# Pilot 6 – Agriculture

## Pilot Introduction

Viticulture is an important source of employment in Portugal. However, the growing lack of human labour to manage vineyards effectively has become a concern., namely in the Douro Demarcated Region (DDR), the oldest demarcated wine region in the world. Managing a vineyard requires a significant investment of workers’ time and energy.

This is a problem because human labour is essential in this region, where a mountain viticulture is practiced, that is, where the vineyards are located on steep slopes, in which modern machinery cannot manoeuvre.

In this sense, the intent of this agricultural pilot is to reduce workers’ physical stress to make this trade more attractive while, at the same time, to improve the consistency of grapes / wine production and to reduce the grapevine mortality rate. For this, a novel solution for high-performance sustainable management of the old, terraced vineyards of Quinta do Crasto (QDC), is expected to be developed that will be supported on advanced trustworthy digital technologies.

The goal is to: i) ensure that human workers remain central to the process, with AI and robotics serving as tools to enhance their capabilities; ii) use AI and robotics to assist personnel in their tasks, improving efficiency and accuracy; iii) use leverage data and AI insights to help workers make more informed decisions about vineyard management.

## Description of Use Cases

### UC-AGR-1: Identification of grape varieties in Quinta do Crasto’s old vineyards

**Objective:**

To accelerate the preservation of old vineyards, this approach will use human-centred digital twins, AI-powered decision support, and explainability mechanisms to identify all grape varieties. The system will operate during the summer, assisting workers by performing tasks during the hottest hours of the day. Autonomous drones will play a key role in this process, enabling efficient data collection by covering large vineyard areas quickly and ensuring consistent, high-quality imagery for AI analysis. Preserving this terroir is only possible through the identification of its varietal diversity. Since some grapevines are expected to die due to their advanced age, this identification process ensures that each lost vine can be replaced with a genetically identical one, maintaining the vineyard's unique characteristics.

**Scenario:**

In this use case, vineyard conditions will be analysed, and grape varieties will be identified based on collected photographic data. Leaf morphology, a critical factor in varietal identification, will be assessed primarily using images captured from drones but may also be provided by other data sources, such as ground-based cameras or mobile devices. The collected data includes leaf images for morphological analysis, which are essential for varietal identification. The AI-powered classification models process these images and function as an extension of the researcher’s vision, assisting in the identification of grape varieties. The decision support system ensures transparent, explainable predictions, allowing vineyard experts to validate AI recommendations. When uncertainty arises (e.g., overlapping vines or difficult classifications), task-sharing mechanisms will shift the task to a human expert for final verification.

**Key Requirements:**

* The identification of grape varieties shall be transparent, explainable, and validated by human experts through a context-aware decision support system (Shall).
* Task planning shall balance AI-driven automation and human intervention when uncertainty is high, while also ensuring that worker presence data is acquired and used to adjust operations accordingly to maintain safety (Shall).
* A digital twin shall manage grape variety data, ensuring traceability and supporting autonomous vineyard operations (Shall).
* Varietal identification data shall be provided in a GIS-compatible format to enable direct integration into Quinta do Crasto’s management system.

### UC-AGR-2: Monitoring of remote steep-slope vineyard plots

**Objective:**

Enhancing vineyard management through AI-driven monitoring and decision-making that provides accurate insights into key vineyard conditions. By automating data collection and analysis, the system minimizes manual labour, particularly in hard-to-reach areas such as QDC’s old vineyards. The integration of drones and other sensing technologies ensures comprehensive and timely data acquisition, enabling precise assessments of vine health, environmental conditions, and weather-related risks.

**Scenario:**

A monitoring system analyses vineyard conditions in remote steep-slope vineyard plots, where traditional monitoring is difficult and labour-intensive. Using multispectral imaging and environmental sensors, drones and other data sources capture information on vine vigour, air temperature, humidity, radiation, precipitation, and wind speed. Data processing algorithms detect trends, identify anomalies, and support routine vineyard monitoring, phenology tracking, and post-weather event assessments (e.g., after heatwaves or heavy rainfall).

