Deliverable

Project Acronym: PRECIMED

Project full Name: Precision Irrigation Management to Improve Water and Nutrient Use Efficiency in the Mediterranean Region

D1.5 Final EC report

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1. Explanation of the work carried out by the beneficiaries and Overview of the progress

This report aims to review the tasks carried out during project. As described in detail in the following sections, the project has been implemented appropriately, besides some forced changes already mentioned in previous reports, as a consequence of the global situation caused by the pandemic.

Regarding project deliverables, these have been updated to the MEL platform and presented on the scheduled dates, and they will be referenced along this report to mention the work carried out by the project partners.

1.1 Objectives

PRECIMED project aimed to research, develop, and validate a Standards-based Decision Support System (DSS) including irrigation and fertigation models to improve the efficient use of water, nutrients and energy. For this, the consortium integrated the knowledge on fertilisation and irrigation of Mediterranean crops with innovative information and communication technologies (ICTs) and developed an environmentally friendly and economically profitable solution.

The PRECIMED DSS has been developed with the objective that the end user can easily access and manage water and fertilizers through web interfaces from anywhere with an Internet connection using their mobile phones, tablets or PC. The DSS platform is able to collect a large amount of crop and environmental data, which are processed and analyzed in order to provide recommendations in real-time to farmers regarding the best irrigation and fertilization practices.

The DSS offers management services and remote actuations to improve the lives of Mediterranean farmers and also save water and fertilizers in a region with significant problems of water stress and soil pollution. The challenge is to create stronger bridges between the two areas of the Mediterranean basin, which is composed of EU and non-EU countries: Tunisia, Algeria, Spain, and Greece. In this sense, the consortium is made up of SMEs, research centers and end users that collaborate to validate the solution for subsequent commercialization.

The main objectives are presented in table 1.

Table 1. Main objectives of PRECIMED project

Objective number	**Measurability**	**WP**	**Period for accomplishment**					
			M6	M12	M18	M24	M30	M36
O1	To Improve Water and Nutrient Use Efficiency (**WUE and NUE**) in the Mediterranean Region by using intensive ICT solutions	2,3,4,5	**X**	**X**	**X**	**X**	**X**	**X**
O2	To facilitate **the interchange of technology and best goods practices between EU and non-EU Mediterranean countries** in order to improve the water and nutrient use efficiency in all the Mediterranean Region	2	**X**	**X**	**X**	**X**	**X**	**X**
O3	To develop and validate (in different demonstration farms) **a Standards-based Decision Support System for data-driven irrigation/fertilization management** that evaluates the medium-term evolution of crop nutritional status, soil salinity, yield and fruit quality and safety, optimizing the water and fertilizers needs and the energy costs at farm level.	3,4	**X**	**X**	**X**	**X**	**X**	**X**
O4	**To ensure that the project activities and outcomes reach the relevant target groups**, especially end-users (farmers), thus enhancing the market uptake of PRECIMED's solutions.	5	**X**	**X**	**X**	**X**	**X**	**X**

1.2 Explanation of the work carried per WP

Project activities were carefully designed to achieve the project goals and most importantly, to deliver the maximum socioeconomic impact, transfer of knowledge, and deal with challenges in the agricultural sector. PRECIMED project was organized in 5 work packages which are presented along this report, describing the most important activities of the consortium as well as the milestones achieved during the project.

1.2.1 WP1 Project Management

WP1 aimed to enable efficient coordination and guide the project partners for achieving the overall project objectives while following the directives set by the EC in the PRIMA grant agreement and the consortium regulation provisions set by the consortium agreement.

The WP leader is CSIC

T1.1 Team and project coordination.

A general coordination has been proposed and followed in order to synchronize the project more effectively. This includes the project management by the Project Coordinator (PC), assuring technical coordination on the level of subproject leaders, assuring interaction between the different WPs and the quality of intermediate project results. Furthermore, this coordination also covered tasks such as, the preparation, organization, administration, minutes and follow-up of scheduled meetings:

- Management of the consortium: legal, contractual, ethical and administrative matters.
- Organization of the Kick-off meeting (19/11/2019), First year annual meeting (15/10/2020), Second year annual meeting (26/10/2021) and Third year annual meeting (25-26/10/2022).
- Perform day-to-day management as efficient administrative support.
- Overall management and coordination of the project, ensuring that the project stays focused and that there is a good cooperation and coordination between all work packages.
- Organization of the Mid-term evaluation meeting (23/11/2021).
- Set up an internal project communication and document repository platform (PRECIMED Dropbox).

The PC has performed all communication with the PRIMA Secretariat. The PC took care of the day-to-day project coordination with the support of the PMT (Project Management Team).

Within this task, during the first 18 months of the project, deliverables were revised and submitted by the PC to the PRIMA Secretariat via PRECIMED Smartsheet and distributed among the consortium partners. From that date onwards, deliverables were uploaded on MEL platform. The PC with the support of PMT has been actively involved with all management and technical parts with respect to the submissions of the deliverables.

As part of this task, the mid-term report was drawn up following the indications of the MEL platform. All the information requested from the partners was collected and the information requested was completed for subsequent review by the Project Officer. In this sense, the Final Report will also be elaborated with the information of the whole project from the partners for the final review.

<u>Corresponding deliverables to Task 1.1</u>

- D1.1 ‘Project Management Procedure’ submitted on M7
- D1.3 ‘1st Annual EC report’ submitted on M14 and M16 (update version)
- D1.4 ‘2nd Annual EC report’ submitted on M26
- D1.5 ‘Final EC report’ submitted on M42

T1.2 Management of activities between the consortium members

This task was led by the Quality manager (QM), and the activities were:

- Development of a Quality Assurance Plan (QAP). This was reflected in the deliverable D1.2.
- Quality monitoring of the execution of WPs and tasks.
- Managing any quality issue with respect to the project and establishing actions (preventive or corrective) when necessary.

Corresponding deliverable to Task 1.2

- D1.2 'Quality Assurance Plan' submitted on M7

T1.3 Project Progress reports' technical coordination

This task comprises the technical coordination at project level, supervising all the deliverables carried out during these first two years and the flow of technical information.

T1.4 Financial and Administrative coordination CSIC

In this project there is no financial coordination of the consortium by CSIC, as each partner is funded directly by its own national funding agency. Therefore, it is up to each partner to meet the financial objectives set out in the project for each year and for each task. Each partner will be held accountable to comply to the legislative and financial requirements and regulations of its own country where appropriate. The Administrative Manager is in charge of the necessary actions for the achievement of a fair and effective internal administration within the consortium to meet EC requirements. In this sense, the actions carried out during the complete duration of the project have been:

- Designing and maintaining partner specific templates for the deliverables and the presentation of the meetings.
- Implementing and maintaining the internal platform (Dropbox) for information exchange and email lists.
- Administrative support to all partners on an individual level for any needs that may arise.

During this period, the PC had to communicate with the Project Officer to request changes in delivery dates and other issues that arise in the day-to-day running of the project. Actually, a project extension of six months has been evaluated, mainly due that several tasks were postponed (mostly during the first year when the pandemic began) making difficult the validation of the DSS, scheduled for the last year of the project.

1.2.2 WP2 Establishments of end-user's requirements

The aim of WP2 was to establish the characteristics and issues related to the agricultural crop production in the Mediterranean basin and the requirements that had to be recognized.

The WP Leader is UTH.

T2.1 Identification of farmers participating in the project and establishment of experimental approach in the pilot farms.

The assessment of pilot farms for the design of the PRECIMED DSS has been focused on identifying the requirements of the farms and the farmers, analysing nutrients' and water availability management in the context of climate change, taking into account the impact of irrigation technologies on the productivity of water and fertilizers use efficiency, and defining the most interesting system suitable for each one of the pilot farms included in the assessment, concerning the type and the number of sensors required to manage water and fertilizers in each case study.

To carry out this task, at the beginning of the project, several meetings were held with farmers, cooperatives and agricultural partners from the area where the local farms were established. The findings that the project partners found are listed below.

In the case of the Greek greenhouses, growers use some indices that help them in the greenhouse microclimate and fertigation management. These indices are:

- Solar radiation inside or outside the greenhouse
- Air vapour pressure deficit and if not available, the greenhouse air temperature and relative humidity
- Volumetric water content of the crop substrate
- pH and EC values of the nutrient solution in the substrate and in the drainage solution
- Ratio of drained to applied nutrient solution

Based on these indices, growers modify on a weekly basis the dose and frequency of the applied nutrient solution. However, they have no tools or basic indices to use in order to modify the composition of the applied nutrient solution and thus they usually apply a standard solution depending on the growth stage of the crop (e.g., four stages for tomato, three stages for cucumber). Nevertheless, they point out that it would be ideal if they could modify the composition of the nutrient solution applied on a weekly or half month basis so that the applied nutrient concentrations are closely related to the fertilisation needs of the crop.

Usually, the modification of the composition is based on the EC of the drainage solution and is done by changing the EC of the applied nutrient solution rather than changing its composition. Accordingly, it was pointed out that except of an irrigation scheduling program, the development of a fertigation guide to change the composition of the nutrient solution according to the climate inside the greenhouse and the plant growth status would be really helpful.

Regarding open-field crops, both in Spain and Algeria, similar approaches were considered appropriated to establish the pilot farms where the DSS would be tested and validated. It was concluded that to develop a DSS to improve the water use efficiency through precise irrigation scheduling, each pilot needed:

- An agroclimatic station, to monitor, at least, rainy events and crop evapotranspiration.
- Some devices to monitor soil water content and temperature.
- To characterize the soil, through an initial physico-chemical analysis, describing soil texture, organic matter content, salinity and nutrient content.
- To analyze irrigation water, to check water quality, electrical conductivity and pH.
- To describe the crop coefficient (Kc) for each phenological state of the plant, to apply it according the to the local conditions of the farm.

During the firsts meetings with farmers, they also exposed the need of technical support to improve the application rates and timings of the fertilizers as well as the irrigation scheduling.

According to the main requirements which were identified in the different countries, the pilot leaders configured the most appropriate approach for the deployment of the PRECIMED system in each pilot. In addition an experimental protocol was developed, considering the previous research works on different irrigation management effects on crop physiology and nutritional value of fruits, which was presented in deliverable D4.2. In this sense, in each one of the project countries, several farming scenarios were developed as objects of study. The information related to these pilot farms is described in deliverable 2.1, however a brief description of each pilot farm is presented below.

Regarding open field crops, in Spain there have been two farming scenarios; a pomegranate tree field and a pear tree field, in Algeria two farming scenarios, which have been focused on citrus and on potato cultivation and in Tunisia, there were an olive tree farm, where the trials had to be cancelled due to the reasons unrelated to the project (restrictions of mobility during the pandemic).

Regarding greenhouse crops, two farming scenarios were settle in Greece, in which the research focused on the soilless cultivation of tomato and cucumber.

The pomegranate farm is located at the experimental station from CEBAS-CSIC, in Santomera, Murcia (Spain). This is a 0.8 ha plot, irrigated by means of a drip irrigation system which is managed through the PRECIMED web based platform, which has been developed during the project to support the DSS. Several sensors have been deployed at farm level and connected to the platform, as it is the case of four Drill and Drop probes (Sentek) which accurately measures soil moisture and temperature. Micrometeorological data (air temperature, solar radiation, air relative humidity, rainfall, and wind speed) were also collected by an automatic weather station which reports the average data every 15 minutes to the PRECIMED platform.

Figure 1. Pomegranate farm in Spain

The pear tree field is a commercial farm located in Jumilla, Murcia, and it is part of the Miraflores Irrigation Community which due to the lack of water in the area, water for irrigation is obtained from wells and by concessions of reclaimed water from a local treatment plant. The pear trees are Ercolini variety and the plot has an area of 0.4 ha. The plot is equipped with an agroclimatic station, which measures temperature, humidity, radiation, wind, solar radiation, rainfall and vapour pressure deficit and there are soil humidity sensors, installed at different locations of the farm, which were connected to the PRECIMED platform.

