes to soil health and reduces the risk of future infestations.

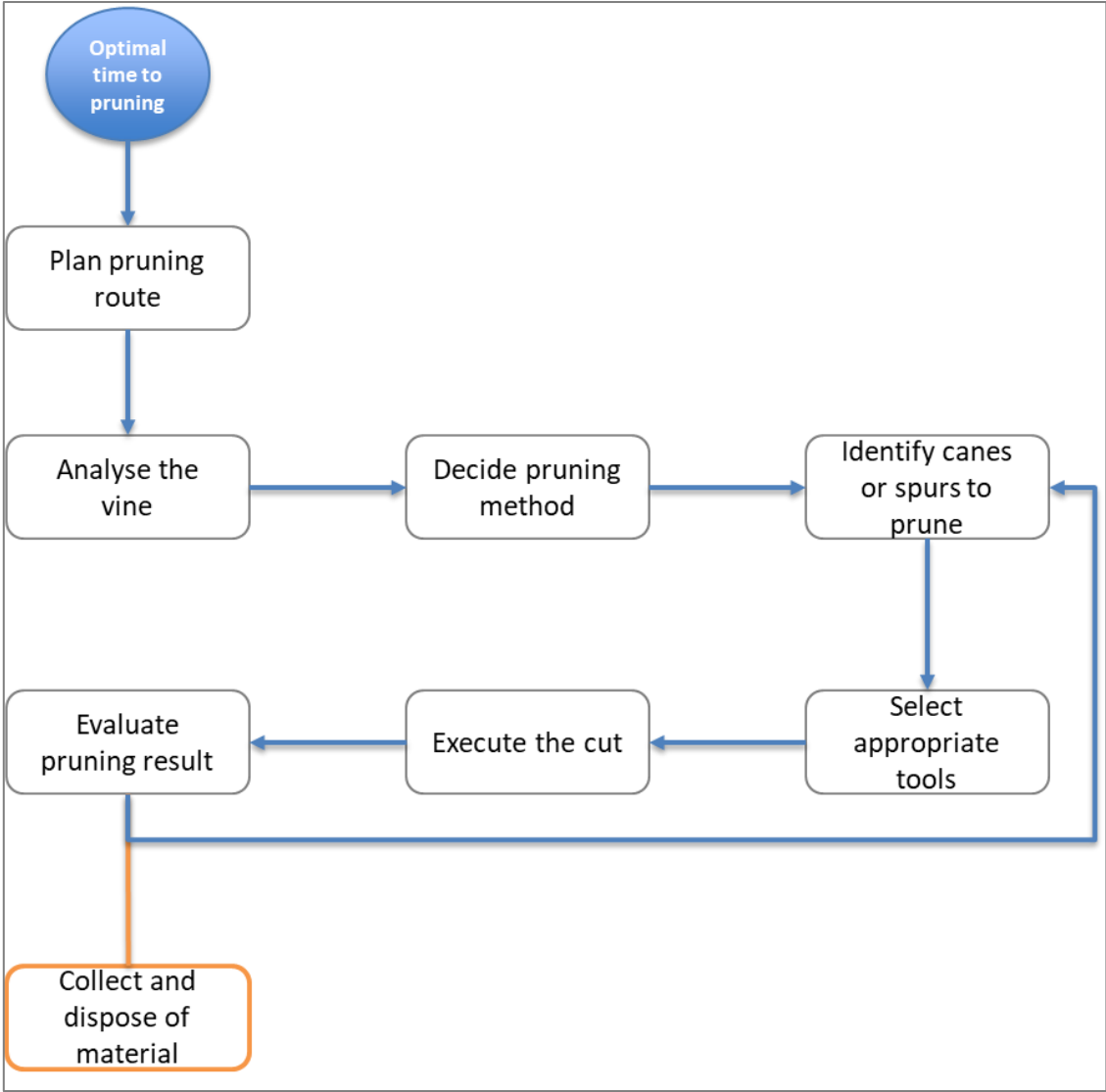


Figure 31. Vineyard pruning process flowchart.

This overview reflects the intricate nature and expertise required in olive pruning. It is a task that combines careful observation, informed choices, and skilled hands, all rooted in a profound knowledge of the vines and its surroundings. The next section presents this information in a structured table format.

Pruning Tasks	Subtasks	Contributing Factors / Cues	Key Decision Points and alternatives	Common Risks
Select optimal time for pruning	- Decide winter or summer pruning	• Vine dormancy • Climate • Grape variety • Labor availability • Sap flow • Terrain • Desired pruning system	Winter pruning (dormant season) vs. summer pruning (green pruning) Adapt to seasonal conditions Pruning stricter schedules in nurseries.	• Pruning too early/late • Weather disruptions • Labor shortages • Failure to achieve quality standards
Plan pruning route	- Organize by block - Vine age - Dormancy stage	• Terrain • Labor logistics • Weather forecast	Start with younger vines or blocks with earlier dormancy	• Poor planning increases time and physical strain • Increase physical demands
Analyse the vine	- Observe vine structure and vigour	• Vine age • Training system • Previous year's growth • Slope • Health status	Identify training system (Guyot, Royat, etc.) Assess vigour and health	• Misidentifying vine condition or training system • Not preserving genetic integrity
Decide pruning method	- Choose between spur or cane pruning	• Variety • Training system • Production goals • Terrain type • Organic or biodynamic principles	Spur pruning (Royat) vs. cane pruning (Guyot) Mixed pruning in some cases	• Inappropriate method for vine type or terrain

Pruning Tasks	Subtasks	Contributing Factors / Cues	Key Decision Points and alternatives	Common Risks
Identify canes or spurs to prune	- Select fruitful canes or spurs - Identify and evaluate latent buds - Evaluate bud position and vine nutrition - Balance between vegetative and reproductive growth	• Cane thickness • Node count • Vine vigour/health • Variety (e.g., Sultanina), • Specific fertility patterns: fertility curve (base to middle of cane) • Buds position: Located at leaf axils	Leave 1–2 canes with 6–10 buds (Guyot), or 2–3 spurs with 2 buds (Royat) Choose canes with optimal bud fertility	• Cutting productive canes or leaving weak ones • Misjudging bud fertility reduces yield
Select appropriate tools	- Choose and maintain tools	• Cane thickness • Vine age • Slope • High ergonomic and lightweight tools requirements • Hygiene needs (nurseries)	Manual vs. electric shears Saws for thick wood Sanitize tools in nurseries	• Fatigue • Injury • Disease spread • Inefficiency
Execute the cut	- Pre-pruning cleanup (remove unproductive canes) - Make clean, angled cuts	• Bud position • Sap flow direction • Tool sharpness	Remove non-productive wood before main pruning Cut above last bud at angle Adjust based on vine vigour and training system	• Poor cuts lead to disease or poor regrowth
Evaluate pruning result	- Check balance and vine shape	• Vine symmetry • Bud distribution • Training system	Adjust to maintain structure and productivity	• Unbalanced pruning affects yield and vine health

Pruning Tasks	Subtasks	Contributing Factors / Cues	Key Decision Points and alternatives	Common Risks
Collect and dispose of material	- Remove or shred canes	• Local regulations • Vineyard hygiene • Terrain accessibility	Use for mulching or remove from field Follow hygiene protocols in nurseries	• Debris can harbour pests or diseases

Table 5. Cognitive task analysis on vineyard pruning summarize.

4.5 Operational challenges of the process

As part of the Cognitive Task Analysis (CTA) conducted for olive and vineyard pruning, a comprehensive examination of expert practices, decision-making processes, and contextual demands was performed. This analysis highlighted both cognitive and physical challenges faced by workers, such as the need for expert judgment in branch selection, adaptation to diverse terrains and tree types, and the use of appropriate tools. Key operational challenges include the absence of standardized procedures, reliance on tacit generational knowledge, and the physical and mental fatigue associated with prolonged pruning activities. The following table summarizes the main challenges identified during the analysis.

Operational Challenge	Description
Lack of Standardization	Pruning practices vary by region and are based on experience rather than formal standards.
Labor Shortage	Difficulty in finding experienced and qualified labour due to physical demands.
Physical Fatigue	Long hours of physically demanding work, especially on hilly terrain.
Mental Fatigue	High cognitive load due to constant decision-making during pruning.
Terrain Challenges	Hilly or mountainous terrain complicates mechanization.
Tool Selection Complexity	Choosing the right tool depends on tree age, branch size, and pruning type.
Inconsistent Pruning Techniques	Different types of cuts (blind, shedding, thinning) require expertise.
Timing Sensitivity	Pruning time varies by olive type, climate, and frost risk.
Knowledge Transfer Issues	Reliance on generational knowledge with limited formal training.
Tool Efficiency	Need for clean cuts to avoid damage and ensure olive oil quality.
Environmental Concerns	Burning branches is no longer acceptable; mulching is preferred.

Table 6. Pain points of the process

These insights directly will inform the identification of user requirements, guiding the development of solutions such as decision-support tools, ergonomic equipment, AR-based training systems, and autonomous robotic pruning systems. By grounding the requirements in real-world observations and expert strategies, the project ensures that the proposed innovations are both relevant and responsive to the actual needs of end users in the field.

4.6 Results validation and application

In the Cognitive Task Analysis (CTA) methodology, the final phase called "Results Validation and Application" is essential because it ensures that the findings accurately reflect the

cognitive processes involved in the task. Validation involves reviewing the results with subject matter experts or end users to confirm their accuracy and completeness, helping to identify any gaps or misinterpretations in the data.

Among all the stakeholders of the project, the “Pilot Partners” have been chosen to carry out this task because they are uniquely positioned to lead the “Results Validation and Application” phase of CTA because they are directly involved in testing AgRimate solutions in real-life agricultural environments. Their role gives them firsthand experience with the tools, workflows, and cognitive demands being analysed, making them ideal for assessing whether the CTA findings accurately reflect practical realities. Their feedback is grounded in actual field conditions, which is essential for validating the relevance and accuracy of the results.

The Pilots Partners are UNION DE PEQUEÑOS AGRICULTORES Y GANADEROS (UPA) focused on olive trees pruning pilot (in Jaen, Spain) and GEOPONIKO PANEPISTIMION ATHINON (AUA) focused on vineyards pruning (in Spata, Greece).

The two partners have reviewed the information presented in this document as data analysis, extracted because of the knowledge acquisition process. And these have been their conclusions:

About the olive trees pruning process:

“Congratulations on the work, I find it very interesting. So much so that once the deliverable is submitted, it might be a good idea to use the survey part for some communication purposes—for example, a kind of article for our magazine.” (UPA)

In addition to that, they made some minor corrections regarding the typical temperatures during pruning. They also emphasized that pruning is carried out with the intended harvesting method in mind.

About the vineyards pruning process:

“Based on our field experience and the interviews conducted with vineyard pruners, we find that the information presented in section 4.4.2 accurately reflects the main tasks, decision-making processes, and cues involved in grapevine pruning. The emphasis on factors such as grape variety, plant vigour, intended harvest method, and seasonal timing is consistent with the feedback we received from practitioners. We particularly agree with the importance placed on visual cues (such as bud position and cane thickness) and the influence of climate on the timing of the pruning task.” (AUA)

5 Requirements Elicitation

5.1 Methodology

The Volere methodology ⁹ is widely recognized in the field of requirements specification due to several key factors. Firstly, Volere provides an organized structure of requirements knowledge, which allows different elements to be related from the business level to the implementation level. Additionally, it uses established principles and practices in systems engineering, avoiding the need to reinvent techniques. It also emphasizes the importance of a common language, understandable to all those involved in the project, from business analysts to engineers and designers. This common language facilitates communication and understanding among people with different skills and perspectives.

Regarding its widespread use, the Volere methodology has been utilized in projects across various sectors, including banking, air traffic control, retail, aviation, government, real-time control, business analysis, and manufacturing. Its popularity is due to the seemingly contradictory characteristics of rigor and flexibility, which make it effective for discovering, understanding, writing, and communicating requirements.

The main characteristics of the system are as follows:

- **Comprehensive and Structured Template.** Volere provides a detailed requirements specification template that covers: Functional requirements, Non-functional requirements (performance, usability, etc.), Constraints, Assumptions, Stakeholder needs... This ensures that no important aspect is overlooked.
- **Strong Emphasis on Traceability:** Each requirement can be traced back to its origin (e.g., stakeholder, regulation), which is essential for: Managing changes, Ensuring compliance, Validating the final product.
- **Business and User-Centric:** Volere focuses on understanding the business context and the real needs of users, not just technical specifications. This helps ensure the system delivers real value.
- **Adaptable to Agile and Traditional Approaches:** Although originally designed for more formal environments, Volere can be adapted to Agile workflows.
- **Reduces Ambiguity:** Volere encourages the use of precise and unambiguous language, reducing misunderstandings between stakeholders and developers.