**Key Requirements:**

* Vineyard conditions - including environmental factors and vegetation indices (e.g., NDVI, SAVI) — shall be collected, analysed, and integrated into a site-wide assessment using drone imagery and sensor data (Shall).
* A digital twin shall manage vineyard monitoring data, supporting predictive environmental analysis and long-term vineyard health assessments (Shall).
* Vineyard monitoring shall be explainable and validated by human experts through a decision support system that integrates AI-driven analytics for detecting environmental anomalies and tracking vineyard health trends over time (Shall).
* Vineyard monitoring data shall be provided in a GIS-compatible format to enable its integration with Quinta do Crasto’s vineyard management system for decision-making (Shall).

### UC-AGR-3: Transport of the grapes in a steep-slope vineyard during the harvest season

**Objective:**

To improve harvest efficiency and worker safety in steep-slope vineyards by integrating AI-powered grape transport and monitoring of worker fatigue. Automation reduces the need for manual carrying of grape boxes, alleviating physical strain, and optimizing harvest operations through intelligent scheduling and adaptive workload distribution.

**Scenario:**

Harvesting grapes in steep-slope vineyards requires workers to manually transport 22 kg boxes up difficult terrain, leading to fatigue and injury risks over 40-50 days of continuous work. To reduce strain, an AI-powered cargo drone will assist with grape transport, reducing the number of manual trips required.

Additionally, workers will wear IoT sensors that track fatigue, repetitive movements, and sun exposure. The system will analyse collected worker fatigue data to optimize task distribution and ensure sustainable harvesting conditions. Fatigue and transport efficiency data shall be integrated into a vineyard management system, allowing vineyard managers to adjust workload distribution as needed.

**Key Requirements:**

* Worker fatigue can be assessed using wearable sensor data, enabling informed adjustments in task scheduling where applicable (Shall).
* The AI system shall dynamically adjust transport task allocation at predefined intervals, ensuring optimized drone dispatch while allowing workers to validate and refine scheduling suggestions based on operational conditions (Shall).
* The system shall provide clear reasoning for its recommendations, ensuring workers understand why breaks or task adjustments are suggested (Shall).
* The system should provide vineyard supervisors with tools to optimize worker allocation and auxiliary equipment use, particularly when labour shortages impact demanding tasks (Should).
* The AI transport scheduling shall prioritize drone dispatch based on worker fatigue levels, harvest rates, and terrain constraints (Shall).

## Plan for Integration of Technologies

This section explains the envisaged use of the AI4Work technologies in each UC.

### UC-AGR-1: Identification of grape varieties in Quinta do Crasto’s old vineyards

Several advanced technologies are required to promote the success of this use case:

* **Data Collection and Handling for AI/Robotics Services:** Captures and processes leaf images from drones and other photographic sources, integrating additional sensor data where applicable, to support AI-driven grape variety identification.
* **Long-Term Adaptation:** AI models can be updated periodically based on new data and user feedback to refine predictions and improve adaptability.
* **Runtime Monitoring for Trustworthy AI:** Ensures the consistency and accuracy of collected data, validating image quality and detecting anomalies during processing.
* **Digital Twin:** Digital Twin models of grapevine varieties by integrating morphological and environmental data, supporting identification and long-term preservation.
* **Context Awareness:** AI models analyse visual and environmental data to enhance grape variety classification, adapting to seasonal and vineyard-specific variations.
* **Sliding Work Sharing:** AI collaborates with vineyard researchers by providing automated variety identification while allowing human experts to refine, validate, and improve AI-generated results.

Figure . AI4Work Architecture adapted for the EP of the Agriculture Pilot – Use Case 1

### UC-AGR-2: Monitoring of remote steep-slope vineyard plots

Several advanced technologies are required to promote the success of this use case:

* **Data Collection & Handling for AI/Robotics Services:** Drones and environmental sensors collect high-resolution images and real-time data (e.g., temperature, precipitation, humidity). AI processes these datasets to create vineyard maps and monitor conditions.
* **Long-Term Adaptation:** AI models can be periodically updated to analyse drone data, supporting improvements in vine health tracking, seasonal trend detection, and environmental analysis.
* **Run-Time Monitoring:**Collected data is processed to validate accuracy in environmental and vine health assessments. Machine learning detects anomalies and identifies risks, aiding vineyard management decisions.
* **Digital Twin:** A Digital Twin of the vineyard integrates multispectral drone data and environmental monitoring to assess vine health and support decision-making.
* **Context Awareness:** AI models factor in slope orientation, climate variations, and terrace layouts, refining predictions based on real-world environmental influences. Continuous learning ensures adaptive monitoring and improved forecasting accuracy.
* **Sliding Work Sharing:** The AI system collaborates with vineyard personnel, assisting in data interpretation and decision support. The drone gathers field data, while vineyard workers provide expert insights and validation, ensuring the monitoring system remains as accurate and reliable as possible.

Figure . AI4Work Architecture adapted for the EP of the Agriculture Pilot – Use Case 2

### UC-AGR-3: Transport of the grapes in a steep-slope vineyard during the harvest season

Several advanced technologies are required to promote the success of this use case:

* **Data collection and handling for AI/Robotics Services:** Wearable sensors track worker fatigue levels throughout the harvest and grape transport process. This data can be used to analyse physical strain, optimize task assignments, and enhance workplace safety.
* **Long-Term Adaptation** AI models and robotic systems can be updated periodically based on new data and user feedback to refine transport efficiency, adapt to vineyard conditions, and improve coordination between drones and workers.
* **Digital Twin:** A Digital Twin of vineyard logistics integrates grape transport dynamics, worker activity, and environmental conditions to support decision-making in harvest operations.
* **Context Awareness:** AI models can incorporate terrain conditions, weather data, and operational constraints to adjust drone performance and optimize transport decisions.
* **Sliding Work Sharing:** The system can dynamically balance transport tasks between drones and vineyard workers, improving workflow efficiency and resource utilization.

Figure . AI4Work Architecture adapted for the EP of the Agriculture Pilot – Use Case 3

## Initial Plan – Early Prototypes

In this section, the early prototype development milestones were identified, as well as the timeline showing the implementation stages of each early prototype.

### UC-AGR-1: Identification of grape varieties in Quinta do Crasto’s old vineyards

**O1.1 Define data model for grape variety classification [December ‘24]**

* Select a set of representative grapevines for initial identification and classification.
* Define basic metadata requirements for recorded grapevine images, including location, time of capture, and environmental conditions.
* Ensure that GPS coordinates of selected grapevines are recorded for integration with vineyard monitoring systems, including drone navigation and Digital Twin updates.

**O1.2 Develop ground truth database for grape variety identification [March ‘25]**

* Collect photographic and sensor-based data of known grapevine varieties.
* Manually validate and label datasets with the assistance of vineyard researchers and agronomists.

**O1.3 Train and validate AI-based image analysis model for grape variety detection [June ‘25]**

* Implement a preliminary AI model for leaf morphology analysis, leveraging deep learning for classification.
* Conduct pilot testing on drone-acquired imagery combined with synthetic datasets, comparing AI outputs with expert-labelled data.
* Define AI accuracy targets before full deployment into vineyard management.

**O1.4 Prototype integration of AI results into a Digital Twin of grape varieties [June ‘25]**

* Develop an initial Digital Twin that catalogues classified grape varieties and preserves historical vine data.
* Ensure AI-Digital Twin integration enables future analysis of variety distribution and vineyard planning.

### UC-AGR-2: Monitoring of remote steep-slope vineyard plots

**O2.1 Identify critical vineyard locations for monitoring [March 2025]**

* Identify high-priority monitoring areas based on historical data, expert input, and key risk factors (e.g., steepness, wind exposure, disease susceptibility, soil variation). Validate these locations through ground truthing or analysis of existing high-resolution imagery.

**O2.2 Select and configure drone for vineyard monitoring [March 2025]**

* Select a drone with GPS navigation, high-resolution imaging, and multispectral sensors to support UC-AGR-1 and UC-AGR-2. Document the selection rationale, including sensor capabilities, flight time, and payload capacity.