The citrus farm is located in Mitidja plain, in Sidi Moussa (Algeria). Several type of citrus are distributed along the 10 ha farm, although the project pilot has focused on orange trees. The plot was equipped with an automatic agrocliamtic station which records air temperatures, relative humidity, solar radiation, wind speed at 2 m height, rainfall, dew point, vapor pressure deficit and daily evapotranspiration. During the last year of the project and with certain delay due to the no availability of the equipment, a Drill and Drop probe was installed at the farm from June 2022. Irrigation water comes up from 2 wells, with a depth of 160 m and equipped with an electrical pump of 25 cv and a flow of 30 m^3 per hour. The wells are connected to the drip irrigation system. The irrigation scheduling is scheduled based on visual observations of the plants and the soil and the farmer experience, which is the common method used by the farmers around this region. The farm is equipped with a drip irrigation system. Drippers are spaced 1 meter to each other and have a flow rate of 8L/h. Citrus trees have two lateral pipes per tree row. Each tree includes four drippers.

Figure 2. Citrus farm in Algeria

Regarding the second Algerian pilot, located at Sebain, Tiaret region, two farming scenarios were adopted at the beginning of the project. However, the first scenario (a glass greenhouse with hydroponic system for seed potato production) could not be used due to some technical problems in the facilities.

The second scenario is a commercial farm specialized in vegetables, although during the project the focus has been on potato cultivation. The farm uses sprinkler irrigation system and there are two growing seasons per year (April-July and September-December). The plot was equipped with an automatic agrocliamtic station which records air temperature, relative humidity, solar radiation, wind speed at 2 m height, rainfall and daily evapotranspiration. As for citrus farm, the irrigation water comes from wells and the irrigation is scheduled according to visual observations of the plants and the soil and the farmer experience. For this scenario, it’s was difficult to implement the trials during the first year and the first and the second quarter of the second year due to the restrictions of mobility during the pandemic.

Regarding greenhouse crops, the 1st farming scenario is a commercial greenhouse dedicated to the cucumber production (Columbia cultivar). It is located in Pyrgetos, Larissa (Greece). It has an area of 0.5 ha, it is of arched type, it has five sections and a polyethylene cover with polycarbonate on the gables and glass on the sides. There are two cultivation periods in every year: the first one starts in February and ends in July (total duration: 160 days), and the second one starts in August and ends in January (total duration: 180 days). It is a soilless hydroponic system which uses rockwool as substrate. The greenhouse is equipped with heating system, natural ventilation, forced ventilation, fan and pad system and a thermal screen.

Figure 3. Cucumber greenhouse with heating (floor pipes, grow pipes) and the cooling systems (wet pads).

The irrigation system is equipped with drippers every 0,25 m and has a flow rate of 2L/h and the irrigation doses are scheduled based on time-program and measurements –mainly of solar radiation intensity.

The 2nd farming scenario sited in Greece, is at "Agroktima Velestino", an innovative hydroponic greenhouse placed at the farm of the University of Thessaly, in Volos. The greenhouse has a total area of 1500 m^2, and it is divided into six independently controlled compartments of 250 m^2 each. It is a high-tech gothic type greenhouse, covered by a single polyethylene film in the roof and transparent polycarbonate sheets on the side and gable walls.

The cultivated plant is tomato, and it is done in one cultivation period which starts between January and April and it ends on January of the following year (total duration: 9-12 months).

Figure 4. Overview of the "Agroktima Velestino" tomato greenhouse.

It is also a soilless greenhouse, the main substrate being perlite or rockwool. The greenhouse is equipped with a pipe rail heating system, natural (roof vents) and forced ventilation system, pad and fan system for cooling, automated thermal screen for energy saving and shading and crop suspension system. The hydroponic system could function as an open, closed and semi-closed system. The irrigation system is equipped with drippers every 0.25 m and every dripper has a flow rate of 2L/h. The system is controlled by a central computer which is equipped with a DSS that was developed in house. Irrigation scheduling is based on leachate fraction, solar radiation intensity and the plants growth stage. The irrigation dose and frequency have been based on the predictions for water and fertiliser needs that were given by the PRECIMED system.

During the course of the project, additional meetings have been carried out with different farmers (owners and visitors) at the different pilot locations. The purpose of these meetings was to jointly evaluate the development of the DSS and to improve it according to the requirements. The information gathered in these meetings is presented in Deliverable 4.4.

<u>Corresponding deliverable to Task 2.1</u>

- D2.1 'Assessment of pilot farms for the design of the PRECIMED DSS' submitted on M22

T2.2 Analysis of nutrients and water availability and management in the context of climate change.

An intensive review of previous scientific results and information obtained from previous R&D work and related projects on agricultural conditions in the Mediterranean Region have been carried out. The following factors have been considered in particular: soil, substrate, plant material, atmosphere, water resources and quality (surface water, underground resources, etc.), irrigation systems (agronomic design, application efficiency and distribution uniformity), irrigation-related performances (irrigation scheduling, failures in the irrigation system, economic losses, water use efficiency, etc.) and fertilizers application. Therefore, the challenges to be considered in PRECIMED DSS have been identified.

In the frame of this task and Deliverable 2.2, WP2 leader proposed to contact an Editor for the development of a special issue in a scientific Journal. All partners would be able to submit a manuscript for peer review and the synthesis of the manuscripts would compose D2.2. However, this was not finally put forward and each partner elaborated a part of the deliverable related to the expertise and knowledge of the team without necessarily publishing this material elsewhere. This deliverable was submitted on M36. In addition, the work related to this task, which has been published by some partners in scientific journals is presented below:

- E. Ben Abdallah, R. Grati, K. Boukadi, 2023. Towards an explainable irrigation scheduling approach by predicting soil moisture and evapotranspiration via multi-target regression, Journal of Ambient Intelligence and Smart Environments, Pre-press, pp. 1-22, https://doi.org/10.3233/AIS-220477
- Bamoray, Rima Grati, Bassem Bouaziz, Khouloud Boukadi and Faiez Gargouri, 2023. Machine Learning-Based Irrigation Scheduling. Agronomy, Special issue "Applications of Deep Learning in Smart Agriculture" (under review)
- Malek Frej, Rima Grati, Khouloud Boukadi, 2023. Plant disease prediction using Deep Learning: A systematic literature review. Applied Intelligence (under review)
- Dalila, S., Lakhdar, Z., Mawhoub, A., Hakim, B., Mohamed, S., 2022. Monthly Rainfall Variability and Vulnerability of Rainfed Cereal Crops in the Tellian Highlands of Algeria. In: Gökçekuş, H., Kassem, Y. (eds) Climate Change, Natural Resources and Sustainable Environmental Management. NRSEM 2021. Environmental Earth Sciences. Springer, Cham. https://doi.org/10.1007/978-3-031-04375-8_28.
- Belkhiri, F.E, 2021. Evaluation of the performance of eighteen reference evapotranspiration estimation models in the sub-humid conditions of the Mitidja. Recherche Agronomique, 19(1), 5-32, https://www.asjp.cerist.dz/en/article/148748
- Nikolaou, G., Neocleous, D., Kitta, E., Katsoulas, N., 2021. Advances in irrigation /fertigation techniques in greenhouse soilless culture systems. Advances in horticultural soilless culture (ed. Prof Nazim Gruda, University of Bonn, Germany). ISBN (pdf): 978-1-78676-438-6.
- Nikolaou, G., Neocleous, D., Christou, A., Polycarpou, P., Kitta, E., Katsoulas, N., 2021. Energy and water related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part I: Energy and microclimatic parameters. Horticulturae, 7(12), 521; https://doi.org/10.3390/horticulturae7120521.
- Nikolaou, G., Neocleous, D., Christou, A., Polycarpou, P., Kitta, E., Katsoulas, N., 2021. Energy and water related parameters in tomato and cucumber greenhouse crops in semiarid Mediterranean regions. A review, Part II: Irrigation and fertigation. Horticulturae 2021, 7(12), 548; https://doi.org/10.3390/horticulturae7120548.
- Nikolaou, G., Neocleous, D., Kitta, E., Katsoulas, N., 2020. Implementing sustainable irrigation in water-scarce regions under the impact of climate change. Agronomy, 10(8):1120. https://doi.org/10.3390/agronomy10081120.
- Bañón, S., Ochoa, B., Bañon, D., Ortuño, M.F., Sánchez-Blanco, M.J. 2020. Assessment of the Combined Effect of Temperature and Salinity on the Outputs of Soil Dielectric Sensors in Coconut Fiber. Sustainability 2020, 12, 6577; doi:10.3390/su12166577.

The achievement of this task has given birth to the proposition of a topical collection on advances of deep learning for smart farming (https://www.springer.com/journal/521/updates/24099052) and a mini-track entitled “decision systems for smart farming” of A ranked conference (https://hicss.hawaii.edu/tracks-57/decision-analytics-and-service-science/#decision-systems-for-smart-farming-minitrack)

Additionally, CEBAS-CSIC prepared an article for a Spanish informative journal (Horticultura, -in Spanish), describing the most innovative aspects of the PRECIMED project:

- Ortuño, M.F, Alarcón, J.J. 2021. Proyecto PRECIMED: Transformación digital del sector agroalimentario de la Región Mediterránea.

Corresponding deliverable to Task 2.2

- D2.2 'Report on the agronomical and environmental characteristics of the main agricultural crops of the Mediterranean Basin' submitted on M36

T2.3 Assessment of each agricultural farm linked to practical feasibility of irrigation scheduling based in sensing plant and soil water status.

In parallel to the analysis of results obtained in T2.1 and T2.2, this task identified the main important farmer requirements for each specific pilot farm. In this way, this work defined the most interesting quality and number of sensors required for each case study and the better telecommunication devices needed to upload the sensor-reading to the cloud. For this purpose, the partners deployed the sensor networks for data collection in the different pilot farms in order to prove the practical feasibility of irrigation scheduling based on sensing plant and soil water status. A summary of the different devices which have been deployed at the different pilot farms is presented in the Table 2. In addition, and according to the pilot leaders, in each location was done a specific follow up of the crop water/nutrient status to evaluate the effect of the different fertigation strategies which had been applied during the project.

Table 2. Sensor devices installed at the different pilot farms during the project.

Pilot farm	Sensor type
Pomegranate farm, CEBAS-CSIC	Automatic weather station
	Capacitance probes Drill and Drop
	TDR sensors
	Infrared temperature sensors
	IPex 12 Datalogger
Pear farm, CEBAS-CSIC	Automatic weather station
	TRD sensors
	IPex 12 Datalogger
Citrus farm, INRAA	Soil moisture sensor Diviner 2000 n
	Capacitance probe Drill and Drop
	Automatic weather station
Potato farm, INRAA	Automatic weather station
	Soil moisture sensor Diviner 2000
Greenhouse crops, UTH	Automatic weather station
	pH and EC sensors
	Manometers
	Dielectric sensors
	Rain gauges

The deliverable 2.1 which makes reference to this task was delivered on month 22, after its extension was approved by the project officer. Due to various delays, mainly derived from COVID-19 pandemic, the corresponding Deliverable D2.3, was submitted on M42. This deliverable presents a practical guide for farmers in which the technical aspects to choose the most suitable location for sensor installation and their maintenance is described. This farmer practical guide covers both greenhouse and open-field crops, to boost and promote the use of precision agriculture by mean of the PRECIMED DSS.

Corresponding deliverable to Task 2.3

- D2.3 'Farmers practical guides' submitted on M42

1.2.3 WP3 Decision Support System Development

The aim of WP3 was to perform the Decision Support System (DSS) development. The goal of these activities was to deliver a demonstration prototype at the end of the project that fits perfectly the farmers needs assessed throughout the project.

The WP Leader is ODIN.

T3.1 Design and Development of IoT-data management platform with cost-effective devices for optimized irrigation scheduling.

This task addresses the cost-effective data acquisition and remote actuation with wireless gateways connected to an IoT-standards-based platform through Internet. The task leads to develop a FIWARE-based platform supporting edge/cloud computing and the integration of three subsystems (i.e. data acquisition, data processing and end-users services) in the context of precise irrigation and fertilization. Moreover, the FIWARE-based platform employs and integrates outcomes of the EU FIWARE project, like the ORION Broker, open and standardized lightweight IoT-data protocols such as MQTT, CoAP or even REST services based on HTTP, as well as NGSI to facilitate the acquisition, integration and exchange of massive data with Cyber Physical Systems (CPS) gateways.

In this task, ODIN carried out the analysis of the IPv6 and 6Lowpan protocols and different LPWAN networks (Sigfox, LoRa, and NB-IoT/LTE-M 5G) to consider the best wireless communication option in terms of long range, low consumption, and low cost for the CPS systems. Taking into account the results of the analysis performed, ODIN suggested as a more scalable and flexible solution, to separate the communications module in the design of the PCBs for the CPS, in order to integrate different communications technologies through commercial LPWAN modules.