Within the Volere methodology, the project will focus on the Atomic requirements, which are measurable, testable, traceable, and detailed enough to define all aspects of a need without further breakdown. These requirements are considered the lowest level of requirements, meaning they specify everything the solution needs to do in a clear and concise manner.

An Atomic Requirement is a single, self-contained, and indivisible requirement. It expresses one and only one need or constraint. Their main characteristics are:

- **Clarity and Precision**
 - By focusing on one idea per requirement, ambiguity is reduced.
 - Stakeholders can more easily understand and validate each requirement.
- **Traceability**

⁹ <https://www.volere.org/>

- Each atomic requirement can be traced back to its source (e.g., stakeholder, regulation).
- This makes it easier to manage changes and assess impact.
- Prioritization and Planning
 - Atomic requirements can be individually prioritized, estimated, and scheduled.
 - This supports incremental and agile development approaches.
- Testability
 - A well-written atomic requirement is easier to verify through testing.
 - It helps ensure that each requirement is measurable and testable.
- Reusability
 - Atomic requirements can sometimes be reused across projects or components.

From the previous section about Task Analysis, and the performed data analysis done in section 4.4 and the pain points identified in section 4.5, a complete list of requirements has been identified and it's presented in next section.

5.2 Requirements

One of the pillars of Volere is its requirements specification template, which provides a structured basis for documenting requirements. It is used for the formalization of the requirements, each of them described with a set of attributes:

Field	Description (Volere Context)
ID	A unique identifier for the requirement. Helps with traceability and referencing throughout the project.
DESCRIPTION	A clear, concise statement of the requirement. Should be atomic (one idea only), unambiguous, and testable.
REQ TYPE	The category of the requirement, such as: Human Centric, Technical and Business.
FUNCT / NON FUNCT	Specifies whether the requirement is Functional (describes behaviour or features of the system) or Non-Functional (describes qualities like performance, usability, security, etc.) and are further divided into categories such as Usability and Humanity (Section 11), Performance (Section 12), Operational (Section 13), Maintainability and Support (Section 14), Security (Section 15), and Compliance (Section 17), according to Volere methodology
RATIONALE	Explains why the requirement exists, the business or user need it addresses. This helps justify its inclusion.
PRIORITY	Indicates the importance or urgency of the requirement (e.g., High, Medium, Low). Useful for planning and trade-offs.
DIFFICULTY	An estimate of how challenging the requirement will be to implement (e.g., Easy, Moderate, Hard). Helps with resource planning.

ORIGINATOR / USER	The stakeholder or user who proposed or needs the requirement. Supports traceability and validation.
APPLIED TO	The system component, module, or process that the requirement applies to. Helps with scoping and architecture.
PILOT / UC	Refers to the Use Case or Pilot scenario where the requirement is demonstrated or validated. Useful for testing and prototyping.
WP/Tasks	Work Package or specific tasks related to implementing the requirement. Helps with project management and tracking.
Technology	A proposed or implemented technology that satisfies the requirement. This may evolve over time as the design progresses.

Table 7. Volere: Atomic Requirements formalization table.

This section presents a summary of the different types of requirements detected: human centric, technical, business. They are the result of knowledge acquisition in each pilot, presented in section 4.3. The overall information gathered in T1.1 is presented in Annex F: Complete requirements table.

A total of **44 global requirements** have been identified from the different fields: and 21 human centric, 12 technical, and 11 business. The decomposition of them according to the functional / non-functional classification is (numbers come from the points in the Volere classification system¹⁰):

- 9. Functional: (3 general to all pilots)
- 11. Usability and Humanity Requirements: (12 general (to all pilots) and 1 pilot specific)
- 12. Performance Requirements: (5 general (to all pilots) and 3 pilot specific)
- 13. Operational Requirements: (9 general (to all pilots) and 2 pilot specific)
- 14. Maintainability and Support Requirements: (4 general (to all pilots))
- 15. Security Requirements: (3 general (to all pilots) and 1 pilot specific)
- 17. Compliance Requirements: (1 general (to all pilots) and 1 pilot specific)

¹⁰ <https://www.volere.org/templates/volere-requirements-specification-template/>

Human Centric Requirements table

ID#	DESCRIPTION	FUNCT / NON FUNCT	PRIORITY	DIFFICULTY	PILOT
Req_01	Standardized pruning guidelines and decision support tools	9. Functional	COULD (preferred but not necessary)	Medium	All
Req_02	Training programs on pruning and assistive technologies	9. Functional	COULD (preferred but not necessary)	Medium	All
Req_03	Ergonomic tools design for pruning	11. Usability and Humanity Requirements	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)
Req_04	Necessity of real-time, data-informed decision-making capabilities during pruning tasks	12. Performance Requirements	MUST (mandatory)	Medium, High	All
Req_05	Adaptable machinery or lightweight tools for uneven terrain	13. Operational and Environmental Requirements	SHOULD (of high priority)	Medium, High	Grape vines pruning (Athens)
Req_06	Smart tool recommendations for pruning tool selection	11. Usability and Humanity Requirements	WOULD (can be postponed and suggested for future execution)	Medium	All
Req_07	Visual guiding support for branch cut selection	12. Performance Requirements	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)
Req_08	Integrate weather forecasting and scheduling tools	13. Operational and Environmental Requirements	WOULD (can be postponed and suggested for future execution)	Medium	All
Req_09	Develop digital knowledge bases or interactive learning platforms	12. Performance Requirements	COULD (preferred but not necessary)	Medium	All
Req_10	Precision cutting tools with feedback mechanisms	15. Security Requirements	COULD (preferred but not necessary)	Medium	All

Req_11	The worker shall have their hands-free during pruning and training operations	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_12	Assistive tools design for pruning tailored to user diversity	11. Usability and Humanity Requirements	COULD (preferred but not necessary)	Medium	All
Req_13	Assistive tools design for pruning tailored to environmental status (clarity, luminance, contrast)	13. Operational and Environmental Requirements	COULD (preferred but not necessary)	Medium	All
Req_14	Assistive tools for pruning handling easy to learn and self-explaining	11. Usability and Humanity Requirements	MUST (mandatory)	Medium, High	All
Req_15	Assistive tool control in hands of end user	13. Operational and Environmental Requirements	MUST (mandatory)	Medium, High	All
Req_16	Perception of physical wellbeing with the help of an assistive tool	15. Security Requirements	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)
Req_17	Agility and precision of movements allowed by the assistive tool	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_18	Assistive tool safe to use by worker	15. Security Requirements	SHOULD (of high priority)	Medium, High	All
Req_19	The system will task allocate depending on worker skills	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_20	The system gives the worker personalized information for learning depending on worker skills	11. Usability and Humanity Requirements	COULD (preferred but not necessary)	Medium	All
Req_21	Assessment of anticipated health risks for the worker	17. Compliance Requirements	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)

Technical Requirements table

ID#	DESCRIPTION	FUNCT / NON FUNCT	PRIORITY	DIFFICULTY	PILOT
Req_22	Interactive guide for real-time pruning instructions	12. Performance Requirements	COULD (preferred but not necessary)	Medium	All
Req_23	Inclusive and personalized training tools for pruning education	11. Usability and Humanity Requirements	MUST (mandatory)	Low, Medium	All
Req_24	Robotic pruning system should be automatized	12. Performance Requirements	MUST (mandatory)	Medium, High	Grape vines pruning (Athens)
Req_25	Centralized system to record and access individual tree history and pruning data	9. Functional	MUST (mandatory)	Medium, High	All
Req_26	Pruning plans based on tree's traceable history	12. Performance Requirements	MUST (mandatory)	Medium	All
Req_27	Assistive tools design for pruning with heavy tools	12. Performance Requirements	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)
Req_28	Possibility of using the assistive tool in different pruning tasks	13. Operational and Environmental Requirements	COULD (preferred but not necessary)	Medium	Traditional Olive Trees Pruning (Jaen)
Req_29	Assistive tool correct response to unexpected situations (fall or bad weather conditions)	13. Operational and Environmental Requirements	MUST (mandatory)	Medium, High	All
Req_30	Graphic interface for communicating information enriching messages	11. Usability and Humanity Requirements	COULD (preferred but not necessary)	Medium	All

Req_31	Clear information of the system status	15. Security Requirements	MUST (mandatory)	Medium	All
Req_32	Sufficient energy load for assistive and autonomous tools	13. Operational and Environmental Requirements	MUST (mandatory)	Medium, High	All
Req_33	Ease of exchange of end effectors of the autonomous system	14. Maintainability and Support Requirements	MUST (mandatory)	Medium	All

Business Requirements table

ID#	DESCRIPTION	FUNCT / NON FUNCT	PRIORITY	DIFFICULTY	PILOT
Req_34	Sustainable practices with mulching equipment	13. Operational and Environmental Requirements	MUST (mandatory)	Medium	All
Req_35	Assistive tool focused on productivity increase	13. Operational and Environmental Requirements	MUST (mandatory)	Medium	All
Req_36	Pruning leftovers should have a sustainable management	14. Maintainability and Support Requirements	MUST (mandatory)	Low	All
Req_37	Pruning outcomes should be assessed based on various pruning techniques	12. Performance Requirements	MUST (mandatory)	Medium, High	All
Req_38	Assessment of psychosocial working conditions pre- and post-AI implementation	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_39	Build peer networks and social support platforms for farmers	14. Maintainability and Support Requirements	MUST (mandatory)	Low, Medium	All

Req_40	Ensure inclusive task allocation between human and AI to maintain autonomy and competence	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_41	Monitor AI technology acceptance and its impact on well-being	11. Usability and Humanity Requirements	MUST (mandatory)	Medium	All
Req_42	Demonstration of technological solutions in real-world vineyards and olive trees pilot scenarios	13. Operational and Environmental Requirements	SHOULD (of high priority)	Medium	All
Req_43	Dissemination project results and foster collaboration through open calls	14. Maintainability and Support Requirements	MUST (mandatory)	Low, Medium	All
Req_44	Ensure ethical implementation, data privacy, and inclusivity	17. Compliance Requirements	SHOULD (of high priority)	Medium	All

The following table serves as a strategic mapping tool that links each Technological Enabling Object (TEO) to its practical application in two distinct agricultural contexts: traditional olive tree pruning in Jaén and grapevine pruning in Athens. The aim is to provide a clear overview of how each TEO contributes to addressing specific operational challenges and user needs identified in these pilot sites.

Each row in the table outlines a TEO along with its core technological component, indicating whether it is deployed in one or both pilots. The **usability index** reflects the degree to which each TEO (Tangible Expected Outcome) is expected to be user-friendly, effective, and accessible in real-world pruning scenarios across the two pilot sites. It is derived from the number and nature of usability-related requirements (e.g., ergonomic design, intuitive interfaces, hands-free operation) associated with each TEO. A higher usability index indicates that the TEO is more aligned with human-centric design principles, ensuring better adoption, comfort, and efficiency for agricultural workers during pruning tasks. Additionally, the **associated requirements** highlight the functional and technical specific needs that the TEO is designed to fulfil.

Furthermore, the table includes **Key Performance Indicators (KPIs)** tailored to each pilot, offering quantifiable metrics to assess the effectiveness of the TEOs in improving pruning accuracy, reducing physical strain, increasing labour availability, and enhancing overall productivity. This structured approach not only facilitates the evaluation of technological impact but also supports decision-making for future scaling and adaptation of these solutions in diverse agricultural settings.