**O2.3 Integrate GPS coordinates of monitoring locations [June 2025]**

* Store and manage pre-selected critical vineyard locations in a central monitoring system, ensuring consistent route planning across multiple drone flights.
* Flight paths shall be optimized for elevation changes, weather conditions (e.g., wind, fog), and data quality requirements (e.g., image overlap for orthomosaics).

**O2.4 Define flight conditions and restraints [June 2025]**

* Establish monitoring routes based on key objectives (e.g., pest and disease detection, soil condition monitoring, microclimate tracking).
* Set altitude and obstacle avoidance guidelines to ensure safe drone operation.

**O2.5 Digital Twin Development & Human-AI Collaboration [June 2025]**

* Develop a preliminary Digital Twin that consolidates drone-collected environmental and plant health data for vineyard assessment and strategic planning.

### UC-AGR-3: Transport of the grapes in a steep-slope vineyard during the harvest season

**O3.1 Define worker fatigue monitoring and AI-assisted task allocation [March 2025]**

* Identify wearable IoT devices to track worker fatigue based on exertion levels, allowing AI to analyse fatigue trends and suggest task adjustments at predefined intervals.
* Establish fatigue thresholds to inform task balancing between drones and human workers.

**O3.2 Select and test cargo drone for vineyard transport [March 2025]**

* Choose a cargo drone with sufficient payload capacity and test flight stability in vineyard terrain.

**O3.3 Develop Digital Twin prototype for transport logistics [June 2025]**

* Create a Digital Twin to simulate grape transport scenarios, integrating:
* Drone activity
* Worker fatigue levels
* Environmental constraints (e.g., slope steepness, wind speed)

**O3.4 Implement AI-driven context awareness and Sliding Work Sharing [June 2025]**

* Train a system to factor in environmental conditions (wind, slope, weather) for adaptive drone transport planning.
* Develop Sliding Work Sharing, where AI assists but workers review and refine transport task assignments.

## Prototype Iteration Cycle

The development of the AI4Work prototypes for UC-AGR-1, UC-AGR-2, and UC-AGR-3 follows an iterative methodology, ensuring a progressive refinement of AI-driven solutions for vineyard management. The process involves continuous collaboration between technology providers and vineyard stakeholders, integrating real-world feedback to improve usability, efficiency, and AI-assisted decision-making.

Each use case undergoes three key phases: initial testing in controlled conditions, deployment in real-world vineyard environments, and final optimization to ensure AI and human collaboration remain central to operations.

**Phase 1: Early Prototype Development and Baseline Testing (December 2024 – June 2025)**

* Controlled deployments begin in designated vineyard plots, where AI models, drones, and Digital Twins undergo initial validation.
* Data collection focuses on grape variety identification (UC-AGR-1), vineyard monitoring (UC-AGR-2), and AI-assisted grape transport (UC-AGR-3).
* Proxy operators (vineyard researchers and managers) interact with the system, providing feedback on AI-generated recommendations.
* Initial Sliding Work Sharing mechanisms are introduced, where AI assists but vineyard personnel retain final control over interventions.

**Phase 2: AI Refinement, Human-AI Interaction, and Context-Aware Learning (June – December 2025)**

* AI models are improved using real-world data, allowing them to adapt to seasonal variations, environmental changes, and operational needs.
* The Digital Twin evolves from a static model to a dynamic decision-support tool, incorporating GIS-compliant data for better vineyard logistics.
* AI-driven transport scheduling (UC-AGR-3) and anomaly detection (UC-AGR-2) are tested.
* Human-AI collaboration is fine-tuned, ensuring AI-generated transport and monitoring plans can be overridden or refined by vineyard managers.

**Phase 3: Full-Scale Deployment and Optimization (January – December 2026)**

* AI-assisted operations are deployed under real harvest conditions, ensuring drones, workers, and vineyard managers interact seamlessly.
* The Digital Twin supports predictive analytics, enabling vineyard personnel to anticipate transport bottlenecks, plant health risks, and workload imbalances.
* Sliding Work Sharing is fully optimized, where AI learns from human feedback, continuously refining its task recommendations while maintaining human oversight.
* The iterative cycle concludes with performance validation, ensuring AI systems meet efficiency, accuracy, and human-centred usability standards before full-scale adoption.