Regarding the PRECIMED IoT platform, ODIN worked together with the rest of the partners in its design, that was carried out based on open standards (IETF of IoT, MQTT, and EU FIWARE) to ensure interoperability, with a multilayer architecture to ensure scalability and support for edge and cloud computing and following the distribution model of SaaS (Software as a Service) for its development.

During its development, the backend and frontend have been developed and updated. Different connectors (IoT agents) were created to integrate external data sources, such as the deployed IoT devices, weather services (Weatherbit) and satellite multispectral imagery (Sentinel-2). ODIN worked on different solutions (advanced graphics, data files, REST API, and Context Broker) to cover the end user needs identified by the partners and offer the data registered on the platform for its exploitation by users or by other services (i.e. DSS services). Also, different agronomic services (irrigation planning, rules management, plot and agronomic data management, etc.) were included together with needed HMI interfaces.

Different OpenSource Web technologies have been used for development. The Frontend has been developed using Vue.js, a framework based on HTML, CSS and JavaScript, and using OpenLayers, a JavaScript library for displaying interactive maps. The backend has been developed on top of JavaScript and integrates several components:

- A MQTT Broker (Mosquitto), that receives data from MQTT-compliant sources to be processed by the IoT agents.
- The IoT FIWARE JSON Agents, a software that translates information received from the MQTT Broker and other data sources into a superior JSON-based data model to record them in the internal DB as historical data.
- An internal document-oriented NoSQL JSON database (MongoDB) where the IoT agents record the data.
- A REST API based on the FIWARE NGSI data model to give access to the registered information for exploitation, for example giving support for data integration to DSS algorithms identified in T3.2 and implemented in T3.3.
- In addition, ODIN has tested the possibility of deploying a FIWARE Orion-LD Context Broker, that supports the FIWARE NGSI-LD data model and offers an API REST, to access the data registered by publishing/subscribing.

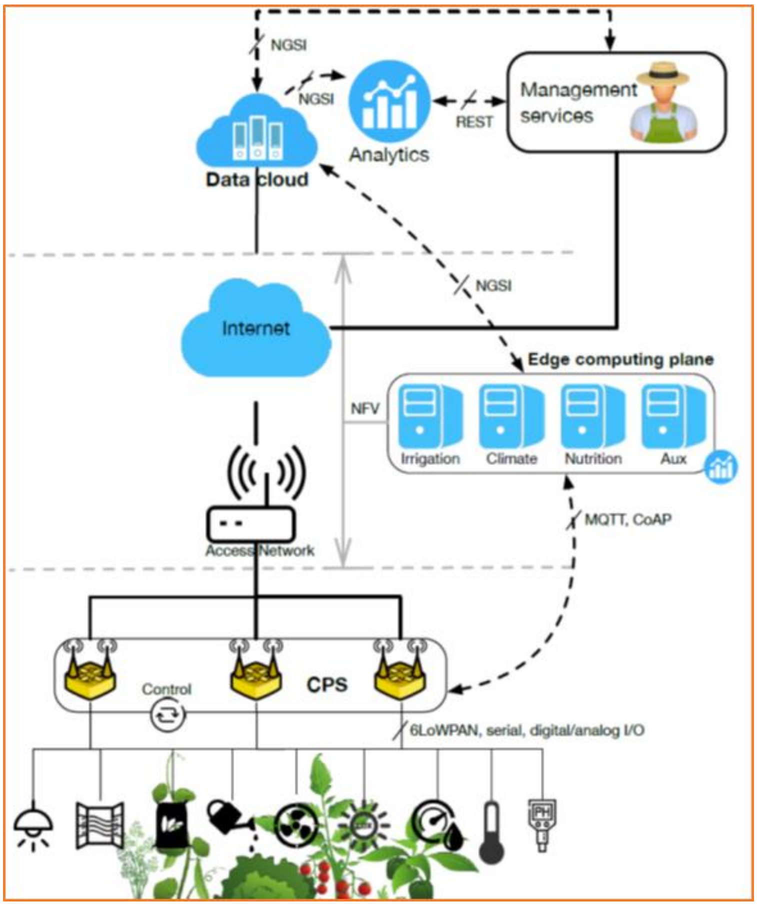

Figure 5. Architecture of the PRECIMED platform

The climate and soil sensors corresponding to the farm at Miraflores Irrigation Community and the experimental field of CEBAS-CSIC were deployed and connected through the use of CPS gateways with wireless LPWAN communication to the IoT platform developed and deployed by ODIN.

During the second half of the project, INRAA had the IMETOS Weather Stations deployed and configured, and ODIN integrated them with the platform developing an IoT Agent, a specific software adapter to retrieve and register data in the platform. INRAA also deployed a soil moisture probe but there has been no way to achieve its integration directly with the platform.

On the other hand, the greenhouse information provided by UTH was also integrated in the platform thanks to the development of a specific software adapter. An IoT system was developed to transfer the data from UTH to ODIN (www.precimed.eu).

Finally, the PRECIMED platform will take advantage of the BigData models identified in T3.2 and implemented in T3.3.

Corresponding deliverable to Task 3.1

- D3.1 'IoT-based platform with cost-effective gateways for optimizing irrigation' submitted on M16.

T3.2 Models to determine fertigation management in greenhouse and in open field.

Data recorded in open-field and greenhouse crops related to soil and crop status and the weather forecast (see task 3.1.) were used to develop irrigation/fertilization scheduling models with the goal of developing optimal irrigation/fertilization scheduling programs enhancing water and fertilizers efficiency. In this sense, a group of equations needed for the models has been identified and organized so that both irrigation and fertilization in both open air and greenhouses crops could be developed. In this context, the deliverable 3.2 "Integrated models of irrigation and fertilization for open-field crops and greenhouses" that describes the methodology followed and the mathematical expressions used to estimate the fertigation needs was presented on M24, following the approval of the extension requested.

These models concern major greenhouse crops such as tomato and cucumber crops, and several fruit orchard crops and aim to enable growers to use more effectively advanced technical systems for optimal irrigation and nutrient management.

The concept for fertigation management in greenhouse crops can be summarised into the following four steps. 1) At the first stage, the crop nutrient needs in relation to dry matter production (DMP), are calculated. Any changes in DMP as the plant grows or when there is biomass removal due to harvesting or leaves and stems pruning, are taken into consideration daily. 2) At the second stage, the crop water needs, as a function of crop transpiration, are estimated. 3) Then, the fertiliser and water that need to be applied in total are estimated and adjust the nutrient solution based on the cultivation daily needs. 4) Lastly, the fertigated solution recipe is adapted based on any changes in the crop biomass and/or climatic conditions and weather forecasting.

Regarding to the concept of irrigation scheduling and fertilization planning can be summarized as follows:

1) Computing the daily water depletion and then 2) calculate the required net irrigation when the threshold of soil water content is reached. Several levels of soil water content thresholds for irrigation triggering can be allowed in function of the irrigation strategies adopted. In addition, regarding the irrigation of soilless greenhouse crops, the daily transpiration, i.e. the daily plant water demand, was calculated based on the predicted solar radiation values and was the result of subtracting an average of 30% of the imposed irrigation solution, which is expected to be the draining solution of the crop, by the total volume of irrigation solution supplied to the crop.

Regarding to the fertilization, the reasoning of NPK fertilisation will be based on soil fertility crop extractions. The fertilization of the greenhouse crops was based on a weekly nutrient recipe based on average calculations of the daily predicted nutrient uptake and was provided to the crop through the fertigation system.

For the Algerian pilots, a water balance model was proposed to generate irrigation scheduling program for citrus orchard and potato crops. This approach is proposed to allow a large group of farmers that can use a limited number of weather stations. The main steps for the calculation of the net irrigation are as follow: 1) calculation of daily ET_O according to the Hargreaves method, 2) calculation of daily k_c, 3) calculation of daily water requirements, 4) calculation of net irrigation taking into account the irrigation system efficiency, 5) calculation of effective rain, 6) calculation of daily change in water balance, 7) estimation of the remaining availability water in the soil and 8) calculation of irrigation needs.

In this case, the use of the soil probes can be used to control/validate the soil water content calculated by the model.

At CEBAS-CSIC experimental farm a classical approach according to the Penman-Monteith model was used to irrigate the crop during the first growing season (2021). In addition, different deficit irrigation strategies were established, aiming to obtain a large number of data that could be used to feed and train the algorithms developed in Task 3.3, which supposed to be validated on the field in the next season. Due to some delays on the development of these algorithms, in the growing season 2022 another irrigation protocol (described in Deliverable 4.2) was adopted, taking advantage of the functionality of the PRECIMED platform and the sensors which have been deployed at the farm.

At the end of the project, ODIN contributed with the prototype of a model to demonstrate how to exploit Sentinel-2 satellite imagery of a crop. In this case, the model works with information corresponding to the NDVI index, used to estimate the quantity, quality, and development of vegetation, and the NDWI index, used for exploring water content at single leaf level as well as canopy level. This model uses those values, which are provided in 2D georeferenced images of a crop for a given date, to analyse them discarding no vegetable areas and considering only crop areas whose values may correspond to possible issues, both in vegetation quality and in water content status.

Corresponding deliverable to Task 3.2

- D3.2 'Integrated models of irrigation and fertilization for open-field crops and greenhouses' submitted on M24.

T3.3 Development of BigData algorithms for irrigation and fertilization services for decision support of precision irrigation and fertilization.

This task aims to design and implement Big Data/Deep Learning/optimization algorithms for irrigation and fertilization services of decision support. It considers the irrigation and fertilization models designed in Task 3.2 and provides dedicated analytic interfaces for end-users (e.g. timing and amount of irrigation according to the weather forecast, irrigation system constraints, etc.). In this task, ODIN has carried out the development of the algorithms corresponding to the models designed in task T3.2 of CEBAS-CSIC and UTH. Also, at the end of the project, ODIN contributed to the development of the algorithm based on its prototype model based on satellite imagery data proposed to identify possible anomalies related to the water status of the crop. ODIN has also worked on the design and implementation of end-user HMI interfaces to provide the needed dashboards to manage the DSS services once integrated with the platform, interfaces that were designed to be simple, easy to use, and responsive.

In parallel, OPTIM developed two models for this purpose based on the most recent advances in machine learning and neural networks. The first model is intended for open-air crops, while the second is intended for greenhouses. As for open-air crops, several studies have noted the relevance of soil moisture prediction in irrigation environments.

The prediction of soil moisture might capture possible ground-water variations otherwise difficult to capture, thus avoiding inefficient irrigation decisions.

A typical scenario of irrigation prediction involves three main steps: 1) collect weather and soil data, 2) these data help predict, in the second step, the soil moisture, and 3) predict the irrigation requirements.

This way, a Machine Learning model for soil moisture prediction is proposed, which can be used to manage irrigation scheduling efficiently. Furthermore, soil moisture prediction is a time-series forecasting problem, meaning that there is time-dependency between soil moisture observations. However, past studies dealing with soil moisture prediction largely used feed forward type of Artificial Neural Networks (ANN), which ignores the temporal-dependency nature of time series data. Contrastingly, Recurrent Neural Networks are a special type of ANNs that have the ability to store neurons' outputs between different time steps, making them more suitable for time series processing. This particularity of RNNs leads to their adoption in some soil moisture prediction studies. In the case of OPTIM, the suitability of the hybrid CNN-LSTM model for time-series soil moisture forecasting is being investigated.

Then, a traditional LSTM model in several preliminary experiments to determine ideal values of aggregation period and number of time steps was used. Moreover, OPTIM developed two other variants of LSTM, namely Bi-LSTM, and CNN-LSTM, to assess their performances. Each model achieved significant results with Mean Absolute Errors.

Furthermore, CNN-LSTM and Bi-LSTM proved to be more robust than classic LSTM on unseen data. Although OPTIM has designed an efficient and generalizable soil-moisture prediction model, additional datasets may be needed to further validate the model's generalization ability.

On the other hand, greenhouses have different irrigation needs than open-air crops. Hence, a second model was created specifically for greenhouses. This is based on UTH data and an irrigation amount estimation method. The target feature, irrigation amount, was calculated using the UTH formula, but Vapour Pressure Deficit was also taken into account.

Hence, the two models developed by OPTIM have been exposed as REST APIs hosted at Railways and available through the endpoints listed below. Examples of user interfaces, including the required parameters for each endpoint, are also given below.