Table 8. TEO mapping to pilots

Code	Technological Components	Traditional Olive Trees Pruning (Jaen)	Grape vines pruning (Athens)	Usability index	Requirements associated	KPIs associated Olive Trees (Jaen)	KPIs associated Grape vines (Athens)	WP / Tasks
TEO1	AR Guide	✓		19	Req_01, Req_04, Req_06, Req_07, Req_08, Req_09, Req_10, Req_11, Req_12, Req_13, Req_14, Req_15, Req_17, Req_19, Req_20, Req_22, Req_30, Req_32, Req_37	AR Guide effectiveness >80%	Improvement in Pruning Accuracy and Quality +15 to 25%	WP2 (T2.4 and T2.5)
TEO2	AR Trainer	✓	✓	9	Req_01, Req_02, Req_06, Req_09, Req_11, Req_13, Req_22, Req_23, Req_44	Increase in labour availability +10%	AR Training effectiveness >75%	WP2 (T2.4) WP3 (T3.3)
TEO3	Automatic Pruner		✓	15	Req_03, Req_05, Req_10, Req_18, Req_24, Req_29, Req_30, Req_31, Req_32, Req_33, Req_35, Req_36, Req_40, Req_42, Req_43	Increase in yields: +15% Reduction in time spent pruning -5%	Increase in yields + 5 to 10% Reduction in pruning-related errors or corrective actions -30%	WP3 (T3.3)
TEO4	Assistive Exoskeleton	✓		22	Req_02, Req_03, Req_05, Req_12, Req_14, Req_15, Req_16, Req_17, Req_18, Req_21, Req_23, Req_24, Req_27, Req_28, Req_29, Req_31, Req_35, Req_40, Req_41, Req_42, Req_43, Req_44	Reduction of physical effort -25%	Reduction in time spent pruning -15%	WP3 (T3.4)
TEO5	Assessing Tool	✓	✓	11	Req_04, Req_08, Req_19, Req_25, Req_26, Req_34, Req_36, Req_37, Req_38, Req_39, Req_41	Worker acceptance >80%	Worker acceptance >80%	WP6 (T6.4)

6 Prominent Standards, Reference Architectures and Enabling Platforms for Interoperability

This section covers prominent standards and reference architectures that are to be exploited as a starting point for the AgRimate project. Related platforms will be mentioned with the aim of ensuring interoperability and maximizing impact. Hence, this section will outline the current state of the art, with an initial TRL and draw an initial analysis of how these existing solutions/standards/platforms will be built upon.

6.1 In-the-fields sensing for Agriculture

Recent advances in sensor technologies, particularly those enabled by computer vision and multimodal data fusion, have significantly transformed in-the-fields sensing capabilities for agriculture. These sensing solutions are increasingly heterogeneous in terms of spatial scale (from field-level monitoring to individual plant inspection), data modalities (RGB, multispectral, hyperspectral, thermal, environmental sensors, LiDAR), temporal resolution (fixed intervals vs. real-time streaming), and mobility platforms (e.g., drones, satellites, ground robots, handheld devices).

In agricultural settings, sensor deployments must often deal with complex outdoor conditions characterized by high variability, occlusions, and dynamic environments. These challenges result in different Technology Readiness Levels (TRLs) compared to more controlled indoor scenarios. In the literature, most available datasets are collected in controlled or semi-controlled environments, limiting their applicability to real-world field conditions. In this context, AgRimate focuses on high-TRL, real-world use cases where sensing technologies must operate autonomously and robustly under unstructured conditions.

Several categories of sensors are currently employed in the field:

- **Environmental Sensors:** Monitor soil and atmospheric conditions such as moisture, pH, temperature, and solar radiation. These are critical for optimizing irrigation and fertilization strategies.
- **Optical Sensors:**
 - **RGB Cameras** for canopy analysis and general inspection.
 - **Multispectral/Hyperspectral Cameras** used also for early stress and disease detection.
 - **Thermal Cameras** used for example for evaluating plant water status.
- **3D Sensing Technologies:**
 - **LiDAR** provides accurate 3D point clouds of plants and environments with high robustness to lighting.
 - **SfM and MVS** offer passive, image-based 3D reconstruction using multi-view geometry.
 - **Stereo/Depth Cameras** combine RGB and depth for real-time, close-range 3D perception.
 - **NeRF and 3D Gaussian Splatting (3DGS)** represent recent breakthroughs in AI-driven 3D scene reconstruction, offering fine-grained geometry and view synthesis capabilities.

3D image reconstruction methods to model trees/vines/etc. vary significantly in terms of required assumptions, input modalities, and output formats. A classification based on active/passive sensing, direct/photometric/geometric approaches, and learning-based methods is summarized in Figure 32 which highlights their applicability to agriculture use cases.

Setting	Approach	Method	Input	Assumption	Output	Scale
Passive	Geometric	(Two-view) stereo	Two images with disparity	Known camera poses (position/orientation)	Distance to each pixel (i.e., depth image)	Yes
		Structure-from-motion (SfM)	Multi-view images	Unknown camera poses	Camera pose + sparse 3D points	No
		Multi-view stereo (MVS)	Multi-view images	Known camera poses	Dense 3D point cloud or 3D mesh	No
		- Shape from silhouette - Space carving - Computed tomography (CT)	Multi-view images	Known camera pose	3D voxel occupancy or density	Yes
	Learning (or optimization)	Single-image 3D reconstruction	A single image	Using a pre-trained neural network or a parametric shape model on the specific domain	Depth image or surface normal (+ reflectance, structure, etc., depending on methods)	Yes/No
Active	Direct	- Time-of-flight (ToF) - 3D laser scanners/ LiDAR	Light (temporal) pattern + receptor		Distance to each point (usually as a 3D point cloud or depth image)	Yes
	Geometric	Active stereo (structured light)	Light (spatial) pattern (e.g., by projector) + camera	Known relative pose between projector & camera	Distance to each point/pixel (usually as depth image)	Yes
	Photometric	Photometric stereo (PS) ^a	Images (fixed view-point) with different light source	Known/unknown light position (depending on methods)	Surface normal (+ reflectance and/or camera pose, depending on methods)	No
		Shape from shading ^b	A single image	Known light source + surface reflectance (and additional constraints)	Surface normal	No

^a Passive setting of PS is possible using *uncalibrated* methods captured under unknown lighting positions.

^b Active but casual setting using the sunlight (and its direction acquired by latitude/longitude and time) is a possible extension.

Figure 32. Categorisation and classification of different standards for in-field-sensing using 3D information. (Okura, 2022)

Notably, recent learning-based techniques such as NeRF and 3D Gaussian Splatting enable high-quality 3D reconstruction from standard optical sensors (e.g., RGB cameras), which are more affordable and versatile compared to traditional depth sensors. This opens the possibility of reusing existing visual sensing pipelines for both inspection and geometry acquisition, significantly reducing hardware complexity and deployment costs in the field.

6.1.1 Existing standards and reference architectures and datasets

Sensing architectures are typically composed of heterogeneous mixes of devices and platforms tailored to specific tasks and scales. Environmental sensors (e.g., Meter Atmos 41 or SEnviro) are generally fixed in the field and installed on poles or weather stations to continuously monitor parameters such as temperature, humidity, soil moisture, and solar radiation. These fixed setups provide essential background information that complements mobile and aerial sensing. Optical cameras are also being deployed across different mobility platforms. 2D RGB cameras, particularly global shutter models (e.g., LucidVision Atlas or Daheng Imaging MERCURY cameras), are mounted on tractors, robotic arms, or handheld systems to ensure motion-stable acquisitions during dynamic operations. Multispectral and hyperspectral sensors are commonly integrated into drone systems (e.g., Parrot Sequoia or

DJI Mavic 3M) or accessed via satellite platforms such as Sentinel-2 or PRISMA, enabling large-scale monitoring with spectral sensitivity useful for plant health analysis and stress detection. 3D sensing technologies are also quite heterogeneous. LiDAR units, such as Livox Mid-360 or LucidVision Helios2, are typically mounted on ground robots or UAVs to acquire dense, high-precision 3D point clouds of crops and terrain, with strong robustness to varying illumination. Vice versa, Stereo cameras (e.g., ZED2) and depth sensors (e.g., Intel RealSense or Azure Kinect) are used for real-time, close-range depth perception and are often integrated on robotic platforms, as for example shown in Figure 33. These systems are sometimes combined in multi-sensor architectures where, for instance, LiDAR is paired with RGB or thermal cameras to enrich spatial information with texture or thermal profiles.

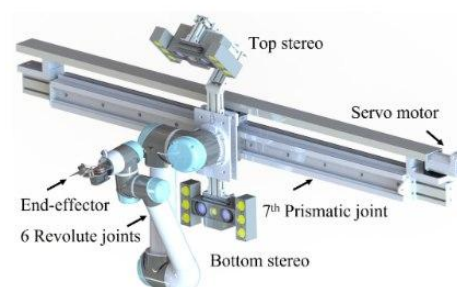


Figure 33. Example of stereo cameras mounted on the 7-DoF robot proposed by Silwal et al. (2022).

In literature, several datasets support plant analysis tasks through different sensing technologies and acquisition modes. These datasets can be grouped based on their dimensionality and sensor types. In the 2D category, both the *3D2cut Single Guyot Dataset* (Corre (2023)) and the *Grapevine Dataset* (Fernandes et al. (2021)) for Plant Segmentation focus on grapevines and were collected using high-resolution RGB cameras. The 3D2cut dataset (Figure 36) includes over 1500 images, each showing a single grapevine isolated against a coloured background, captured in vineyards across France. The Grapevine dataset, with 149 annotated images, was acquired in a simulated vineyard in Italy and is structured for plant organ segmentation using the COCO format. Both datasets rely on standard RGB imaging for canopy-level inspection and segmentation tasks. Among 3D datasets, *TreeNet3D* (Tang et al. (2024)) provides synthetic 3D tree models generated procedurally, without real sensor input, offering point clouds and structural data for various tree species. In contrast, *LeWoS* (Wang et al. (2021)) and *Pheno4D* (Schunk et al. (2021)) are based on real-world LiDAR scans. *LeWoS* (Figure 34) focuses on classifying leaf and wood structures in tropical trees using terrestrial LiDAR, while *Pheno4D* (Figure 35) presents time-series 3D scans of maize and tomato plants, useful for growth modelling and segmentation. These datasets use LiDAR to capture precise 3D geometry, independent of lighting conditions. *PlantDreamer* (Hartley et al. (2025)) combines synthetic and real data, including point clouds generated with methods like SfM, MVS, and 3D Gaussian Splatting (3DGS). SfM and MVS use passive RGB images, while 3DGS leverages neural rendering for high-quality geometry. This dataset bridges procedural modelling and advanced 3D reconstruction for diverse plant representations. Together, these datasets reflect a range of sensing strategies: RGB, LiDAR, and image-based 3D modelling applied to tasks from segmentation to temporal growth analysis.

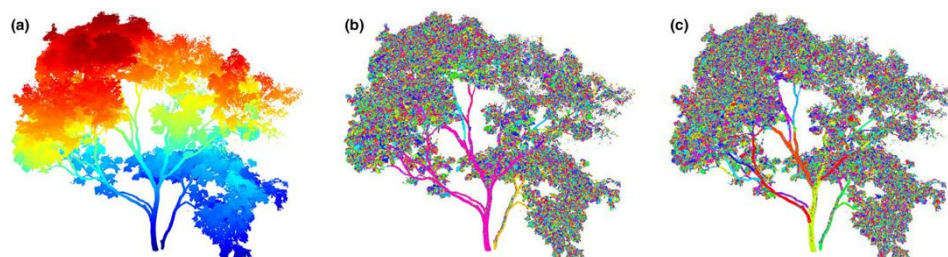


Figure 34. Wang et al. (2021): example of segmentation steps. (a) Original point cloud. (b) Resulted segments from recursive graph segmentation. Each segment is randomly coloured. (c) Final segmentation result after branch splitting.

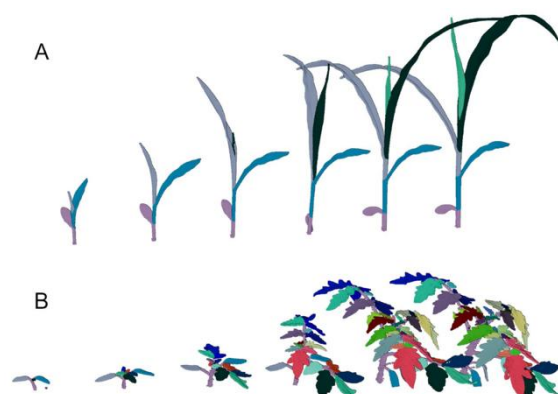


Figure 35. Schunk et al. (2021): Sample data of a maize (A) and a tomato plant (B) scanned periodically. Temporally consistent labels are assigned to each individual leaf, as indicated by colour.

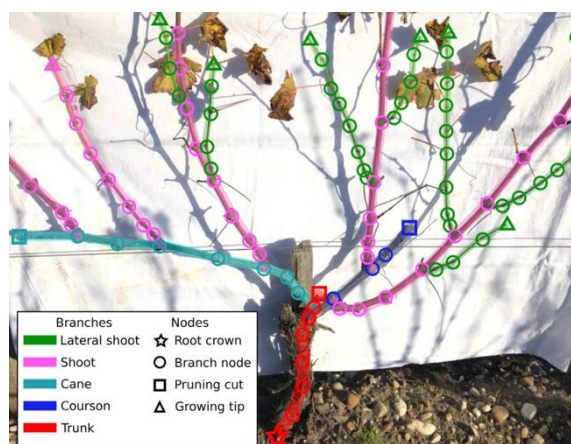


Figure 36. Corre (2023): Target output of the visual processing system.

6.2 Robotic platforms and manipulators for Agriculture

In the past decade, continuous progress has been made in developing robotic platforms for agricultural applications, applied to different tasks such as harvesting, weeding, spraying, and pruning. These platforms typically combine navigation, manipulation, and perception capabilities following a modular architecture and are increasingly being integrated with AI and data-driven control systems. In viticulture and tree crop management, pruning remains a high-value target for automation due to its labour intensity and importance for yield and quality.

Mobile platforms are the foundational element of autonomous agricultural robots. Their main function is to transport sensors, actuators, and manipulators across uneven outdoor terrain,

while maintaining stability, precision, and autonomy. In vineyard contexts, the following technologies and configurations are currently relevant:

- **Traction design:** Both tracked and wheeled bases are relevant in the agriculture market. Tracked vehicles offer superior grip on loose or sloped soil and are more stable on uneven terrain. Wheeled vehicles have simpler kinematics, lower energy consumption and are more efficient in flatter and more structured terrain, they also require lower maintenance.



<https://sagarobotics.com/thorvald-platform/>



<https://www.naio-technologies.com/en/ted/>



<https://vitibot.fr/productos-y-servicios/robot-viticole-bakus-s/?lang=es>



<https://www.agricobots.com/atomatika/>

Figure 37: Robotic platforms and manipulators for Agriculture

- **Weight:** Robotic platforms in agriculture vary greatly in terms of weight, which directly affects their traction capabilities, energy consumption, and soil compaction impact. Heavier platforms (up to several tons), such as Bakus, offer better stability and traction on sloped or muddy terrains and can carry larger payload. On the other hand, lightweight robots (around 200–300 kg), such as Thorvald, are specifically designed to minimize soil compaction, which is critical for maintaining long-term soil structure. These platforms use all-terrain wheels or small tracks, and are designed for low-speed, high-precision operations. The choice between heavy-duty and lightweight platforms must balance operational range and payload needs.

- **Integration of Manipulators:** Agricultural robots can be divided into two functional categories: those that include robotic manipulators to interact physically with the crop, and those that focus on non-contact tasks such as monitoring, mapping, or spraying. Robots with manipulators are typically used for complex tasks like pruning and harvesting, where precise coordinated tasks are required.



<https://robotnik.eu/es/projects/bacchus/>



<https://www.yanmar.com/fr/viticulture/>

Figure 38: Manipulator designs

In contrast, many commercial agricultural robots, such as Naïo's Ted or Vitibot's Bakus are designed for simpler tasks, like weeding, fumigation and crop monitoring. These systems often rely solely on locomotion and sensor data, which reduces cost and complexity but limits the range of operations they can perform.

- **Split design:** Commercial agricultural robots can be split into two different structural configurations: split-style bridge platforms and side-reaching vehicle-type platforms. The split-style robots cover the whole crop row with a U-shaped or H-shaped bridge chassis, enabling operations over the entire plant canopy from above. This design is well-suited for tasks such as spraying, or overhead 360° sensing, and can be seen in platforms like Naïo's Ted (see Figure 37). On the other hand, side-reaching robot vehicles approach the crop row from only one side. Robotic arms are typically integrated into this second type of design, as it provides better stability and less spatial limitations. An example of this configuration can be seen in the table above with Robotnik's RB-VOGUI for Bacchus project with two arms.
- **Sensors:** Outdoors autonomous navigation requires the fusion of multiple sensors to achieve robust localization, obstacle detection, and path planning. Most state-of-the-art platforms rely on a combination of GNSS (e.g. RTK-GPS) for global positioning, LiDAR for 2D/3D obstacle detection, and vision-based sensors (RGB-D cameras) for semantic understanding of the environment. IMUs and wheel encoders are also integrated to provide motion estimation.

6.2.1 Existing standards and reference architectures

Developing robotic systems for agriculture increasingly relies on well-established software architectures and international standards to ensure interoperability, modularity, and safety. Among software frameworks, ROS 2 (Robot Operating System 2) is currently the most widely adopted middleware in both academia and industry. It offers a modular, node-based structure, real-time capabilities, and seamless integration with tools for navigation, motion planning, or communication with embedded hardware.

From a software perspective, modern autonomous navigation stacks are typically built on ROS 2, which provides a mature ecosystem with standard drivers for most used robotic sensors (LiDARs, GPS, RGB-D cameras, IMUs), as well as out-of-the-box navigation and control algorithms. Key functionalities include:

- **SLAM (Simultaneous Localization and Mapping):** algorithms such as RTAB-Map¹¹, Cartographer¹², or Gmapping¹³ for simultaneous mapping and self-localization in unstructured environments.
- **Navigation:** Nav2¹⁴ library, which allows for easy customization and integration of different navigation components, including planners, controllers, and localization algorithms.
- **Sensor fusion:** algorithms based on Extended Kalman Filters (EKF) or Unscented Kalman Filters (UKF) are used to combine GNSS, vision, IMU, and encoder data for robust pose estimation.

From a manipulation perspective, ROS 2 also supports a rich ecosystem of libraries and tools for motion planning, robot arm control, and task execution. **Movelit 2** is the most prominent motion planning framework in ROS 2, offering capabilities for inverse kinematics, collision checking, trajectory planning, and allowing seamless integration with perception pipelines, and robot controllers. This enables flexible planning for single- and multi-arm systems, with support for custom planning algorithms and controllers. Additionally, **ros2_control** provides a standardized interface for managing hardware resources and implementing real-time controllers for manipulators, grippers, and mobile bases. Its modular architecture allows developers to easily integrate custom hardware and tune control strategies for specific tasks. Finally, ROS 2 also provides tools for high-level task planning and coordination. For instance, **FlexBE** (Flexible Behaviour Engine) can be used to create state machines for decision making and sequencing complex behaviours in an intuitive and modular way. Together, these tools provide a robust foundation for building advanced manipulation capabilities in ROS 2-based robotic systems.

Regarding modularity and distributed control, ROS 2 natively supports DDS (Data Distribution Service), which enables real-time, scalable integration of subsystems for perception, navigation, and manipulation. Moreover, ROS 2 includes drivers for M2M communication protocols, such as MQTT, CANbus, and OPC-UA, which are often employed to connect robots to Management Systems or cloud-based platforms.

In terms of hardware and system-level standards, agricultural robots must comply with several domain-relevant norms. ISO 18497 defines safety requirements for autonomous mobile

¹¹ https://github.com/introlab/rtabmap_ros

¹² https://ros2-industrial-workshop.readthedocs.io/en/latest/_source/navigation/ROS2-Cartographer.html

¹³ <https://wiki.ros.org/gmapping>

¹⁴ <https://github.com/ros-navigation/navigation2>

agricultural machines, while ISO 13482 establishes safety criteria for collaborative arms. These standards must be carefully analysed to ensure a safe design with the required protective measures.

6.3 XR Human interfaces for Agriculture

Extended Reality (XR) technologies, which include Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), are playing an increasingly prominent role in the digital transformation of agriculture. Their application aims to boost productivity, improve operational accuracy, and enhance ergonomic safety by facilitating more effective human-machine interaction and enabling real-time decision-making support (Anastasiou, 2023).

In crop management and harvesting, Augmented Reality (AR) allows workers to receive contextual visual guidance through smart glasses or head-mounted displays (HMDs). Overlays projected onto the real-world environment can assist in tasks like pruning, determining optimal harvest times, or inspecting fruit for quality, all without the need for handheld devices or manual consultation (Hurst et al., 2021). This seamless access to information reduces cognitive load and supports on-the-fly decision-making.

In livestock farming and other high-turnover environments, Virtual Reality (VR) serves as a powerful training tool. VR simulations enable workers to practice critical operations—such as machine handling, animal welfare protocols, or biosecurity procedures—in safe, immersive environments. These solutions are especially valuable where experienced personnel may be limited, or onboarding needs are frequent (Srikanthnaik, 2024).

Mixed Reality (MR), meanwhile, is being explored for its potential in interacting with advanced agricultural systems such as autonomous vehicles, smart irrigation setups, and robotics platforms. MR allows users to engage with digital controls and dashboards overlaid on the physical world, using voice commands or natural gestures to monitor or adjust systems in real time, thereby improving usability and situational awareness (Anastasiou, 2023).

XR systems are also increasingly integrated with IoT sensors, drones, and geospatial information systems (GIS), particularly in the context of farm machinery and environmental monitoring. These integrations support real-time diagnostics and remote equipment control. Through digital twins, virtual replicas of physical systems, technicians and agronomists can assess machinery status, crop health, and soil conditions remotely, accessing layered visualizations that combine sensor data, environmental metrics, and operational insights (Lohan et al., 2025).

Beyond operational guidance, XR technologies contribute to precision agriculture by making localized, context-rich data accessible at the point of need. For instance, live visualizations of parameters such as soil moisture, vegetation indices, or pest distribution can inform data-driven interventions, reducing waste and increasing adaptability to climate variability (Hurst et al., 2021).

In summary, XR technologies are moving from experimental trials to strategic enablers of smart farming ecosystems. They support a wide range of agricultural goals, from operational efficiency and workforce training to sustainability and digital integration, driven by technological advances, lower hardware costs, and growing connectivity in rural areas.

6.3.1 Existing standards and reference architectures

The progressive adoption of Extended Reality (XR) technologies in agriculture requires standardized frameworks and reference architectures to ensure interoperability, scalability, and long-term sustainability. As XR applications and devices proliferate, especially in precision and smart farming, the absence of unified standards presents both technical and economic barriers to widespread deployment. Several open standards and reference models have emerged to address these challenges, enabling cross-platform development, seamless data integration, and compatibility across heterogeneous systems.

One of the most influential standards in this domain is OpenXR, a royalty-free, open specification developed by the Khronos Group. OpenXR defines a unified application programming interface (API) that allows XR applications to operate across a wide range of hardware platforms, including AR glasses, VR headsets, and MR devices, without requiring device-specific adaptation. This is particularly valuable in agricultural settings, where cost constraints, rugged environments, and hardware diversity are common (Khronos Group, 2018). OpenXR also supports extensibility, enabling integration with geospatial systems, IoT sensor networks, and edge computing platforms.

Another key framework is WebXR, which enables browser-based XR applications. Its low resource requirements make it ideal for lightweight training simulations, remote diagnostics, and agricultural data visualization in regions with limited computing infrastructure or internet bandwidth (Fundación CTIC, 2023).

The ISO/IEC 23093-1:2022 standard defines a modular reference architecture for multimedia Internet-of-Things (IoT) applications. It supports efficient data compression and interaction across smart devices, making it suitable for multimedia-enabled sensors and actuators in precision agriculture (ISO/IEC, 2022).

oneM2M offers a global standard for IoT interoperability. It provides a unified service layer to enable seamless communication between devices and applications across multiple sectors, including agriculture. It also supports semantic annotation of data resources, facilitating semantic interoperability among heterogeneous systems, critical for XR applications connected to diverse sensor networks and robotics (IETF, 2017).

Additional relevant standards and architectures include:

- ISO/IEC 14772-1:1997 reviewed and confirmed in 2021 (VRML): Defines the Virtual Reality Modeling Language, a standard for 3D interactive vector graphics. Although developed in the early stages of XR, VRML remains useful for ensuring compatibility in simulation environments and 3D modelling of agricultural operations (ISO, 1997).
- ISO 9241-210 – Ergonomics of human-system interaction – Human-centred design for interactive systems: This standard outlines key principles and requirements for designing interactive systems that are usable, accessible, and well-suited to users' needs. It is particularly relevant for XR applications in agriculture, as it emphasizes iterative user involvement, environmental context awareness, and ergonomic considerations—essential for ensuring safety, comfort, and efficiency in physically demanding tasks such as outdoor fieldwork or machinery operation (ISO, 2019).
- IEEE P2048 Series: Developed under the IEEE Digital Reality initiative, the IEEE P2048™ standards series addresses various aspects of Augmented Reality (AR), including interface architecture, data models, wearable compatibility, and safety

protocols. One of the key standards, IEEE 2048.101-2023, defines general requirements for AR systems on mobile devices, covering software frameworks, system components, integration, and technical specifications. These standards are essential to ensure the safe and effective deployment of head-worn displays and spatial interfaces, particularly in demanding environments such as agricultural settings (IEEE Standards Association, 2023).