- Open-field crops
    - Http method: POST
    - Endpoint: "http://web-production-794e.up.railway.app/opencrop/predict"

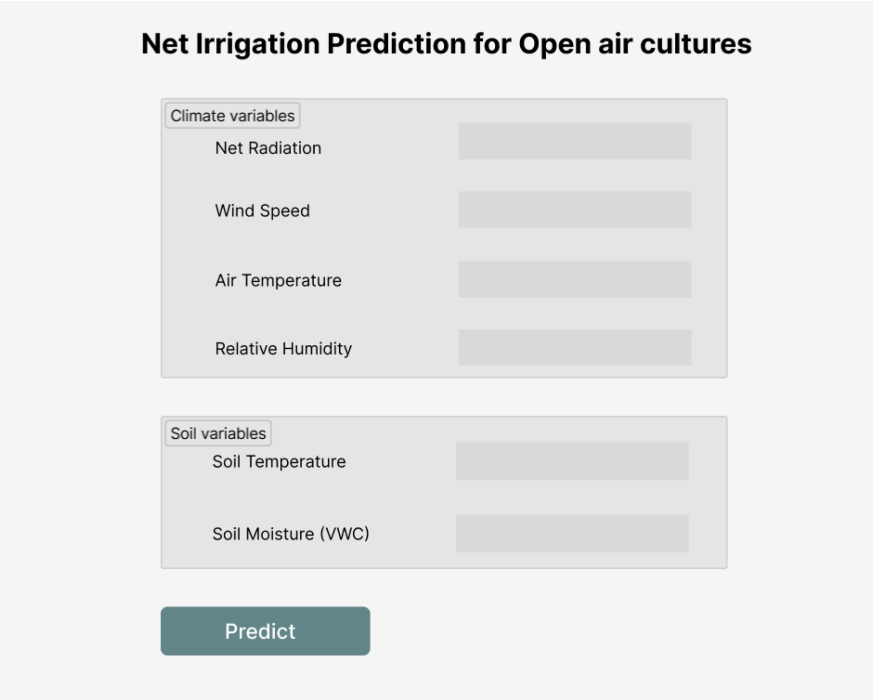

Figure 6. The user interface example for net irrigation prediction for open air cultures

- Greenhouses
    - Http method: POST
    - Endpoint: “http://web-production-794e.up.railway.app/greenhouse/predict”

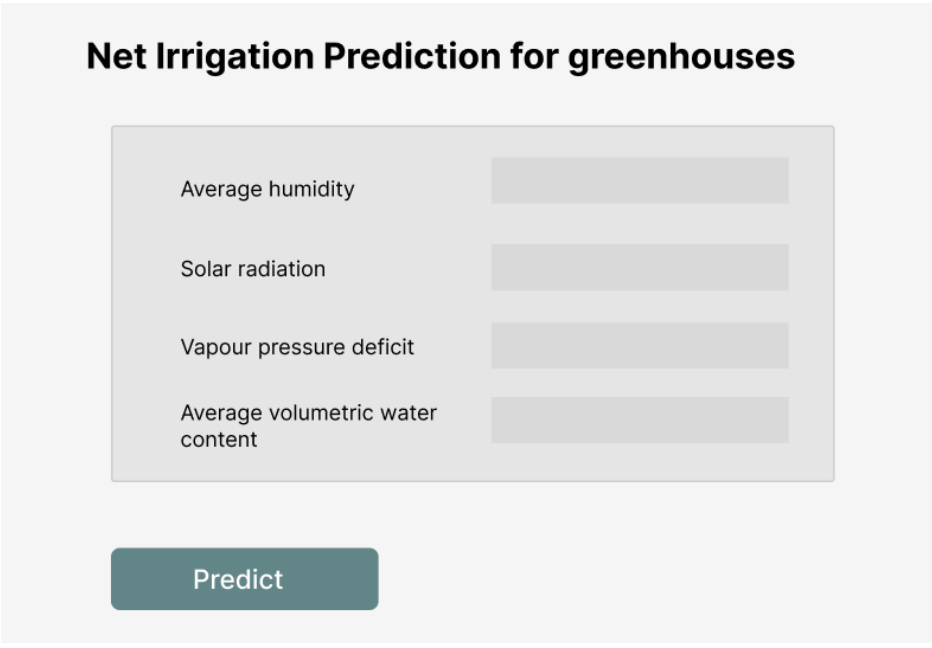

Figure 7. The user interface example for net irrigation prediction for greenhouses

<u>Corresponding deliverable to Task 3.3</u>

- D3.3 ‘BigData algorithms for precise irrigation and fertilization services’ submitted on M40

1.2.4 WP4 Validation and Demo of Decision Support System

The aim of WP4 is to test the PRECIMED DSS, developed in WP3, under field conditions to evaluate its performance and versatility for different agricultural conditions, and to explore those aspects that can be improved to obtain a more accurate tool.

The WP Leader is OPTIM. This WP started on M13 and finished in M42.

T4.1 Deployment and validation of the DSS system in the different agricultural exploitation.

The main goal of this task is to perform the deployment and validation of PRECIMED DSS prototypes in the different crops for wide evaluation in Mediterranean climates to build successful showcases that will be fully functional and may encourage business opportunities in the exploitation of project results.

In the frame of T4.1, the deployment and validation of PRECIMED DSS prototypes took place in the different farms defined in T2.1. For this, cost-effective CPS gateways, the EU FIWARE-based data IoT PRECIMED platform, agronomic DSS models based in BigData techniques, and end-users interfaces, were integrated to build successful showcases fully functional that may encourage business opportunities in the exploitation of the project’s results, making emphasis on crops productivity, water efficiency, end-user experience and business model testing.

In the case of CEBAS-CSIC, in the pomegranate pilot farm, soil moisture measurements obtained from capacitive probes and climatic parameters obtained by a weather station described in T2.3 were integrated in the PRECIMED IoT platform developed and deployed by ODIN (described in D3.1), where data were transmitted by the data logger and registered for further exploitation, like that done by the CEBAS DSS protocol (described in D4.2). Details of the CEBAS DSS prototype deployment are described in deliverable D.4.1. is this DSS prototype can be accessed by a third party?

Regarding UTH, during the first year of the project, the sensor system was deployed earlier in one of the two pilot farms (UTH-pilot farm) and started collecting data in a greenhouse with tomato plants. This data were used for the validation of the DSS, using the relevant methodology and set of equations and algorithms presented in D3.2.

In both cases (CEBAS-CSIC and UTH), ODIN deployed and integrated the DSS services for final users, specifically those based on the algorithms of the models of CEBAS-CSIC and UTH, and also of the prototype proposed by ODIN itself at the end of the project. Those algorithms, developed in the frame of WP3, were adapted to be used as Web services, providing them also with an API REST and, finally, virtualizing them as containers for an easier deployment using to do so the Docker technology. Then, those services have been integrated with the IoT platform using the platform's REST API to access the registered data and by the HMI interfaces to interact with them and show the results. This way, the DSS services became available for testing in the PRECIMED platform integrated with registered data. Are these DSS services can be accessed by a third party? By others end users?

In the case of INRAA, soil moisture sensors and agrometeorological stations were deployed in the two Algerian pilot sites, located in Central and West Algeria (described in D2.1). An Imetos weather station and Diviner 2000 probe were used under each pilot site during 2021 and 2022. The device installed in Sidi Moussa farm, was completed by the installation of a drill and Drop probe from July 2022. The Imetos weather stations were linked to the PRECIMED platform via an API service provided by Pssl company. However, the Drill and Drop Triscan 120 cm probe is, so far, not yet connected to the platform due to some technical issues of connection. The DSS model based on water balance model will use data from Imetos weathers stations, and other data sources from end users, like information on soil properties (like the total available water and the readily available water) and from some references related to crop coefficient and the length of crop stages. The Drill and Drop probe will be used, only, to validate the reliability of the model. The simulation of the remaining water in the soil and the defining of the dates of irrigation were calculated during two growing seasons, 2021 and 2022, using climatic data recorded from Imetos weather station installed at Sidi Moussa farm. Soil water measurements contents were followed between Citrus rows. Diviner 2000 was used from January to August 2023 and from June to December 2023 a Drill and Drop Triscan probe installed at 0.5 meter from the Dripper was used. In fact, the Drill and Drop is acquired in June 2023 and the Diviner posed some technical problems. The analyse of data showed the soil water content between the tree rows seem better correlated with the predicted results by the irrigation scheduling using crop evapotranspiration data. The Data from Drill and Drop showed, always, an over irrigation.

Furthermore, in this task, an evaluation plan including the definition of Key Performance Indicators (KPIs) and end-users questionnaires were formulated. This evaluation plan is defined in the deliverable D4.3, which describes the Key Performance Indicators (KPIs) measured for the plant physiology parameters and crop nutrient status as well as the efficient use of water, soil and energy. To assess the most appropriate irrigation methods, some indicators commonly used to measure/weight the performance of an irrigation system were selected. Among these indicators, we used indicators to measure water stress like water potential, stomatal conductance, leaf temperature, the crop water stress index and net photosynthesis. These indicators were used to assess the impact of the different levels of deficit irrigation tested on the behaviour of the crops, notably the pomegranate. Others indicators were, also, selected to evaluate the efficiency of water management like, the product use efficiency, water use efficiency and the annual relative water supply. The crop water requirement and the irrigation water requirement were also used to quantify the impact of the different irrigation strategies on water saving.

<u>Corresponding deliverables to Task 4.1</u>

- D4.1 'Deployment of Enhanced Prototype of IoT-standards-based Decision Support System' submitted in M38.
- D4.3 'Performance Evaluation of Crop Productivity and Resource Efficiency' submitted in M42.

T4.2 Demo and evaluation of the DSS performance in agricultural farm according to plant physiology parameters and crop nutrient status in open air crops and horticultural crops under greenhouse conditions

Once deployment and validation of the DSS system in the different agricultural exploitations have been done, task 4.2 was carried out. This task should have started in month 18. However, COVID-19 restrictions led to a delay in the application of the system in practice that was carried out in the T4.2.

This task focuses in the acquisition of knowledge on physiological response of the species of interest of this project to different cultural practices and irrigation strategies to evaluate the agronomic performances of a given irrigation strategy under different irrigation scenarios. To this aim, the different research groups of the project studied in their experimental sites the physiological behaviour of open- field crops (pomegranate, citrus and potato) and greenhouse crops (tomato and cucumber) under different water and nutrient management practices suggested by the simulation model described in T3.2.

This action covers the selection of better cultural practices and fertigation strategies to improve the appearance and the nutritional value of the fruits grown in open-fields and greenhouses. Therefore, this task focuses on environmental factors (water availability, plant nutrition and water quality, etc.) highly suspected to interfere with fruit products composition and, consequently, to determine their final appearance and their nutritional and dietetic values.

In the case of CEBAS-CSIC, in order to evaluate the agronomic performance of pomegranates to different irrigation strategies, a two year trial (2021 and 2022) was conducted in Murcia at CEBAS-CSIC experimental farm (described in D2.1).

To reach the final objective of the study, during the first season (2021), four irrigation treatments were applied in order to explore crop responses to the timing and the regime of the irrigation applications. These treatments were: Control (well-irrigated treatment; 120% ETc), sustained deficit irrigation treatment (SDI, 50% ETc through the whole season) and, two regulated deficit irrigation treatments (RDI_{fg} and RDI_{r}, 50% ETc during the linear fruit growth phase and 25% during the ripening phase, respectively, and the rest of the season were irrigated at 100% ETc). During the second year (2022), four irrigation treatments were also applied: Control and SDI treatments (as described above), $C_{PRECIMED}$ treatment, where the plants were irrigated according to the PRECIMED-CEBAS protocol (described in D4.2) and $SDI_{PRECIMED}$, where irrigation was applied at 50% of the $C_{PRECIMED}$ treatment during through the whole season.

Morphological changes in plants were estimated by plant growth parameters such as stem and trunk diameter, tree height, leaf area index, crow diameter and canopy architecture. Determination of the physiological response of plants was estimated by water use efficiency, stomatal conductance, net photosynthesis, and water status obtained from leaf water potential, current osmotic potential, osmotic potential at maximum saturation and turgor potential. The anion absorption and distribution of minerals in the plant were determined by leaf mineral analysis. Indicators to diagnose the water status of plants such as thermal indicators in the leaf were evaluated through the use of infrared thermography. Analysis of different indices of water stress obtained from physiological and morphological parameters were obtained. The amount of water applied to each treatment was estimated using online water meters and gravimetrically. The yield (expressed as total kg of fruits per tree) and the total numbers of fruits per tree (including not commercial fruits) were determined. The mean fruit weight was calculated from total mass and number of fruits per tree. Fruit quality parameters were analysed measuring fruit size (equatorial diameter and height of the fruits), the soluble solids content (SSC), titratable acidity (TA) and the maturity index (MI) calculated as the SSC/TA ratio. In addition, analysis of some primary and secondary metabolites was determined. More details are described in the deliverable D4.2.

In UTH pilot farm, the collection of data continued also during the third year of the project to evaluate the DSS in practice in both cucumber and tomato soilless crops. These experiments performed in Agroktima Kalliantzis-pilot farm with a cucumber crop from M25 and continued until M35. In addition, the DSS was also validated in UTH-pilot farm in a tomato crop from M28 to M36. For the validation and test of the DSS in the two pilot farms, two treatments were applied:

1) a conventional fertigation strategy where irrigation scheduling was performed as commonly done in the region with the fertilisation recipe changed two to three times during the cultivation period, according to the growth stage of the crop, and

2) the fertigation management based on the PRECIMED DSS where the irrigation scheduling and the fertilisation recipe changed once per day (for irrigation scheduling) or week (for the recipe) according to the predictions of crop needs from the PRECIMED system approach. The data were used to evaluate two scenarios: the water and nutrients use efficiency achieved when using a conventional fertigation management practice (as will be shown by the collected data) and the water and nutrients consumption when using the fertigation management strategy proposed by the DSS. In addition to water and nutrient savings, the amount of fertilizer discharged into the environment was also evaluated. Moreover, in each experimental location, the physiological behaviour of each species under different fertigation management practices was studied. Specifically for greenhouse crops, morphological measurements such as plant height, number of leaves and fruits, as well as gas exchange measurements (photosynthesis, transpiration, and stomatal conductance) were performed, followed by fruit productivity measurements. Finally, the energy use efficiency and the environmental impact of these trials was also assessed to better understand the dual role of the PRECEIMED DSS, that is to save both water and nutrients as well as energy resources in soilless crops grown in the Mediterranean region.

In the case of INRAA, the trial was carried out during 2021 and 2022 on a farm located in Mitidja region, central Algeria (details are described in D2.1). The parameters measured on the farm to estimate the irrigation requirements are listed below:

- Climatic conditions, using an automatic “Imetos” weather station.
- Soil water content, using a Diviner 2000 to monitor the soil profile of 1,20 m depth between the citrus rows. The measurements were made each two days during the irrigation season 2021 and 2022; and by mean of a Drill and Drop probe Triscan 120cm from June to December 2022, which is installed at 0.50 cm from the dripper.

The evaluation of water management, according to farmer practices, during the crop cycle 2021 showed that the active root zone for citrus conducted under drip irrigation was limited to 0.90m. By analyzing the soil water content evolution curve measured by the use of Diviner 2000, the soil parameters (refill point, onset stress and full point) were identified.

Regarding to year 2022, the crop citrus was conducted under water stress due to insufficient water supply (month of July) and to excess water (from August to November 2022).

The total water supply applied during the crop cycle of citrus, in 2022 irrigation season, estimated via the cumulated of soil water storage variation is 1516 m^3 per ha, against 1316 m^3 for irrigation scheduling using water balance method. The use of the water balance method allowed to save 13,19% compared to conventional agricultural practices.

Another experiment on potato was implemented in the second pilot farm located at Sebain, Tiaret region. This experiment includes three water regimes and two levels of nitrogen fertilizer.

- Treatment 1 (T1): The irrigation starts at soil water content at about 100mm by 0.40m depth;
- Treatment 2 (T2): Trigger of irrigation when soil water content reach about 80mm by 0.40m depth;
- Treatment 3 (T3): Trigger of irrigation when soil water content reach about 60mm by 0.40m depth.
- The nitrogen fertilizers treatments (N1 and N2) consisted on
    - Treatment N1: Application of 120 kg N ha-1. 50% of the total nitrogen fertilizer was applied at planting and 50% was applied 02 two months after planting.
    - Treatment N2: Application of 250 kg N ha-1. As for the treatment N1, 50% of the total nitrogen fertilizer was applied at planting and 50% was applied 02 two months after planting.

The soil water contents of the three water regime treatments were estimated during the growth cycle using the Diviner 2000 probe.

The results showed that the potato yields are strongly affected by water stress. The yield losses compared to the best irrigated treatment were estimated at 24,12% for treatment T2 and 35,37% for the treatment T3.

Corresponding deliverable to Task 4.2

- D4.2 'Identification of different irrigation management strategies on crop physiology and nutritional value of fruits' submitted in M18 and M42.

T4.3 Analysis of the users' feedback and business model testing.

This task focuses on the evaluation of the PRECIMED Decision Support System (DSS) platform according to user experience and on the potential business model for all the different demo pilots developed in Spain, Greece and Algeria under T4.3 and D4.4. During the demonstration of the system, valuable end-user feedback was collected from the local farmers directly affected by the demo pilots (described in D4.4). Thus, the fertigation performance and business model of the PRECIMED DSS were evaluated by the end-user farmers within the implemented pilots according to the questionnaires defined in Task 4.1 to provide useful feedback regarding any optimizations and further customizations of irrigation services and end-users interfaces.

UTH designed and distributed among partners a questionnaire defined in Task 4.1 to assess end-users' technological familiarity, environmental awareness, water management practices followed in their farms, as well as their familiarity in using DSS. Moreover, the fertigation performance of the PRECIMED DSS were evaluated by the end-user farmers within the implemented pilots to provide useful feedback regarding any optimizations and further customizations of irrigation services and end-users interfaces

The questionnaire for open-field crops was distributed during the Interregional Conference sustainable production in agroecosystems with water scarcity (SUPWAS), held in Albacete during September 2022 and organized by three PRIMA projects (PRECIMED, SUPROMED and MEDWATERICE). It was a forum for meeting and reflection between farmers, technicians and researchers and it was held simultaneously, as an in-person and online conference. The questionnaire focused in the evaluation of the extent of knowledge and satisfaction of the conference participants with the use of DSS to manage irrigation. The sections of the questionnaire were similar to those described above in the greenhouse, only that a specific section was added for open field crops, where questions about the characteristics of the soil, irrigation water and irrigation scheduling were asked.

The results of both the questionnaires for greenhouse crops and outdoor crops are described in deliverable D4.4.

Finally, a business model was presented under this task to offer a better insight into project outcomes and guide activities toward impact-driven business development and exploitation. The business model developed and presented herein offers a better insight into project outcomes to guide activities toward impact-driven business development and exploitation.

Corresponding deliverable to Task 4.3

- D4.4 'Analysis of User Experience and Business Model Testing' submitted in M42.

1.2.5 WP5 Communication, Dissemination and Exploitation

The aim of WP5 is to increase the impact of the project through the wide dissemination of project outcomes. Communication activities will also actively support the involvement of end-users in particular for iterative design and development process and business model formulation.

The WP Leader is INRAA.

T5.1 Communication and Dissemination activities

This task has covered all the efforts to plan, implement, monitor and sustain a long-lasting visibility of the project through communication and dissemination of different activities.
At the beginning of the project (M6), UTH has developed a Communication and Dissemination Plan focused on the dissemination strategy, including the design and production of necessary material and the development of communication tools. The communication tools identified can be summarized as follow:

Development of Project's website, project logo, newsletters and brochures, publicity, electronic communication & multimedia including E-mails, online Forum and social media (Facebook, Twitter), participation in external events, dissemination of Promotional material like pens, leaflets, posters, banners, bags, USB-sticks, folders, notepads, Communication with horizontal projects to create synergies (participation in events- and, capitalization of project results).

The communication and dissemination plan were updated and finalized on M18 by UTH to include more details about the dissemination, notably, some indicators to take into account during the meeting with stakeholders, for the Social media communications, Communication in local media, Presentation or workshop of project concept, Distribution of dissemination materials, Project website and Communication to local policy makers.

UTH designed the templates for the trifold leaflet, the poster and the newsletter of the project. The material is used by all partners of the project at events, meetings and other types of activities/actions concerning the project.

Adding to these communication tools, the communication activities were defined at the beginning of the project. These activities were related to the different events to implement during the project like the organization of kick off meeting, the final conference, the participation in conferences and in external events.

During the project evolution, different communication and dissemination actions have been carried out:

- Design of the logo of the project (INRAA).
- Set up an internal project communication and document repository platform (PRECIMED Dropbox)
- Organization of the kick off meeting: The Project was presented at the kick-off meeting in CEBAS/Murcia on 19/10/2022 where all the partners had the opportunity to discuss and agree about the aspects related to the scheduled timetable of the Project, the goals of the Project, the structure and partnership, the structure and the content of the work packages and the deliverables and the dissemination of the outcomes;
- Regular meetings of the Project partners: The arranged meetings were planned as follows:
  - GENERAL ASSEMBLY: Once per year (in person) and when required. Although as it is explained below, the meetings could not take place in person, the consortium has settled an online meeting whenever it was needed.
  - Proposed meetings locations and dates:

    - October-2020. Greece (UTH): Due to the pandemic situation, the meeting was organized on Online on 15/10/2020;
    - October-2021. Algeria (INRAA): The meeting was planned to be held in Greece. However, taking into account the view point of partners and the uncertainty that still exists in relation to COVID-19, the partners considered that the most appropriate is to hold the 2nd annual meeting of PRECIMED project on online on 26th October 2021.
    - October-2022. Tunisia (OPTIM). The third annual meeting was, also, organized on online on 25-26 October 2022.

- Dissemination and publicity actions, which include:
    - Design, development and update of the official website for the PRECIMED project (INRAA). In the first time, the official registration was made as the subdomain name: https://www.precimed.inraa.dz, nevertheless the consortium agreed to change this subdomain to https://www.precimed-prima.org. The main information included are: Presentation of the project, Workplan, 12 Public deliverables, 13 Scientific Publications, 13 Communications and some scientific activities related to the field experiments. In March 2023 the website is visited by 9322 visitors. PRECIMED official website platform could be the main tool for the communication and the dissemination of project's activities/results to stakeholders.
    - An informative leaflet is developed by UTH concerning the Project and its goals. About 1917 documents were printed and distributed to the interest actors (farmers, students and researchers) by all the partners. Adding to this, 12 banners from all partners and one poster from CEBAS were printed and distributed.
    - Two project newsletters, produced by UTH, were Inserted in the project Facebook and the project website. CEBAS and OPTIM produced, also, newsletters inserted in their respective institution Facebook.
    - The press, radio and television media and YouTube were used by INRAA to disseminate the project activities.
- One day workshop presenting a practical guide for farmers and open days
    - After 2 years of activity, PRECIMED project planned to organize a 1-day workshop in each of the PRECIMED regions to present a practical user's guide to the farmers about fertigation. For Algeria, the device of measurement is presented to the key stakeholders as students and agricultural room in charge of the dissemination of the good agricultural practices.
    - 2 Open Day events took place on 18/09/2019 and 23/5/22 at UTH facilities. The Pilot Greenhouse Park of the University of Thessaly was open to the public where a visit and a presentation of all activities conducted under the PRECIMED project were performed.
- Create a Forum of PRECIMED : UTH has created a project forum https://www.linkedin.com/company/precimed-prima/. The statistic showed, until March 2023, 75 subscribers.
- Create a social media and update (Facebook and Twitter) (UTH). Some important activities associated to the project experimental devices were published by the consortium like: Measurement Devices of plant water stress (CSIC), Soil water content measurements and automatic weather station to collect climatic Data (INRAA), Microclimate station to monitor the climatic and the water status of crop and Hydroponic system developed by UTH. Facebook page presented several posts and has more than 474 followers.
- Participation to the national Day of the extension by INRAA with the presentation of:
    - ✓ The project leaflet.
    - ✓ Poster titled "Precise Irrigation Using ICTs"
- Presentation of the results at Conferences and Scientific Magazines.
  Under this dissemination activity the project consortium co-organized and participated in two conferences:
    - Interregional Conference 'Sustainable Production in Agroecosystem with Water Scarcity (SUPWAS)' (5-7/09/22). Albacete (Spain). Organized by SUPROMED, MEDWATERRICE

and PRECIMED projects and CIGR Section I. PRECIMED participated with four communications.
https://crea.uclm.es/crea/SUPWASConference/programa

- PRECIMED project: Introduction and overview (CEBAS-CSIC, Spain)
- Development of a DSS based on soil moisture sensors to improve fertigation efficiency. A pomegranate case study. (CEBAS-CSIC, Spain).
- Development and evaluation of a DSS for fertilisation management in a hydroponic cucumber crop grown in the Mediterranean region. (UTH, Greece).
- IoT-based platform with cost-effective gateways for optimizing irrigation scheduling. (ODIN, Spain).