- IEC 62541 (OPC UA – Unified Architecture): Widely adopted in industrial automation, OPC UA provides a secure, platform-independent framework for machine-to-machine communication. In agricultural XR applications, OPC UA can support the integration of visualization systems with backend sensor networks and robotic equipment (IEC, 2020).
- RAMI 4.0 (Reference Architectural Model for Industry 4.0): This framework maps technological components—such as sensors, actuators, digital twins, and XR interfaces, within the context of cyber-physical production systems. RAMI 4.0 supports modularity and alignment with Industry 4.0 principles, making it suitable for designing scalable XR systems in smart agriculture (Platform Industrie 4.0, 2015).

Several research and innovation initiatives have contributed architectural prototypes that serve as reference models for agricultural XR deployment. For instance, the SmartAgriHubs project promotes modular, interoperable digital infrastructures for farming, enabling the development of XR-ready ecosystems across European agriculture (SmartAgriHubs, n.d.). Similarly, the XR4DRAMA project has explored the integration of XR with cloud analytics, digital twins, and edge computing to enhance situational awareness—principles directly transferable to agricultural monitoring and decision-making (Vrochidis et al., 2021). Both initiatives emphasize human-centred design, semantic interoperability, and open architectures, offering valuable frameworks for XR integration in the farming sector.

In conclusion, although XR-specific standards tailored to agriculture are still emerging, a combination of existing industrial, ergonomic, and XR frameworks provides a solid foundation for designing and deploying effective XR systems in farming. These standards reduce development costs, promote cross-device compatibility, and facilitate human-centred, modular, and secure XR implementations that can adapt to evolving agricultural needs.

7 Conclusions

This document serves as a foundational analysis for the AgRimate project, offering a comprehensive overview of its use cases, olive groves and vineyards, and initial stakeholder requirements. As a direct output of T1.1, it is instrumental in defining the project's purpose and scope. The document has provided a meticulous outlining of use cases, a thorough analysis of both functional and non-functional requirements, and the development of a robust reference architecture, all designed to guide the seamless development and integration of the various AgRimate modules.

One of the most significant findings relates to the inherent complexity of pruning processes in both olive groves and vineyards. These tasks are not merely mechanical but deeply cognitive, requiring nuanced decision-making based on plant morphology, environmental conditions, and long-term cultivation goals. Our cognitive task analysis revealed that expert pruners rely heavily on tacit knowledge—such as recognizing subtle cues in branch structure or recalling the historical treatment of individual plants—to make pruning decisions that cannot be easily codified. This complexity presents a challenge for automation and standardization, but also an opportunity: by capturing and modelling these expert strategies, AgRimate can develop AI and AR tools that support rather than replace human expertise.

Equally important is the value of worker input in shaping system design. Interviews and field visits highlighted the importance of ergonomic considerations, intuitive interfaces, and inclusive training tools. Workers emphasized the need for technologies that adapt to diverse physical abilities, environmental conditions, and levels of experience. Their feedback has directly informed the requirements for exoskeletons, AR guidance systems, and robotic platforms, ensuring that these tools enhance well-being and productivity without compromising autonomy or safety. Moreover, the challenge of translating tacit knowledge into measurable KPIs has underscored the need for hybrid evaluation methods—combining quantitative metrics with qualitative insights—to assess the real-world impact of AgRimate technologies.

The identification of human-centric problems and proposed solutions will inform the technical and functional specifications for subsequent project tasks/deliverable, notably T1.2, T1.3 and D1.2.

Furthermore, T1.1 has established an initial suite of benchmarks and Key Performance Indicators (KPIs). These are vital for evaluating performance during the pilot phase (WP6) and align directly with WP5's objectives concerning psychosocial and human-centred approaches. To maximize the project's impact and ensure interoperability, D1.1 also considered prominent industry standards and reference architectures.

In conclusion, this report, encompassing the details presented and supported by comprehensive annexes, represents a significant launch pad for the AgRimate project. It provides the essential analytical foundation for the development of innovative agricultural technologies that are not only technologically advanced but also deeply considerate of human well-being and environmental sustainability.

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Annex A: Questionnaire on olive pruning

DEMOGRAPHIC DATA

Alias (Not a real name, it will simply serve as an anonymised identifier): _____

Age category:

- ☐ 18-29
- ☐ 30-39
- ☐ 40-49
- ☐ 50-59
- ☐ 60-69
- ☐ More than 69

Gender:

- ☐ Male
- ☐ Female
- ☐ Non-binary
- ☐ Prefer not to say
- ☐ Other: _____

Position: (they do not have to be exclusive)

- ☐ Owner of an olive farm
- ☐ Cooperative member
- ☐ Field supervisor
- ☐ Worker
- ☐ Day labourer (paid per day worked)
- ☐ Other: _____

Years of experience: _____

OPEN QUESTIONS

1. General questions

- What are the main tasks that you do in your job?
- What tasks do you consider most important in your job?
- Who helps you with your work on the farm? Do you hire seasonal workers? If so, where do they come from?
- Do you miss any kind of help in your daily work?
 - ☐ More manpower, what kind of manpower?
 - ☐ More resources? What kind of resources: machinery...?
 - ☐ More technology?
 - ☐ More breaks?

2. Environment

- What is the terrain you are working in like? Is it flat or does it have slopes? Do you walk a lot during your pruning day? Approximately, how much? (e.g.: kms, hours, % of working day...)
- What weather conditions are usually present when pruning is done?

3. Work organisation

- Is there an established schedule for pruning?
- How many hours a day is pruning usually done and at what times?
- What are the main challenges? (e.g. getting the cut right, choosing the right branch, weather conditions)?
- Who supports you during pruning? Do you work alone?
- What would make the pruning task easier and more efficient?

4. Tools used

- What kind of tools do you mainly use for pruning?
- How much do those tools usually weigh? Are they bulky?
- Do these tools need any special transport? For example, do you need a vehicle, can you carry them with you?

5. Pruning process

- Can you describe the pruning process from the start to the end?
- What are the main aspects to consider, or to take into account in the pruning process?
- How do you decide on the actions to be taken, and on what basis? (e.g. experience, condition of trees, timing of pruning)?

6. Knowledge acquisition

- How did you learn how to do the pruning process? Who trained you?
- Is there any training time beforehand?
- Are there any standards or guidelines for the pruning process?

ESTIMATED EFFORT

- How do you currently value the effort dedicated to a day of olive tree pruning?

Likert scale effort (from min to max):

- (1) - Very low effort
- (2) - Low effort
- (3) - Moderately low effort
- (4) - Moderate effort
- (5) - Slightly moderate effort
- (6) - Considerable effort
- (7) - High effort
- (8) - Very high effort

- (9) - Extremely high effort
- (10) - Maximum effort
- I cannot answer this question

Any comments you would like to make: _____

EXOS TECHNOLOGY

In pruning, lifting the chainsaw for several hours is physically demanding. An exoskeleton, weighing 3 kg, is designed to support the back and muscles. It does not require electricity or batteries, and it is easy to put on.

Agriculture / gardening / forestry

Pruning / fruit picking / handling /cutting / milking



Examples of MATE¹⁵ applications.

Example videos:

- <https://www.youtube.com/watch?v=fjWc2Cfj7pc> (from second 18)
- [Les exosquelettes Comau | Fournials Motoculture - YouTube](#) (from second 17)

1. Functionalities

Question	Likert scale
	1 (strongly disagree)- 5 (strongly agree) or 6 (I cannot answer this question)
• The exoskeleton will support me during pruning.	

¹⁵<https://www.comau.com/en/our-offer/products-and-solutions/wearable-robotics-exoskeletons/wearable-robotics-mate-xt-exoskeleton/>

• The handling of the exoskeleton will be easy to learn.	
• The specific functions of the exoskeleton will be self-explaining.	
• I will be able to control the actions of the exoskeleton at any time.	
• Using the exoskeleton will help me feel better physically at the end of my workday.	
• Operator errors will not lead to serious consequences.	
• I will be able to adapt the exoskeleton to my own needs and abilities.	
• I think that an exoskeleton could help as a support during the process of collecting branches after pruning.	
• The exoskeleton will be able to respond correctly to unexpected situations → example of unexpected situation: fall, rain...	
• If I do not have any physical problems, I do not think I need it.	
• I would wear it, independently of my age.	
• I need the exoskeleton not to affect the agility of my movements.	
• The exoskeleton will help me to improve my movement precision during the pruning.	
• The exoskeleton will increase my productivity.	
• The exoskeleton should be comfortable (not scratch, press or pull anywhere), light and unobtrusive.	

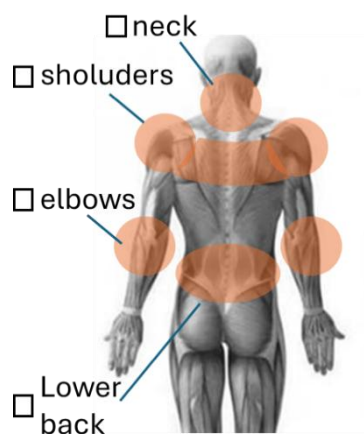
2. Open questions

- How do you think your task will change by using the exoskeleton?
- Is all pruning done with a chainsaw, and is the age of the olive tree relevant for the use of the chainsaw? In other words, in the case of olive trees less than 25-30 years old, is pruning also done with a chainsaw?
- Are there other operations related to the olive grove where an exoskeleton could be of help? For example, the collection of branches, during phytosanitary treatments such as copper spraying or during olive harvesting, such as shaking branches.
- Do you expect benefits from using the exoskeleton? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using the exoskeleton? (in the short- and long-term)? Which ones?
- Are there any other aspects that you consider relevant to this exoskeleton technologies?

3. Questions about fatigued part of the body

Can you tell us in the following tasks which parts of the body suffer the most from fatigue?

These are the areas of the body previously identified:

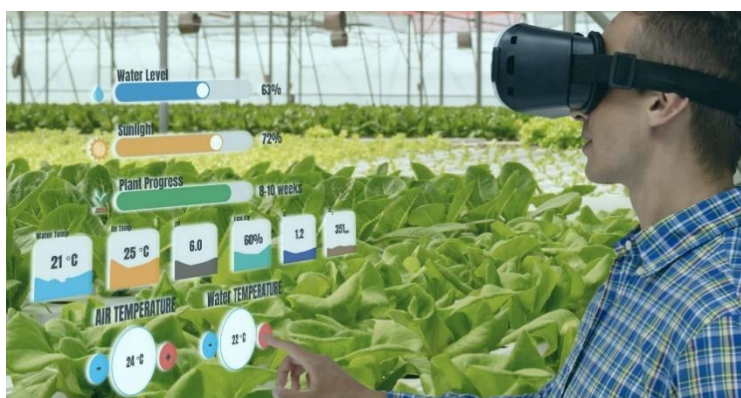


Activity		Fatigue location			
Macro	Micro	Neck	Shoulders	Elbow	Lower back
Pruning	Cutting phase				
	Branch handling				
Harving	Branch shaking				
	Collection from the ground or nets				
	Handling of containers				

AR (AUGMENTED REALITY) TECHNOLOGY

Imagine wearing a pair of smart glasses while pruning olive trees. These augmented reality (AR) glasses overlay digital information onto what you see, helping you identify which branches to cut and which to keep. The goal is to make pruning more efficient and precise, even for less experienced workers or workers in training. The glasses could highlight branches in real time, provide step-by-step guidance, and even offer training support.

Another possibility instead of wearing glasses is to use a mobile device (mobile phone or tablet) with AR technology which, as with the glasses, shows you which branch is the most suitable for pruning.



Example video:

<https://www.youtube.com/watch?v=iWWp8QzRbaU> (show the first 19 seconds of the video)

1. Functionalities

Question	Likert scale 1 (strongly disagree)- 5 (strongly agree) or 6 (I cannot answer this question)
• The AR technology will support my task.	
• The handling of the AR glasses will be easy to learn.	
• The specific functions of the AR technology will be self-explaining.	
• I see any risks associated with wearing the glasses while pruning.	
• I see any risks associated with using a mobile device while pruning.	
• I will be able to understand the information communicated by AR technology graphically rather than textually.	