- 'Intelligent Digitalization in Agriculture in the Mediterranean' (24/11/2022). Murcia (Spain). Organized by the PRECIMED, WATERMED4.0 and BERRIES4.0 projects. PRECIMED participated with five communications.
  - Overview of PRECIMED Project (CEBAS-CSIC, Spain).
  - Soil moisture-based approach for precision agriculture (OPTIM, Tunisia)
  - Assessment of irrigation practices for citrus crop at farm level in sub humid area of Algeria: case of Mitidja region (INRAA, Algeria).
  - Validation of PRECIMED DSS for fertigation management in greenhouse crops (UTH, Greece).
  - Development and validation of PRECIMED DSS under different irrigation strategies. A pomegranate case study (CEBAS-CSIC).

- Other workshops and conferences where PRECIMED have participated:
  - Juan Antonio Martínez Navarro (ODIN) has been invited as Guest Editor for a Special Issue entitled "Digital Transformation in the Agriculture Sector" in an open access journal "Electronics" (ISSN 2079-9292; CODEN: ELECGJ, IF 2.412).
  - Juan José Alarcón (CEBAS-CSIC). Case Study: PRECIMED Project. PRIMA Conference (Partnership for Research & Innovation in the Mediterranean Area), CSIC. 24 January 2019. Madrid (Spain).
  - María Fernanda Ortuño (CEBAS-CSIC). Case Study: PRECIMED Project. PRIMA Conference (Partnership for Research & Innovation in the Mediterranean Area), UPCT. 12 February 2020. UPCT, Cartagena, Murcia (Spain).
  - E. Ben Abdallah, R. Grati, K. Boukadi: A machine learning-based approach for smart agriculture via stacking-based ensemble learning and feature selection methods, The 18th International Conference on Intelligent Environments (IE2022), Beatrice WORSLEY award Best Paper, Class B (core2021).
  - E. Ben Abdallah, R. Grati, K. Boukadi: A Machine Learning Approach for a Robust Irrigation Prediction via Regression and Feature Selection, The 36th International Conference on Advanced Information Networking and Applications (AINA-2022), Class B (core 2021)
  - N. Fattouch, I. Ben Lahmar, K. Boukadi: Towards A Meta-Modeling Approach For An IoRT-Aware Business Process. 36th INTERNATIONAL ECMS CONFERENCE ON MODELLING AND SIMULATION(ECMS 2022), Class B (core 2021)
  - N. Fattouch, I. Ben Lahmar, K. Boukadi: A comprehensive architecture for an IoRT-aware Business Process outsourcing into Fog and Cloud computing. First Tunisian-Algerian Joint Conference on Applied Computing (TACC 2021) indexed DBLP.
  - M. Fredj, R. Grati, K. Boukadi: CropWaterNeed: A Machine Learning Approach for Smart Agriculture. 18th International Conference on Information Technology: New Generations (ITNG 2021), indexed SCOPUS, DBLP and Springerlink.
  - Participation in Workshop on Innovation activities related with SHUI Project-PRECIMED 26 April 2022. Murcia (Spain).
  - Participation in Workshop on Clustering Activities of PestNu's sister projects 7 July 2022. Thessaloniki (Greece).
  - Participation in the '10th International Micro Irrigation Conference' (25-27/01/2023). Dakhla (Morocco). PRECIMED project has participated with six communications.

- Introduction and overview of the project. (CEBAS-CSIC, Spain)
- Soil moisture-based approach for precision agriculture (OPTIM, Tunisia).
- IoT-based platform based on smart technologies for an efficient use and management of water resources optimizing irrigation scheduling (ODIN Solutions, Spain).
- Assessment of fertigation practices for citrus crop at farm level in sub humid area of Algeria: case of Mitidja region (INRAA, Algeria).
- Validation of PRECIMED DSS for nutrient uptake simulation in cucumber and tomato greenhouse soilless crops (UTH, Greece)
- Development and validation of the PRECIMED DSS for open field. A pomegranate case study (CEBAS-CSIC, Spain).

Other communication and dissemination activities:

- Attendance at the fairs (ODIN) of Agrifood Summit Málaga 2020, IoT Solutions World Congress 2022, Fruit Attraction Madrid 2022, Barcelona Expo Smart City World Congress 2022, IoT Solutions World Congress 2023, Fruit Logistica Berlin 2023.
- A visit to the Pilot Greenhouse Park of the University of Thessaly was made on Monday, May 23, 2022, by the Prime Minister Mr. Kyriakos Mitsotakis who was informed about the operation of the Greenhouse Facilities of the University of Thessaly. Professor Nikolaos Katsoulas presented the actions of the Laboratory in the framework of the PRECIMED (PRIMA) research project implemented in the Pilot Greenhouse Park, where modern, high-tech equipment has been installed in recent years. https://www.facebook.com/uth.lacec/posts/962160981128401
- A visit to the Pilot Greenhouse Park of the University of Thessaly was made on Monday, October 31, 2022, by the Member of Parliament of New Democracy Mr. Konstantinos Maraveyas, who was informed about the operation of the Greenhouse Facilities of the University of Thessaly. Professor Nikolaos Katsoulas presented the actions of UTH in the framework of the PRECIMED (PRIMA) research project implemented in the Pilot Greenhouse Park, where modern, high-tech equipment has been installed in recent years.
  https://www.facebook.com/uth.lacec/posts/472418911540416
- Presentation of a work conducted by UTH at the AgEng2022 Land. Technik conference, in Berlin, Germany on November, 22-23, 2022 entitled "PRECIMED: a simulation model for nutrient uptake prediction of a hydroponic cucumber crop grown in the Mediterranean region".
- Presentation (scheduled) of a work conducted by UTH at the International Symposium on Models for Plant Growth, Environments, Farm Management in Orchards and Protected Cultivation - HorchiModel2023 in Almeria, Spain on June, 26-28, 2023 entitled "PRECIMED: a simulation model for nutrient uptake prediction of a hydroponic tomato crop grown in the Mediterranean region".
- OPTIM also managed to have a mini track entitled "decision systems for smart farming" in HICCS (Hawaii, June 2023), a ranked conference, treating smart farming in general and precise irrigation in particular. The different partners of the PRECIMED project will be part of the program committee of the mini-track.
- OPTIM has proposed a topical collection on advances of deep learning for smart farming (https://www.springer.com/journal/521/updates/24099052), which can help disseminate PRECIMED results and allow the consortium to open up to similar initiatives.
- Two more papers are under development by UTH and will be submitted in peer-reviewed journals entitled:
  - "PRECIMED: a model for daily crop growth, nutrient uptake and evapotranspiration simulation for tomato and cucumber soilless crops for use in an on-farm decision support system" and
  - "Validation of PRECIMED DSS in water and nutrient use efficiency, yield and environmental impact of tomato and cucumber soilless crops grown in the Mediterranean region"
- Three more papers are under development by CEBAS-CSIC and will be submitted in peer-reviewed journals entitled:

  - "Searching for a deficit irrigation strategy to save water and improve fruit quality without compromising pomegranate production",
  - "Influence of deficit irrigation on increasing bioactive compounds of pomegranate (*Punica granatum* L.) juice. Exploratory study using LC-MS-based untargeted metabolomics approach" (in the frame of T4.2) and
  - "Development of a DSS based on soil moisture sensors to improve fertigation efficiency in pomegranate crop".
- Final Conference: The Project planned to organize the Final Conference at the end of the project to present its results.
- Stakeholder's involvement: 7 universities, research institutes, agricultural services, one agricultural room and farmers of citrus, olives, fruit trees and hydroponics crops from the four countries participating in the project were involved in the project. In total, about 30 meetings were organized in the pilot areas on the vision of PRECIMED project.

<u>Corresponding deliverables to Task 5.1</u>

- D5.1 'Communication and Dissemination Plan' submitted on M6 and M18 (updated version).
- D5.2 'Data Management Plan' submitted on M10.

T5.2 Exploitation and IPR management of the project's results

In the frame of tasks T5.1 and T5.2, the deliverable D.5.3 was presented on M22, after the extension of its delivery date was accepted. This deliverable defines some key terms and explaining what can be achieved concerning the dissemination and exploitation of results during the project, and presents the design and production of the necessary material, the development of communication tools and the organization and implementation of various communication activities (UTH).

<u>Corresponding deliverables to Task 5.2</u>

- D5.3 'Preliminary Plan for Dissemination and Exploitation of Results' submitted on M22.
- D5.5 'Plan for Dissemination and Exploitation of Results' submitted on M38.

T5.3 Sustainability Plan

An Intermediate Sustainability Plan was developed on M18. It included the project keys stakeholders, the sustainability approach, the strategies to increase the involvement of end users and organizations in the project for a better sustainability of PRECIMED results. It included, also, the description of the activities to deploy the sustainability strategies across the Mediterranean basin. This intermediate sustainability plan was updated on M40 to, precisely, define the sustainability actions implemented during the project lifetime and to define sustainability plan after the end of the project to ensure the continuation of the PRECIMED platform, its extension for others crops and its accessibility by new users. For that perspective, the following actions need to be taking into account:

- Further development and (test under new conditions) of the PRECIMED platform.
- The sustainability of PRECIMED platform and the DSS need to be ensured by the business model. It needs to cover the maintenance of the platform, the data management collected from different IoT devices and the use of DSS developed by each partner.

Regarding the case study developed under the PRECIMED project, the activities to deploy to ensure the sustainability of the platform after the end of the project are listed below, being most of them common to the whole consortium:

- Training for farmers and technical staff including extension agents on the use of the PRECIMED platform and the use of devices used in precision agriculture to improve water and nutrient management.
- Publish in scientific journals the latest trends and research directions for precision agriculture based on precise irrigation and fertilization management, as well as the results obtained during the validation of the PRECIMED DSS.
- Publish in scientific journals all the results obtained from the validation of PRECIMED DSS in hydroponic tomato and cucumber crops.
- Continuation of research and development activities under national projects through the access to public initiatives, which foster innovative solutions for the agricultural development to keep improving the PRECIMED platform.

Corresponding deliverables to Task 5.3

- D5.4 'Intermediate Sustainability Plan' submitted at M18.
- D5.6. 'Final Sustainability Plan' submitted on M40.

1.3 Impact

1.3.1 Innovation and economic impact

The first impact of the project is the development by OdinS of the PRECIMED IoT DSS platform integrating devices and advanced services for precision agriculture, a solution that brings to final users the possibility of deploying and integrating IoT devices and web services from different vendors as well as the use of those advanced agronomic services and decision support systems to help them in everyday tasks like irrigation and fertilization.

OdinS is highly interested in continuous improving our solutions. Our technology used in our IoT hardware solutions will have to evolve, for example, integrating new communication technologies, like satellite communication for scenarios where others are not available; updating hardware designs to continue optimizing energy consumption; configuring IoT devices with enough computing power to support embedded AI algorithms for Edge solutions; and incorporating security technologies, like MQTT/TSL and Blockchain, to secure data received from IoT devices and other sources, just to mention some. The IoT DSS platform will have to evolve too, not only integrating the new services that our clients may need and demand, but also others that, as we understand, could make it more valuable. By means of our business relationships with our customers through our marketing channels, we will receive their feedback with recommendations and new needs that will be studied by our development team to decide its feasibility. Also, I+D+I tasks achieved by our teams will study other possible services of interest. This continuous evolution will allow us target more potential clients and even to open the solution to new marketplaces.

The IoT device prototypes of OdinS upgraded to incorporate different wireless communications based on LPWAN networks such as NB-IoT/LTE-M 5G, SigFox, and LoRA, already have a small-scale manufacturing process that considers the new communications socket design to easily support the right communication technology for each deployment scenario. These devices have been successfully tested in the deployment of the pilots in PRECIMED project as well as in other agronomic scenarios out of the project to better test them. The process of development, maintenance, and evolution of these products will continue having the appropriate organizational structure of OdinS, with its facilities and specialized personnel. We think that the different IoT products are thus prepared so that they can start being tested by the first customers. So, in OdinS we think that the technology readiness level for these IoT devices is now TRL7, and that they have the status of PMV (minimum viable product) so that, after the end of the project, OdinS could start their commercialization.