• In case there is a discrepancy between what the AR technology help system recommends and what I believe, I will accept the help system's recommendation because it will be better for the future.	
• Operator errors will not lead to serious consequences.	
• AR technology devices should offer the possibility of easily adjusting contrast, sharpness and luminance to my needs.	
• AR glasses should have a system that adapts to the operator's physical morphology (holding, adjustment).	
• I would like a well-balanced weight of the AR glasses in order not to have compensatory muscle activity or fatigue.	
• I would like to have visual info of the system status, and/or the next operational steps, with emphasis on ensuring safe operation.	
• It is important that the system provides remote / virtual assistants for learning and training during work.	
• The AR technology will help me to improve my task precision during the pruning.	
• The AR technology will increase my productivity.	
• If I am working with AR glasses for several hours, I would like to have frequent short breaks to take off the device.	
• I clearly see how I could operate a mobile device with AR technology while performing the pruning action.	
• I think that the use of AR technology on a tablet or mobile phone will be just as comfortable as using it with glasses.	
• I think that using AR technology on a tablet or mobile phone will be just as effective as using it with glasses.	

2. Open questions

- How do you think your task will change by using AR technology?
- If you had the possibility to choose which would be the best support for you, for the use of AR technology, which would it be: glasses or mobile device such as tablet or mobile phone?
- Do you expect benefits from using AR technology? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using AR glasses? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using AR in tablet or mobile devices? (in the short- and long-term)? Which ones?
- Are there any other aspects that you consider relevant to this AR technologies?

Annex B: Questionnaire on vineyard pruning

DEMOGRAPHIC DATA

Alias (Not a real name, it will simply serve as an anonymised identifier): _____

Age category:

- ☐ 18-29
- ☐ 30-39
- ☐ 40-49
- ☐ 50-59
- ☐ 60-69
- ☐ More than 69

Gender:

- ☐ Male
- ☐ Female
- ☐ Non-binary
- ☐ Prefer not to say
- ☐ Other: _____

Position: (they do not have to be exclusive)

- ☐ Owner of a vineyard
- ☐ Cooperative member
- ☐ Field supervisor
- ☐ Worker
- ☐ Day labourer (paid per day worked)
- ☐ Other: _____

Years of experience: _____

OPEN QUESTIONS

1. General questions

- What are the main tasks that you do in your job?
- What tasks do you consider most important in your job?
- Who helps you with your work on the farm? Do you hire seasonal workers? If so, where do they come from?
- Do you miss any kind of help in your daily work?
 - ☐ More manpower, what kind of manpower?
 - ☐ More resources? What kind of resources: machinery...?
 - ☐ More technology?
 - ☐ More breaks?

2. Environment

- What is the terrain you are working in like? Is it flat or does it have slopes? Do you walk a lot during your pruning day? Approximately, how much? (e.g.: kms, hours, % of working day...)
- What weather conditions are usually present when pruning is done?

3. Work organisation

- Is there an established schedule for pruning?
- How many hours a day is pruning usually done and at what times?
- What are the main challenges? (e.g. getting the cut right, choosing the right branch, weather conditions)?
- Who supports you during pruning? Do you work alone?
- What would make the pruning task easier and more efficient?

4. Tools used

- What kind of tools do you mainly use for pruning?
- How much do those tools usually weigh? Are they bulky?
- Do these tools need any special transport? For example, do you need a vehicle, can you carry them with you?

5. Pruning process

- Can you describe the pruning process from the start to the end?
- What are the main aspects to consider, or to take into account in the pruning process?
- How do you decide on the actions to be taken, and on what basis? How do you decide on the actions to be taken, and on what basis? (e.g. experience, condition of trees, timing of pruning)?

6. Knowledge acquisition

- How did you learn how to do the pruning process? Who trained you?
- Is there any training time beforehand?
- Are there any standards or guidelines for the pruning process?

ESTIMATED EFFORT

- How do you currently value the effort dedicated to a day of vineyard pruning?

Likert scale effort (from min to max):

- (1) - Very low effort
- (2) - Low effort
- (3) - Moderately low effort
- (4) - Moderate effort
- (5) - Slightly moderate effort
- (6) - Considerable effort
- (7) - High effort

- (8) - Very high effort
- (9) - Extremely high effort
- (10) - Maximum effort
- I cannot answer this question

Any comments you would like to make: _____

AUTONOMOUS ROBOTIC PRUNING PLATFORM (ARPP) TECHNOLOGY

Imagine an autonomous robot designed to assist in vineyard pruning. It consists of a mobile platform with two robotic arms. The control of the robotic arms will be coordinated to obtain collision-free paths, one arm can be used to open space by moving branches away, while the other arm prunes the plant. Both arms will be equipped with custom end-effectors with two positions, enabling both branch grabbing and cutting.

Additionally, the robot is equipped with advanced sensors such as 3D cameras and a navigation system that allow it to identify the branches that need to be pruned and navigate safely and autonomously through the vineyard.



Automatic pruners for the robot



Robotic hand to grasp branches

1. Functionalities

Question	Likert scale
	1 (strongly disagree)- 5 (strongly agree) or 6 (I cannot answer this question)

• The ARPP will support me during pruning.	
• The handling of the ARPP will be easy to learn.	
• The specific functions of the ARPP will be self-explaining.	
• I will be able to control the actions of the ARPP at any time.	
• Using the ARPP will help me feel better physically at the end of my workday.	
• Operator errors will not lead to serious consequences.	
• I believe that the ARPP will be able to function correctly in the different terrains where the vineyards are located.	
• The ARPP should take my preferences into account when communicating with me.	
• The ARPP will be able to respond correctly to unexpected situations → example of unexpected situation: fall, rain...	
• I find useful for ARPP to show me a report of the tasks it has performed, either in real time or on completion.	
• I am confident that the pruning that the ARPP will be correct and will not damage the vineyards.	
• The ARPP will increase my productivity.	
• I am confident that in the event of a stability problem in the ARPP, it will not harm me physically.	
• On the land where the vineyards are cultivated, do you consider that a 'ground station' could be established to provide the necessary infrastructure for a robot (autonomous recharging, telecommunications...)?	

2. Interface human-robot

Regarding the interface for the monitoring or presentation of information by the ARPP, if the ARPP has to communicate a problem or alert to you, what system would you prefer to use for that communication?

Communication system	Likert scale 1-Dislike very much 2-Dislike 3-Neither like nor dislike 4-Like 5-Like very much 6-I cannot answer this question
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• Audio	
• Lights	
• By means of an app with a dashboard type screen	
• Other options:	

3. Open questions

- How do you think your task will change by using the ARPP?
- Do you expect benefits from using the ARPP? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using the ARPP? (in the short- and long-term)? Which ones?
- Are there any other aspects that you consider relevant to this ARPP technologies?

AR (AUGMENTED REALITY) TECHNOLOGY

Imagine wearing a pair of smart glasses while pruning olive trees. These augmented reality (AR) glasses overlay digital information onto what you see, helping you identify which branches to cut and which to keep. The goal is to make pruning more efficient and precise, even for less experienced workers or workers in training. The glasses could highlight branches in real time, provide step-by-step guidance, and even offer training support.

Another possibility instead of wearing glasses is to use a mobile device (mobile phone or tablet) with AR technology which, as with the glasses, shows you which branch is the most suitable for pruning.



Example video:

<https://www.youtube.com/watch?v=iWWp8QzRbaU> (show the first 19 seconds of the video)

1. Functionalities

Question	Likert scale
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	1 (strongly disagree)- 5 (strongly agree) or 6 (I cannot answer this question)
• The AR technology will support my task.	
• The handling of the AR glasses will be easy to learn.	
• The specific functions of the AR technology will be self-explaining.	
• I see any risks associated with wearing the glasses while pruning.	
• I see any risks associated with using a mobile device while pruning.	
• I will be able to understand the information communicated by AR technology graphically rather than textually.	
• In case there is a discrepancy between what the AR technology help system recommends and what I believe, I will accept the help system's recommendation because it will be better for the future.	
• Operator errors will not lead to serious consequences.	
• AR technology devices should offer the possibility of easily adjusting contrast, sharpness and luminance to my needs.	
• AR glasses should have a system that adapts to the operator's physical morphology (holding, adjustment).	
• I would like a well-balanced weight of the AR glasses in order not to have compensatory muscle activity or fatigue.	
• I would like to have visual info of the system status, and/or the next operational steps, with emphasis on ensuring safe operation.	
• It is important that the system provides remote / virtual assistants for learning and training during work.	
• The AR technology will help me to improve my task precision during the pruning.	
• The AR technology will increase my productivity.	
• If I am working with AR glasses for several hours, I would like to have frequent short breaks to take off the device.	
• I clearly see how I could operate a mobile device with AR technology while performing the pruning action.	
• I think that the use of AR technology on a tablet or mobile phone will be just as comfortable as using it with glasses.	

- | | |
|--|--|
| <ul style="list-style-type: none"> I think that using AR technology on a tablet or mobile phone will be just as effective as using it with glasses. | |
|--|--|

2. Open questions

- How do you think your task will change by using AR technology?
- If you had the possibility to choose which would be the best support for you, for the use of AR technology, which would it be: glasses or mobile device such as tablet or mobile phone?
- Do you expect benefits from using AR technology? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using AR glasses? (in the short- and long-term)? Which ones?
- Where do you see potential problems when using AR in tablet or mobile devices? (in the short- and long-term)? Which ones?
- Are there any other aspects that you consider relevant to this AR technologies?

Annex C: Categorisation of statements about perceptions of the use of Exoskeleton Technology in olive tree pruning

This is the list of statements organized by category, used in the questionnaire to harvest the perception about the use of Skeletons Technology in olive tree pruning process:

Acceptance

- If I do not have any physical problems, I do not think I need it.
- I would wear it, independently of my age.

Adaptability

- I will be able to adapt the exoskeleton to my own needs and abilities.
- The exoskeleton will be able to respond correctly to unexpected situations (e.g., fall, rain).

Ease of Use

- The handling of the exoskeleton will be easy to learn.
- The specific functions of the exoskeleton will be self-explaining.

Reliability

- I need the exoskeleton not to affect the agility of my movements.
- The exoskeleton will help me to improve my movement precision during the pruning.

Safety

- Operator errors will not lead to serious consequences.
- The exoskeleton should be comfortable (not scratch, press or pull anywhere), light and unobtrusive. (Note: This statement is also listed under Risk Perception)

Trust

- I will be able to control the actions of the exoskeleton at any time.
- Using the exoskeleton will help me feel better physically at the end of my workday.

Utility

- The exoskeleton will support me during pruning.
- I think that an exoskeleton could help as a support during the process of collecting branches after pruning.
- The exoskeleton will increase my productivity.

Annex D: Categorisation of statements about perceptions of the use of Augmented Reality Technology in olive tree and vineyard pruning

This is the list of statements organized by category, used in the questionnaire to harvest the perception about the use of Augmented Reality Technology in olive tree and vineyard pruning process:

Acceptance

- I would like a well-balanced weight of the AR glasses in order not to have compensatory muscle activity or fatigue.
- I would like to have visual info of the system status, and/or the next operational steps, with emphasis on ensuring safe operation.
- I clearly see how I could operate a mobile device with AR technology while performing the pruning action.

Adaptability

- AR technology devices should offer the possibility of easily adjusting contrast, sharpness and luminance to my needs.
- AR glasses should have a system that adapts to the operator's physical morphology (holding, adjustment).

Ease of Use

- The handling of the AR glasses will be easy to learn.
- The specific functions of the AR technology will be self-explaining.

Reliability

- It is important that the system provides remote / virtual assistants for learning and training during work.
- The AR technology will help me to improve my task precision during the pruning.

Safety

- I see any risks associated with wearing the glasses while pruning.
- I see any risks associated with using a mobile device while pruning.
- Operator errors will not lead to serious consequences.
- If I am working with AR glasses for several hours, I would like to have frequent short breaks to take off the device.

Trust

- I will be able to understand the information communicated by AR technology graphically rather than textually.
- In case there is a discrepancy between what the AR technology help system recommends and what I believe, I will accept the help system's recommendation because it will be better for the future.

Utility

- The AR technology will support my task.
- The AR technology will increase my productivity.

- I think that the use of AR technology on a tablet or mobile phone will be just as comfortable as using it with glasses.
- I think that using AR technology on a tablet or mobile phone will be just as effective as using it with glasses.

Annex E: Categorisation of statements about perceptions of the use of Autonomous Robotic Pruning Platform (ARPP) Technology in vineyards pruning

This is the list of statements organized by category, used in the questionnaire to harvest the perception about the use of Autonomous Robotic Pruning Platform (ARPP) Technology in vineyards pruning process:

Adaptability

- The ARPP should take my preferences into account when communicating with me.
- The ARPP will be able to respond correctly to unexpected situations example of unexpected situation: fall, rain...

Ease of use

- The handling of the ARPP will be easy to learn.
- The specific functions of the ARPP will be self-explaining.

Reliability

- I believe that the ARPP will be able to function correctly in the different terrains where the vineyards are located.
- I find useful for ARPP to show me a report of the tasks it has performed, either in real time or on completion.
- On the land where the vineyards are cultivated, do you consider that a 'ground station' could be established to provide the necessary infrastructure for a robot (autonomous recharging, telecommunications...)?

Safety

- Operator errors will not lead to serious consequences.
- I am confident that in the event of a stability problem in the ARPP, it will not harm me physically.

Trust

- I will be able to control the actions of the ARPP at any time.
- Using the ARPP will help me feel better physically at the end of my workday.
- I am confident that the pruning that the ARPP will be correct and will not damage the vineyards.

Utility

- The ARPP will support me during pruning.
- The ARPP will increase my productivity.

Annex F: Complete requirements table

Human centric requirements

ID	DESCRIPTION	FUNCT / NON FUNCT	RATIONALE	PRIORITY	DIFFICULTY	PILOT	TEOs
Req_01	Standardized pruning guidelines and decision support tools	9. Functional	Standardized pruning guidelines and decision support tools are essential for ensuring consistency, efficiency, and quality in olive tree and vineyards pruning. These tools help workers make informed, uniform decisions aligned with agronomic objectives. They reduce variability, support training, and enhance communication across teams. By promoting best practices and data-driven actions, they contribute to healthier trees, improved yields, and the long-term sustainability of olive cultivation.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer
Req_02	Training programs on pruning and assistive technologies	9. Functional	There is a shortage of skilled labor due to the physical demands of pruning. Training programs on pruning and assistive technologies are crucial for equipping workers with the skills and knowledge needed to perform tasks efficiently and safely. These programs ensure proper pruning techniques, promote the effective use of tools and technologies, and reduce the risk of errors or injuries. Continuous training also supports adaptation to innovations, enhances productivity, and contributes to the overall sustainability of olive trees and vineyard management.	COULD (preferred but not necessary)	Medium	All	TEO2 – AR Trainer, TEO4 – Assistive Exoskeleton
Req_03	Ergonomic tools design for pruning	11. Usability and Humanity Requirements	Workers experience fatigue from long hours and challenging terrain. Ergonomic tool design for pruning is essential to reduce physical strain, prevent injuries, and improve worker comfort and efficiency. Properly designed tools minimize repetitive stress and awkward postures, enabling longer, more productive work sessions. By aligning with human biomechanics, ergonomic tools support worker well-being, reduce fatigue, and contribute to higher-quality pruning outcomes, ultimately enhancing both labor sustainability and overall olive trees or vineyard performance.	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_04	Necessity of real-time, data-informed decision-making capabilities during pruning tasks	12. Performance Requirements	Pruning requires constant decision-making, leading to mental fatigue. Cognitive support systems and AI-based decision aids enhance pruning operations by providing real-time, data-driven recommendations. These tools help workers and managers make more accurate, consistent decisions, especially in complex or variable conditions. By reducing cognitive load and uncertainty, they improve efficiency, training, and outcomes. Integrating AI into fieldwork supports precision agriculture, optimizes resource use, and contributes to more sustainable and intelligent crop management.	MUST (mandatory)	Medium, High	All	TEO1 – AR Guide, TEO5 – Assessing Tool
Req_05	Adaptable machinery or lightweight tools for uneven terrain	13. Operational and Environmental Requirements	Hilly or mountainous terrain complicates mechanization and pruning on uneven terrain presents significant physical and operational challenges, including reduced mobility, increased fatigue, and higher risk of injury. Adaptable machinery or lightweight tools are essential to ensure safe, efficient work in such conditions. By accommodating variable ground conditions, these tools enhance worker comfort, reduce strain, and maintain productivity, ultimately supporting sustainable labor practices and consistent pruning quality across diverse landscapes.	SHOULD (of high priority)	Medium, High	Grape vines pruning (Athens)	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_06	Smart tool recommendations for pruning tool selection	11. Usability and Humanity Requirements	Selecting the right pruning tool for specific tasks, tree types, or worker needs can be challenging, context dependent and time-consuming. Smart tool recommendation systems address this by guiding users toward optimal choices based on context, reducing trial-and-error and improving efficiency. These systems enhance safety, comfort, and pruning quality by matching tools to ergonomic and operational requirements, ultimately supporting more effective and sustainable fieldwork.	WOULD (can be postponed and suggested for future execution)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer
Req_07	Visual guiding support for branch cut selection	12. Performance Requirements	Selecting the correct branch to cut during pruning can be complex, especially for less experienced workers or in dense canopies. Visual guiding support systems help by highlighting optimal cuts based on plant structure and pruning objectives. This reduces errors, improves consistency, and enhances training. By simplifying decision-making in the field, these tools contribute to better plant health, productivity, and overall pruning efficiency.	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)	TEO1 – AR Guide
Req_08	Integrate weather forecasting and scheduling tools	13. Operational and Environmental Requirements	Pruning timing is sensitive to climate and frost risk. Weather conditions significantly impact pruning operations, affecting worker safety, tool performance, and plant response. Integrating weather forecasting with scheduling tools allows for better planning, reducing downtime and avoiding adverse conditions. This leads to more efficient use of labor and resources, minimizes crop damage, and supports timely interventions. Such integration enhances operational resilience and contributes to more sustainable and climate-adaptive agricultural practices.	WOULD (can be postponed and suggested for future execution)	Medium	All	TEO1 – AR Guide, TEO5 – Assessing Tool
Req_09	Develop digital knowledge bases or interactive learning platforms	12. Performance Requirements	Knowledge transfer is often informal and generational. Digital knowledge bases and interactive learning platforms are essential for capturing, organizing, and sharing pruning expertise across teams and generations. They support continuous learning, reduce training time, and ensure consistent practices. By offering accessible, up-to-date information and engaging learning experiences, these tools empower workers, enhance decision-making, and promote the adoption of best practices, ultimately improving productivity and sustainability in pruning operations.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer

Req_10	Precision cutting tools with feedback mechanisms	15. Security Requirements	Clean cuts are essential for tree health and olive oil quality. Precision cutting tools with feedback mechanisms enhance pruning accuracy and safety by providing real-time information on cut quality, pressure, or positioning. This helps workers make more consistent and effective cuts, reducing plant damage and fatigue. Feedback systems also support skill development and error prevention, especially for less experienced users, ultimately improving pruning outcomes and contributing to more efficient and sustainable agricultural practices.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO3 – Automatic Pruner
Req_11	The worker shall have their hands free during pruning and training operations	11. Usability and Humanity Requirements	Having hands free during pruning and training operations is essential for safety, precision, and efficiency. Workers often need to maneuver tools, stabilize branches, or adjust their position, which requires full manual mobility. Ensuring hands-free conditions—through appropriate gear or workflow design—reduces the risk of accidents, enhances task performance, and supports ergonomic practices, ultimately contributing to better outcomes and worker well-being in the field.	MUST (mandatory)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer
Req_12	Assistive tools design for pruning tailored to user diversity	11. Usability and Humanity Requirements	Designing assistive pruning tools tailored to user diversity ensures accessibility, comfort, and effectiveness for workers of different ages, physical abilities, and experience levels. Inclusive tool design reduces fatigue and injury risk, enhances performance, and promotes equal participation in agricultural tasks. By accommodating diverse user needs, these tools support a safer, more productive, and socially responsible approach to pruning across varied labor forces.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO4 – Assistive Exoskeleton
Req_13	Assistive tools design for pruning tailored to environmental status (clarity, luminance, contrast)	13. Operational and Environmental Requirements	Environmental conditions such as low light, glare, or poor contrast can significantly affect visibility and precision during pruning. Designing assistive tools that adapt to or compensate for these factors—through enhanced visibility features, lighting integration, or contrast-sensitive interfaces—improves safety, accuracy, and usability. Tailoring tools to environmental status ensures consistent performance and reduces errors, especially in early morning, late evening, or shaded conditions.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer
Req_14	Assistive tools for pruning handling easy to learn and self-explaining	11. Usability and Humanity Requirements	Pruning tools that are easy to learn and self-explaining reduce training time, lower the risk of misuse, and empower workers to operate confidently and independently. Intuitive design features—such as visual cues, ergonomic grips, and simplified controls—enhance usability for diverse users. These tools support faster onboarding, improve task efficiency, and ensure consistent pruning quality, especially in dynamic or labor-constrained agricultural environments.	MUST (mandatory)	Medium, High	All	TEO1 – AR Guide, TEO4 – Assistive Exoskeleton
Req_15	Assistive tool control in hands of end user	13. Operational and Environmental Requirements	Placing control of assistive pruning tools in the hands of the end user ensures adaptability, responsiveness, and user confidence. When workers can directly manage tool functions, they can adjust to real-time conditions, personal preferences, and specific pruning needs. This autonomy enhances precision, safety, and satisfaction, while also supporting skill development and reducing reliance on external supervision or complex automated systems.	MUST (mandatory)	Medium, High	All	TEO1 – AR Guide, TEO4 – Assistive Exoskeleton
Req_16	Perception of physical wellbeing with the help of an assistive tool	15. Security Requirements	Enhancing the perception of physical wellbeing through assistive tools is key to maintaining worker motivation, comfort, and long-term health. Tools that reduce strain, support posture, and minimize fatigue help users feel more capable and less stressed. When workers perceive physical ease and safety, their performance, satisfaction, and engagement improve—contributing to higher productivity and a more sustainable, human-centered approach to pruning tasks.	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)	TEO4 – Assistive Exoskeleton
Req_17	Agility and precision of movements allowed by the assistive tool	11. Usability and Humanity Requirements	Assistive tools that support agile and precise movements enable workers to perform pruning tasks more effectively, especially in complex or constrained environments. Enhanced mobility and control reduce physical strain, improve cut accuracy, and allow for smoother task execution. This leads to higher-quality outcomes, greater worker confidence, and improved overall efficiency, particularly when navigating dense canopies or uneven terrain.	MUST (mandatory)	Medium	All	TEO1 – AR Guide, TEO4 – Assistive Exoskeleton
Req_18	Assistive tool safe to use by worker	15. Security Requirements	Ensuring the safety of assistive tools used in olive and vineyard pruning is vital to protect workers from cuts, repetitive strain, and equipment-related injuries. These tools often operate in rugged terrain and involve sharp components, so ergonomic and mechanical safety features are essential. A safe tool enhances worker confidence, reduces downtime from accidents, and supports sustainable, efficient agricultural practices in demanding field conditions.	SHOULD (of high priority)	Medium, High	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_19	The system will task allocate depending on worker skills	11. Usability and Humanity Requirements	Allocating tasks based on worker skills ensures efficiency, safety, and quality in vineyard and olive trees operations. Skilled workers can handle complex or delicate tasks like precision pruning, while less experienced staff can support with simpler duties. This targeted assignment maximizes productivity, reduces errors, and enhances job satisfaction. It also supports training by gradually introducing workers to more advanced tasks aligned with their growing competencies.	MUST (mandatory)	Medium	All	TEO1 – AR Guide, TEO5 – Assessing Tool

Req_20	The system gives the worker personalized information for learning depending on worker skills	11. Usability and Humanity Requirements	Delivering personalized learning information based on worker skills enhances training effectiveness and operational performance. By adapting content to individual experience levels, the system ensures that each worker receives relevant, manageable guidance. This approach accelerates skill development, reduces errors, and fosters confidence. In dynamic environments like vineyards and olive trees, it supports continuous learning, enabling workers to grow into more complex roles while maintaining productivity and safety.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide
Req_21	Assessment of anticipated health risks for the worker	17. Compliance Requirements	Assessing anticipated health risks for workers is essential to ensure safety, prevent injuries, and promote long-term well-being. In physically demanding environments like vineyards and olive trees, risks may include repetitive strain, exposure to chemicals, or extreme weather. Identifying these hazards in advance enables the implementation of protective measures, training, and ergonomic solutions, fostering a safer workplace and supporting compliance with occupational health regulations.	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)	TEO4 – Assistive Exoskeleton