The PRECIMED IoT DSS platform, developed based on open standards like EU FIWARE to promote its interoperability and that integrates different agronomic services as well as the developed agronomic DSS with their HMI interfaces, has been deployed for the four agricultural scenarios in PRECIMED to verify its functionalities. The maintenance and improvements processes for the evolution of this platform have the appropriate organizational structure of OdinS, with its facilities and specialized employees. We think that the solution is thus ready to be tested by the first customers. In OdinS we think that the technology readiness level of this solution is now TRL7 with a status of PMV (minimum viable product) so that, after the end of the project, OdinS could start with its commercialization with a business model based on the cloud SaaS (Software as a Service) software distribution model, like Freemium, Pay-as-you-go, Subscription, or Tiered fixed fee, business model that still has to be decided.

For this commercialization, one of the main core target customer groups of OdinS consists of farmers in irrigation exploitations, or in a higher level, of agricultural cooperatives, agricultural managers, and directors. Also, OdinS is considering as potential customers of interest water quality control companies, water treatment industries, and any other companies that may need a solution for data acquisition and controlling. To achieve the firsts customers and contracts after the project ends, OdinS will develop, using the most appropriate strategies, business relationships through marketing channels with our potential customers, both nationally and internationally. A cross-functional team will be assembled from composite sales, technical, and marketing expertise to ensure that the correct marketing channels are used and that the focus will be on profit and convenience. This way, we will work to establish and maintain contact with farm directors and managers within our core customer group, to generate interest and drive conversation with those end customers willing to hire and pay for our solution and services. Also, OdinS expect to grow internally as a SME company, making contracts for new employees for all these expected activities and objectives to be achieved.

1.3.2 Technical scientific impact

The main impact foreseen by PRECIMED is to improve the farm productivity through the reduction of costs and the increase of the crop yield with a solution that minimizes the environmental impact due to the sustainable use of resources (water, fertilizers and energy consumption) and reduce the laborious human tasks while feasible business models are generated for the different farming scenarios.

Some of the main Key Performance indicators (KPIs) achieved under the framework of the PRECIMED project and in particular during the validation of the PRECIMED DSS in the greenhouse and open field real-case scenarios are presented in Table 2 and 3, respectively.

The use of the PRECIMED DSS in greenhouse crops showed significant benefits in terms of productivity, water and nutrient use efficiency and environment in general. In particular, the use of such DSS in greenhouse soilless crops resulted in water reduction and productivity improvement by 10%. Moreover, the DSS resulted in a significant reduction in the ozone formation, impacts on human health or terrestrial ecosystems, global warming, ionizing radiation, terrestrial acidification, fine particulate matter, fossil resource scarcity formation, human carcinogenic toxicity, and freshwater eutrophication by 10-30%. In addition, a significant reduction by 30-36% was observed in terms of fertilizer reduction in greenhouse crops, land use, stratospheric ozone depletion, marine eutrophication, mineral resource scarcity, human non-carcinogenic toxicity, reduction of nitrogen contamination (underground water), freshwater, terrestrial, and marine ecotoxicity, as well as water consumption.

Table 3. Key performance indicators achieved during the validation of the PRECIMED DSS in the greenhouse real-case farming scenarios using tomato and cucumber soilless crops.

Key Performance Indicators	Reduction (%)
Water Reduction	9%
Production Improvement	9%
Fertilizer Reduction	24-36%
Reduction of Nitrogen contamination (underground water)	33%
Global warming	25%
Stratospheric ozone depletion	35%
Ionizing radiation	25%
Ozone formation, impacts on human health	28%
Fine particulate matter formation	19%
Ozone formation, impacts on terrestrial ecosystems	28%
Terrestrial acidification	24%
Freshwater eutrophication	11%
Marine eutrophication	35%
Terrestrial ecotoxicity	31%
Freshwater ecotoxicity	33%
Marine ecotoxicity	31%
Human carcinogenic toxicity	16%
Human non-carcinogenic toxicity	34%
Land use	36%
Mineral resource scarcity	35%
Fossil resource scarcity	18%
Water consumption	30%

In the case of open field crops, specifically in pomegranate crops, the use of the PRECIMED DSS supposed water saving of around 30% with a slight increase in the production improvement (14%). In relation to the physiological KPIs, the increase in the gas exchange parameters and the reduction of the canopy temperature and the CWSI of the plants irrigated based on the DSS PRECIMED showed significant benefits in terms of the good water status of the crop. In addition, regarding fruit quality, total soluble solids increased, without observing an increase in fruit acidity, which can be perceived positively by consumers. Also, PRECIMED DSS irrigation conferred higher content of organic acid and sugars in fruits, giving more flavour to these fruits. An increase of 9% in the total phenolic compounds was observed in fruits from trees irrigated with PRECIMED DSS, which are considered as the most of the health-promoting potential.

Table 4. Key performance indicators achieved during the validation of the PRECIMED DSS in the open field real-case farming scenarios using pomegranate crop.

Key Performance Indicators (KPIs)	Reduction (%)	Increase (%)
Crop KPIs		
Water Reduction	30%	
Production Improvement	14%	
Physiology KPIs		
Stem water potential	3.5%	
Stomatal conductance		10%
Net photosynthesis		2%
Intrinsic water use efficiency		20%
Canopy temperature	12%	
CWSI	8%	
Fruit quality KPIs		
Fruit weight		15%
Total soluble solids		8%
Maturity index		2%
Aminoacids	8%	
Organic Acids	17%	
Sugars	20%	
Total phenolic compounds		9%

The findings on potato showed that the water stress affect strongly the yield. The losses of yield in our experiment varied from 24,12% to 35,37% compared the best scenario of irrigation.

Therefore, PRECIMED project allowed introducing a new agricultural practice to improve water and nutrient use efficiency, notably, in the context of changing climate affecting the water resources in the Mediterranean regions. So, the development of the PRECIMED platform and the services related to irrigation scheduling have a significant impact. The use of DSS for irrigation scheduling can lead a larger group of farmers to use irrigation water more efficiently as the approach don't require a large investment on the measurement devices. In addition, the saved water consequently to the improvement of water use efficiency can be used to extend the irrigated area. Finally, it should be note that the project allowed to raise awareness of farmers and policy makers regarding the precision agriculture, what can promote the development of precise irrigation.

The project had an important international impact as optimising water use is a global priority. The members of PRECIMED project are leading researchers in this field, which allowed the appropriate dissemination of the potential results through conferences, workshops, collaboration with leading international research groups and publication in SCI journals.

1.3.3 Socio-economic impact

PRECIMED has an impact on a variety of stakeholder groups across the agri-food ecosystem: farmers, businesses, citizens/society, public authorities and external communities.

PRECIMED guarantees better resource planning for suppliers of fertilizers and irrigation communities and offers a timely and guaranteed delivery of agricultural products due to a greater predictability of yields (both in quantity and quality) that benefit both food producers and the productivity of their farm will be increased. In addition, PRECIMED has an important impact in mitigating climate change due to its expected impacts in reducing the use of water and fertilizers. The validation of the new irrigation, fertilization and phenology models provided by PRECIMED supports the entire scientific community for future research. Therefore, as a lump sum, PRECIMED is a contribution to all of this modern society, providing tools to improve the quality and productivity of agriculture in areas affected by climate change (arid and semi-arid areas).

It should be noted that there is consensus on the potential of new information technologies (ICT), data science, and artificial intelligence, terrestrial and space-based sensors. All these technologies in an integrated way reduce the costs of producing healthier crop products, moderating input costs, as well as limiting the presence of pollutants and residues in the environment and in final products, resulting in greater food security.

PRECIMED partners have worked closely with Irrigation Communities and farmers who have shown a great interest in our research on sustainable fertigation with PRECIMED DSS. In this frame and with the support of this project we have organized (i) workshops in Universities and other institutions involved in water management for irrigation, (ii) courses and training activities workshops, (iii) public forums, (iv) guided visits to irrigators facilities to connect academics and farmers. The transfer of knowledge to farmers, agricultural cooperatives, ICs and training centres can create job opportunities and increase competitiveness.

Regarding the inclusion of the gender dimension, the content of our project adheres to the principles set out in the European Charter and Code of Conduct for Researchers. It has applied the Principle of Non-Discrimination and Gender Balance, being fully committed to the integration of gender equality in research excellence and has strived to achieve this goal: 1) encouraging the participation of women in all possible research and management activities; 2) encouraging and supporting women's mobility and working conditions; 3) encouraging the participation of female colleagues in all phases of project development; 4) promoting a balanced project workforce; in this regard, it is considered relevant to highlight the balance in the composition of the staff involved in the proposed project. Gender inclusion has been also be reflected and mentioned in all job advertisements and recruitments carried out in this project. Finally, research related to the technologies must be designed and programmed to take into account the physical, psychological and social characteristics of the gendered user.

2. Update of the plan for exploitation and dissemination of result

Due to the pandemic, research and innovation projects has been forced to increase their visibility and dissemination via internet. As already mentioned above, PRECIMED project has already several communications channels running, as the project website and the different social networks. In this sense, the communication plan (D5.1) was updated by adding some new aspects related to the actively participation in the dissemination of the results of the project and in the structure to follow of the posts on social network to increase the impact of our activities.

The preliminary Plan for Dissemination and Exploitation of results (D5.3) was delayed in order to consider another alternative Dissemination and Exploitation plan, taking into account the restrictions imposed by the COVID-19 pandemic and the measures taken for its control. So, the public events planned, as organizing workshops, presentation of the results at Conferences, Open Day and a Final Conference, have been changed. In fact, the virtual meetings or online exhibitions are retained for organizing these events.

3. Update of the data management plan (if applicable)

During the project, no cases have been identified that are subject to changes in the management plan.

4. Follow-up of recommendations and comments from previous review(s)

On 23 November 2021 was held the Mid-Term Evaluation Meeting, in which PRIMA Project Officer, an independent expert evaluator, the project coordinator (PC), the Work Package leaders and the representatives of the PRIMA National Funding Agencies participated.

During the mid-term meeting PC delivered a short presentation highlighting the most significant advancements/achievements of the project, the constraints faced, and any other aspects concerning the development of the project. Then there was a discussion period, in which the expert evaluator shared comments, suggestions, and questions on the implementation and the scientific aspects of the project. All of the evaluator's questions and comments were answered in a report which was approved.

Among the comments received and recommendations to be taken into account are the following:

- *Lack of directed activities and outputs specifically targeting the end users?*
  The dissemination activities implemented, like the participation in the national extension days, the meeting in field experiment with students from universities and farmers- and the organization of conferences to disseminate the project results, aims to raise awareness of farmers and students in term of the precise irrigation.
- *What activities have been undertaken to engage with farming communities, water user associations, farmer groups in each of the pilot regions?*
  In Algiers pilot farms, the project is implemented with the agricultural room that is connected directly with farmers, agricultural services and agricultural ministry.
- *Who are the key stakeholders?*
  The key stakeholders were described in the sustainability plan. It includes farmers, agricultural services, research institutes and universities, farmer association, and extension services of agricultural
- *How are they being used to help disseminate the project activities?*
  The agricultural room is in charge of the dissemination of good agricultural practices. This institution is connected directly with farmers and agricultural services. The project activities is disseminated via the social media (Facebook) of agricultural room and during the meeting organized. The research institutes and university promote the development of smart agriculture tacking into account the ideas developed under the project like the measurement device installed on farm.

5. Deviations from the proposal submitted

Some partners have exposed some deliverables should be delayed and other changes from the proposal.

5.1 Tasks

PRECIMED consortium requested no-cost extension of the project for six months until 31/03/2023 due to the impact of the coronavirus pandemic.

The consortium decided that in order to achieve the project's objective in a satisfactory way, this requested 6-month extension would be necessary. All partners support the proposed extension.

There are some situations or tasks that impacted the timing of the project over the end date:

- Partner's agencies delay. The eligibility of costs from UTH started 4 months later the beginning of the project. This means that UTH needed at least 4 months of extension of the project in order to have the time to use the budget as planned.
- COVID restrictions. Due to COVID-19 restrictions, the interactions with the farmers, needed to carry out task 2.3, were postponed. In addition, restrictions led to a delay in the application of the system in practice that is carried out in the tasks of WP4.
- Material stockpiling and successful implementation. There have been delays in the purchase of materials necessary for the execution of tasks 3.3., and 4.1.