Technical requirements

ID	DESCRIPTION	FUNCT / NON FUNCT	RATIONALE	PRIORITY	DIFFICULTY	PILOT	TEOs
Req_22	Interactive guide for real-time pruning instructions	12. Performance Requirements	An interactive guide for real-time pruning instructions supports workers by delivering step-by-step guidance tailored to the specific plant and context. This reduces uncertainty, improves accuracy, and enhances learning, especially for less experienced users. Real-time support minimizes errors, ensures consistency with pruning objectives, and increases overall efficiency. Such tools empower workers in the field, leading to better plant health and more sustainable pruning practices.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO2 – AR Trainer
Req_23	Inclusive and personalized training tools for pruning education	11. Usability and Humanity Requirements	Inclusive and personalized training tools for pruning education ensure that workers of diverse backgrounds, skill levels, and learning styles can access and benefit from effective instruction. By adapting content to individual needs—such as language, experience, or physical ability—these tools promote equal learning opportunities, improve knowledge retention, and boost confidence. This leads to safer, more consistent pruning practices and supports a more skilled and empowered agricultural workforce.	MUST (mandatory)	Low, Medium	All	TEO2 – AR Trainer, TEO4 – Assistive Exoskeleton
Req_24	Robotic pruning system should be automatized	12. Performance Requirements	Automating robotic pruning systems is essential to increase efficiency, consistency, and scalability in agricultural operations. Manual control limits speed and precision, especially in large or complex environments. Full automation enables continuous operation, reduces labor dependency, and ensures uniform pruning quality. It also allows integration with data-driven decision systems, supporting precision agriculture and long-term sustainability through optimized resource use and reduced human error.	MUST (mandatory)	Medium, High	Grape vines pruning (Athens)	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_25	Centralized system to record and access individual tree history and pruning data	9. Functional	The implementation of a digital passport and historical record for each tree (olive or vine) is essential for optimizing pruning practices and ensuring long-term productivity and health. This digital profile serves as a centralized repository of critical data (including planting date, variety, pruning history, disease incidents, treatments applied, and yield record) for better decision-making and traceability.	MUST (mandatory)	Medium, High	All	TEO5 – Assessing Tool
Req_26	Pruning plans based on tree's traceable history	12. Performance Requirements	By maintaining a comprehensive and traceable history, agronomists and field workers can make informed decisions tailored to each tree's specific needs. This enables precision agriculture practices, reduces the risk of over- or under-pruning, and supports sustainable management strategies. Additionally, the digital passport facilitates compliance with agricultural regulations and certifications, enhances traceability for quality assurance, and provides valuable insights for research and continuous improvement.	MUST (mandatory)	Medium	All	TEO5 – Assessing Tool
Req_27	Assistive tools design for pruning with heavy tools	12. Performance Requirements	Pruning with heavy tools can lead to worker fatigue, strain, and injury, especially during prolonged tasks or in challenging environments. Assistive tool designs—such as supports or exoskeletons—help reduce physical load and improve control. These solutions enhance safety, comfort, and precision, enabling workers to operate more efficiently and sustainably while maintaining high-quality pruning standards across diverse agricultural settings.	MUST (mandatory)	Medium, High	Traditional Olive Trees Pruning (Jaen)	TEO4 – Assistive Exoskeleton
Req_28	Possibility of using the assistive tool in different pruning tasks	13. Operational and Environmental Requirements	Designing assistive tools that can be used across different pruning tasks increases their versatility, cost-effectiveness, and user adoption. A multifunctional tool reduces the need for multiple devices, simplifies training, and supports seamless transitions between tasks. This flexibility enhances operational efficiency, minimizes downtime, and ensures that workers are better equipped to handle diverse pruning scenarios with a single, adaptable solution.	COULD (preferred but not necessary)	Medium	Traditional Olive Trees Pruning (Jaen)	TEO4 – Assistive Exoskeleton
Req_29	Assistive tool correct response to unexpected situations (fall or bad weather conditions)	13. Operational and Environmental Requirements	Ensuring that assistive tools respond correctly to unexpected situations—such as falls or adverse weather—enhances worker safety, tool durability, and task continuity. Tools designed with adaptive features or protective mechanisms can prevent damage, reduce injury risk, and maintain functionality under stress. This resilience builds user trust, supports uninterrupted operations, and contributes to a safer, more reliable pruning environment in dynamic field conditions.	MUST (mandatory)	Medium, High	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_30	Graphic interface for communicating information enriching messages	11. Usability and Humanity Requirements	A graphic interface designed to communicate enriching messages enhances user understanding by presenting complex information in an intuitive, visually engaging format. In agricultural or industrial settings, such interfaces can guide workers through tasks, alert them to hazards, or provide performance feedback. This improves decision-making, reduces errors, and supports training by making information more accessible, memorable, and actionable in real-time environments.	COULD (preferred but not necessary)	Medium	All	TEO1 – AR Guide, TEO3 – Automatic Pruner
Req_31	Clear information of the system status	15. Security Requirements	Providing clear information about the system status is essential for maintaining user awareness and operational efficiency. In dynamic environments like agriculture or machinery use, real-time feedback on tool performance, battery level, or connectivity helps prevent misuse, downtime, or damage. This transparency supports informed decision-making, enhances safety, and builds user trust by ensuring the system communicates its condition effectively and consistently.	MUST (mandatory)	Medium	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton

Req_32	Sufficient energy load for assistive and autonomous tools	13. Operational and Environmental Requirements	In vineyard and olive tree operations, assistive and autonomous tools must have sufficient energy capacity to perform tasks reliably throughout the workday. Inadequate energy supply can interrupt pruning, monitoring, or harvesting, leading to inefficiencies and crop loss. Ensuring a robust energy load supports continuous operation, reduces downtime, and enhances productivity, especially in remote or large vineyard areas where frequent recharging or battery swaps are impractical.	MUST (mandatory)	Medium, High	All	TEO1 – AR Guide, TEO3 – Automatic Pruner
Req_33	Ease of exchange of end effectors of the autonomous system	14. Maintainability and Support Requirements	In vineyard and olive trees automation, the ability to easily exchange end effectors—such as pruning shears, sprayers, or grippers—enhances system versatility and reduces downtime. Quick and tool-free swapping allows the autonomous system to adapt to different tasks or crop conditions efficiently. This flexibility supports cost-effective operations, simplifies maintenance, and ensures the system remains productive across various vineyard and olive trees management activities throughout the growing season.	MUST (mandatory)	Medium	All	TEO3 – Automatic Pruner

Business requirements

ID	DESCRIPTION	FUNCT / NON FUNCT	RATIONALE	PRIORITY	DIFFICULTY	PILOT	TEOs
Req_34	Sustainable practices with mulching equipment	13. Operational and Environmental Requirements	Burning branches is environmentally harmful. Implementing sustainable practices with mulching equipment helps reduce organic waste, improve soil health, and retain moisture in olive trees and vineyards. By recycling pruned biomass into mulch, this approach minimizes the need for chemical inputs and irrigation. It also supports biodiversity and carbon sequestration. Using dedicated mulching tools enhances efficiency and promotes environmentally responsible management, aligning agricultural practices with long-term ecological and economic sustainability goals.	MUST (mandatory)	Medium	All	TEO5 – Assessing Tool
Req_35	Assistive tool focused on productivity increase	13. Operational and Environmental Requirements	Assistive tools designed to boost productivity help workers complete pruning tasks faster and with greater consistency. By reducing physical effort, minimizing errors, and streamlining repetitive actions, these tools enable more efficient workflows. Increased productivity not only lowers labor costs and time requirements but also supports timely interventions, leading to healthier plants, improved yields, and more sustainable agricultural operations overall.	MUST (mandatory)	Medium	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_36	Pruning leftovers should have a sustainable management	14. Maintainability and Support Requirements	Sustainable management of pruning leftovers in vineyards is essential to minimize environmental impact and promote circular agriculture. Improper disposal can lead to disease spread or waste accumulation. By composting, mulching, or repurposing biomass, vineyards and olive trees can enrich soil health, reduce carbon footprint, and align with eco-friendly practices. This approach supports long-term vineyard and olive trees productivity while meeting environmental regulations and sustainability goals.	MUST (mandatory)	Low	All	TEO3 – Automatic Pruner, TEO5 – Assessing Tool
Req_37	Pruning outcomes should be assessed based on various pruning techniques	12. Performance Requirements	Assessing pruning outcomes based on various techniques ensures optimal vine health, yield quality, and long-term vineyard productivity. Different methods—such as spur, cane, or mechanical pruning—affect plant structure and fruit development differently. Evaluating results across techniques allows for data-driven decisions tailored to grape variety, climate, and vineyard goals, ultimately improving efficiency, sustainability, and adaptability in vineyard management practices.	MUST (mandatory)	Medium, High	All	TEO1 – AR Guide, TEO5 – Assessing Tool
Req_38	Assessment of psychosocial working conditions pre- and post-AI implementation	11. Usability and Humanity Requirements	In vineyards and olive trees environment, assessing psychosocial working conditions before and after AI implementation is key to understanding its impact on workers' mental well-being, job roles, and team dynamics. AI may alter task distribution, reduce physical strain, or introduce new stressors. Evaluating these changes helps ensure that technology supports a healthy, inclusive work environment, maintains motivation, and fosters positive adaptation among vineyard staff.	MUST (mandatory)	Medium	All	TEO5 – Assessing Tool
Req_39	Build peer networks and social support platforms for farmers	14. Maintainability and Support Requirements	Creating peer networks and social support platforms for farmers fosters knowledge exchange, emotional resilience, and community-driven innovation. In vineyard and olive trees settings, these networks help share best practices, troubleshoot challenges, and reduce isolation. Social support enhances mental well-being, encourages collaboration, and strengthens adaptive capacity in the face of climate, market, or technological changes—ultimately contributing to more sustainable and connected farming communities.	MUST (mandatory)	Low, Medium	All	TEO5 – Assessing Tool
Req_40	Ensure inclusive task allocation between human and AI to maintain autonomy and competence	11. Usability and Humanity Requirements	Inclusive task allocation between humans and AI ensures that workers retain autonomy, purpose, and skill relevance in evolving vineyard and olive trees operations. By thoughtfully distributing tasks—assigning repetitive or hazardous duties to AI and complex, judgment-based roles to humans—the system supports worker engagement and competence. This balance fosters collaboration, prevents deskilling, and promotes a sustainable integration of AI that respects human value and expertise.	MUST (mandatory)	Medium	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_41	Monitor AI technology acceptance and its impact on well-being	11. Usability and Humanity Requirements	Monitoring AI technology acceptance and its impact on well-being is essential to ensure successful integration in vineyard and olive trees operations. Workers' perceptions influence adoption, trust, and collaboration with AI systems. Tracking acceptance helps identify concerns, reduce resistance, and guide supportive interventions. Evaluating well-being ensures that AI enhances, rather than harms, mental health, job satisfaction, and social dynamics, fostering a balanced and sustainable work environment.	MUST (mandatory)	Medium	All	TEO4 – Assistive Exoskeleton, TEO5 – Assessing Tool
Req_42	Demonstration of technological solutions in real-world vineyards and olive trees pilot scenarios	13. Operational and Environmental Requirements	Demonstrating technological solutions in real-world vineyards and olive tree pilot scenarios is essential to validate performance, usability, and adaptability under actual working conditions. Field trials reveal practical challenges, user feedback, and environmental impacts that lab tests may overlook. These demonstrations build trust among farmers, support iterative improvements, and ensure that innovations are truly effective, scalable, and aligned with the needs of end users.	SHOULD (of high priority)	Medium	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton

Req_43	Dissemination project results and foster collaboration through open calls	14. Maintainability and Support Requirements	Promoting collaboration and dissemination of project results ensures that knowledge, innovations, and best practices reach a wide audience, including farmers, researchers, and policymakers. Sharing outcomes fosters transparency, accelerates adoption, and encourages feedback for improvement. Collaborative efforts strengthen networks, avoid duplication of work, and support the scaling of successful solutions, ultimately maximizing the impact and sustainability of agricultural innovation projects.	MUST (mandatory)	Low, Medium	All	TEO3 – Automatic Pruner, TEO4 – Assistive Exoskeleton
Req_44	Ensure ethical implementation, data privacy, and inclusivity	17. Compliance Requirements	Ensuring ethical implementation, data privacy, and inclusivity is vital for responsible technology deployment in agriculture. Protecting personal and operational data builds trust among users, while inclusive design ensures accessibility for diverse farming communities. Ethical practices prevent misuse, promote fairness, and align with legal and societal values. Together, these principles support sustainable innovation that respects human rights and benefits all stakeholders in the agricultural ecosystem.	SHOULD (of high priority)	Medium	All	TEO2 – AR Trainer, TEO4 – Assistive Exoskeleton