As a consequence of these alternations, the work packages WP1 "Project Management" and WP5 "Dissemination" are extended for a correct coordination and overall coherence of the project.

For all of the above, tasks delayed beyond the end of the project are the following: T2.3, T3.1, T3.3, T4.1, T4.2, T4.3 and those corresponding to WP1 and WP5.

In the Mid-term Evaluation Meeting the extension of the project was approved by the National Funding Agencies of PRECIMED partners.

5.2 Use of resources

Deviations on the pilot farms:

- Farming scenario 4 was tested in UTH pilot greenhouse instead in the greenhouse described in the proposal since it is not operational anymore.
- INRAA changed in their pilot farm 2, adding a glass greenhouse dedicated to the hydroponic production of potato seeds. However, the greenhouses are currently weakly equipped and the different devices as heating and cooling systems or the fertigation equipment need to be fixed and completed.
- CSIC has changed the crops that were indicated in the initial proposal. Pomegranate and pear trees were worked on in the field.
- OPTIM have had to discard the proposed pilot farm, as it was located in a lockdown region (due to COVID-19). The current pilot operates on 12 hectares with irrigated olives, almonds, nectarine and peach.

Other deviations:

- Due to the pandemic, the annual consortium meeting scheduled to take place in Algeria was held virtually on October 26, 2021.

5.2.1.Unforeseen subcontracting (if applicable)

5.2.2 Unforeseen use of in-kind contribution from third party against payment or free of charges (if applicable)

5.3 Deliverables

The organization and coordination of other aspects of PRECIMED project that unexpectedly required priority caused a delay in the delivery of the D1.1, D1.2, D5.1 and D5.2 deliverables. However, this delay did not disturb the overall pace of the project employment.

Deviations at the start of the project:

- **#1** Deliverables D1.1, D1.2 and D5.1 were developed once all partners were able to begin project tasks. Some partners were delayed in tasks due to bureaucratic issues with their funding agencies.

- **# 2** Deliverable D5.2 suffered delays in the drafting of the final version due to the need to wait for more concrete information on the technical side.

Deviations due to COVID-19 pandemic:

- **#3** Due to the limitations forced by the restrictions of the COVID-19 pandemic, complete interaction with stakeholders was restricted and delayed. In addition, the different meetings planned to be held between the farm owners where the pilots were installed and the development team were also restricted and delayed. The above restrictions affected the delivery of D2.1 and D3.2. Furthermore, due to the restrictions forced especially to the Public Organizations and Universities participating in the consortium and the force for application of work from distance, the employment of new personnel was delayed. The above restrictions affected the delivery of all the above-mentioned deliverables for which an extension was requested. PRIMA accepted the extension requested and the delivery date of the final versions of D2.1 was M22 and of D3.2 was M24.

- **#4** The extension of D5.3 was requested in order to consider alternative Dissemination and Exploitation plans, which will take into account the restrictions imposed by the COVID-19 pandemic and the measures taken for its control. Thus, in the final deliverable, we presented potential mitigation measures that were taken in order to present a complete plan that could be compatible with the restrictions due to COVID-19 and presented more alternative strategies. Finally, it needs to be noted that more or less, all partners faced the restrictions imposed by the pandemic, which caused some delays in the implementation of the project activities. Thus, priority was given to field/experimental and modelling activities which had to be completed as they were used as an input in the next steps of the project. PRIMA accepted the extension requested and the delivery date of the final version of D5.3 is M22.

Deviations due to delays in technical developments:

- **#5** ODIN suggested the deliverable D4.1 delays to 38, since the final DSS couldn't be developed/deployed/described before all the expected algorithms (partial DSS) were ready (programmed and deployed) and the needed users' interfaces (frontend) were well known and described. PRIMA accepted the extension requested and the delivery date of the final versions of D4.1 was M38.

- **#6** In relation to D3.3, the due date was M38 (even after the extension of the project). However, it has been delayed for 2 more months. The reasons and the arguments behind this delay are as follows. From 2019-2020, there was a lack of data on the PRECIMED platform due to the circumstances of COVID- 19. Moreover, the controller "CEBAS Advantage Pro 2 controller" contained gaps in the weather data. All these issues do not help the deep learning algorithm predict the output with accurate results. So, OPTIM (Leader D3.3) proposed a deep learning algorithm (LSTM) for open-air crops while relying on the COSMOS database (open data). Once the model was built, they applied the transfer learning on PRECIMED data to enhance the precision of the LSTM model. However, to adjust to the objectives of the project, OPTIM has continued working on the BigData algorithms with the real data from the pilot farms. OPTIM has tried to enhance the model while waiting for "better quality data" and to train the model on offline data directly from the partner stations. Deep learning models require good quality data and large time coverage to provide accurate results. PRIMA accepted the extension requested and the delivery date of the final versions of D3.3 was M40.

Deliverables D2.3, D4.2, D4.3, and D4.4 were successfully delivered on March 2023 (M42).

Table 5. Updated dates for tasks, milestones, and deliverables.

Ref	Work Packages and Task	Leader	APPROVED		EXTENSION PROPOSAL	
			START MONTH	END MONTH	START MONTH	END MONTH
WP1	Project Management	CSIC	1	36	1	42
T1.1	Team and project coordination	CSIC	1	36	1	42
T1.2	Management of activities between consortium members	CSIC	1	36	1	42
T1.3	Project Progress reports' technical coordination	CSIC	1	36	1	42
T1.4	Financial and Administrative coordination	CSIC	1	36	1	42
D1.1	Project Management Procedure	CSIC		2		
D1.2	Quality Assurance Plan	CSIC		2		
D1.3	1st Annual EC report	CSIC		14		
D1.4	2nd Annual EC report	CSIC		26		
D1.5	Final EC report	CSIC		38		44
MS1.1	Signed Consortium Agreement			1		
MS1.2	Kick-off Meeting Performed			2		
MS1.3	Project Completed			36		42
WP2	Establishments of end-user's requirements	UTH	1	36	1	40
T2.1	Identification of farmers participating in the project and establishment of experimental approach in the pilot farms	CSIC	1	18		
T2.2	Analysis of nutrients and water availability management in the context of climate change	UTH	1	18		
T2.3	Assessment of each agricultural farm linked to practical feasibility of irrigation scheduling based in sensing plant and soil water status	CSIC	12	36	12	40
D2.1	Assessment of pilot farms for the design of the PRECIMED DSS	CSIC		22		
D2.2	Report on the agronomical and environmental requirements of the main agricultural crops of the Mediterranean Basin	UTH		36		
D2.3	Farmer practical guides	CSIC		36		42
MS2.1	Establishment of "pilot farms" equipped for monitoring plant-soil water status in each site			18		
MS2.2	Integration of data related to irrigation requirements in Mediterranean Region			18		

WP3	**Decision Support System Development**	**ODIN**	**1**	**36**	**1**	**42**
T3.1	**Design and Development of IoT-data management platform with cost-effective devices for optimized irrigation scheduling**	ODIN	**1**	**30**	**1**	**34**
Ref	**Work Packages and Task**	**Leader**	APPROVED		EXTENSION PROPOSAL	
			START MONTH	END MONTH	START MONTH	END MONTH
T3.2	**Models to determinate fertirrigation management in greenhouse and in open air**	UTH	**1**	**18**		
T3.3	**Development of BigData algorithms and end-user services for decision support of precise irrigation and fertilization**	OPTIM	**12**	**36**	**12**	**42**
D3.1	**IoT-based platform with cost-effective gateways for optimizing irrigation**	ODIN		**16**		
D3.2	**Integrated models of irrigation and fertilization for open-field crops and greenhouses**	UTH		**24**		
D3.3	**BigData algorithms for precise irrigation and fertilization services**	OPTIM		**32**		**38**
MS3.1	**Sensors and actuators integrated in CPS gateway with wireless LPWAN communication developed**			**10**		
MS3.2	**Developed IoT-standardized FIWARE-based platform for irrigation data management**			**12**		
MS3.3	**Defined models for irrigation management in open-field crops and greenhouses**			**23**		
MS3.4	**Implemented BigData algorithms and end-users interface for irrigation services**			**16**		
WP4	**Decision Support system validation and demo**	**OPTIM**	**1**	**36**	**1**	**42**
T4.1	**Deployment and validation of DSS system in 4 different agricultural exploitations**	ODIN	**13**	**36**	**13**	**40**
T4.2	**Demo and evaluation of the DSS performance in agricultural exploitation according to plant physiology parameters and crop nutrient status in open air crops and horticultural crops under greenhouse conditions**	CSIC	**18**	**36**	**18**	**42**
T4.3	**Analysis of the users' feedback and business model testing**	UTH	**24**	**36**	**24**	**42**
D4.1	**Deployment of Enhanced Prototype of IoT-standards-based Decision Support System**	ODIN		**32**		**36**
D4.2	**Identification of different irrigation managements effects on crop physiology and nutritional value of fruits**	CSIC		**18,36**		**18,42**

D4.3	Performance Evaluation of Crop Productivity and Resource Efficiency	CSIC		36		42
D4.4	Analysis of User Experience and Business Model Testing	UTH		36		42
MS4.1	PROTOTYPE 1: Intermediate IoT-based DSS platform integrated			18		
MS4.2	Intermediate IoT-based DSS platform installed in the different crops			20		
Ref	Work Packages and Task	Leader	APPROVED		EXTENSION PROPOSAL	
			START MONTH	END MONTH	START MONTH	END MONTH
MS4.3	Performance evaluated of crops status with intermediate DSS platform			26		30
MS4.4	Farmers feedback obtained for intermediate DSS platform			26		30
MS4.5	PROTOTYPE 2: Enhanced version of IoT-based DSS platform			30		34
MS4.6	Performance evaluated of crops status with enhanced DSS platform			35		39
MS4.7	Analyzed farmers feedback and tested business model			35		39
WP5	Dissemination	INRAA	1	36	1	42
T5.1	Communication and Dissemination activities	INRAA/ UTH	1	36	1	42
T5.2	Exploitation and IPR management of the project's results	CSIC	18	36	18	42
T5.3	Sustainability Plan	INRAA	18	36	18	42
D5.1	Communication and Dissemination Plan	INRAA/ UTH		3		
D5.2	Data Management Plan	CSIC		6		
D5.3	Preliminary Plan for Dissemination and Exploitation of Results	CSIC		12		
D5.4	Intermediate Sustainability Plan	INRAA		18		
D5.5	Plan for Dissemination and Exploitation of Results	CSIC		32		38
D5.6	Final Sustainability Plan	INRAA		34		40
MS5.1	Project logo, website and social media channels published			3		
MS5.2	Sustainability and Exploitation Plans Completed			34		40

6. Overview of the results

6.1 Exploitation and dissemination of the results

1. All the deliverables planned under the WP5 were established and integrated in project web site. The deliverables concerned are:
   - D5.1 Communication and Dissemination Plan (UTH)(M3) and updated by UTH on M.
   - D5.2 Data Management Plan (CSIC) (M6).
   - D5.3 Preliminary Plan for Dissemination and Exploitation of Results (CSIC) (M12)
   - D5.4 Intermediate Sustainability Plan (INRAA) (M18)
   - D5.5 Plan for the Dissemination and Exploitation of Project Results (CSIC) (M38).
   - D5.6 Final Sustainability Plan (INRAA) (M40)

2. Communications and publications
   During the life of the project, 12 publications had achieved and integrated in the website
   - 04 publications from UTH
   - 02 publications from CEBAS
   - 02 publications from INRAA
   - 05 publications from OPTIM
   - 01 publication from ODIN

   For the communications, the following activities were achieved:

   - Co- organization of 02 conferences on 'Sustainable Production in Agroecosystem with Water Scarcity and Intelligent Digitalization of Agriculture in the Mediterranean: PRECIMED has contributed with 09 **communications.**
   - Participation in workshops and conferences. PRECIMED participated in 11 events with 15 communications.
   - Others communication activities:
     - Attendance at the fairs (ODIN) of Agrifood Summit Málaga 2020, IoT Solutions World Congress 2022, Fruit Attraction Madrid 2022, Barcelona Expo Smart City World Congress 2022, IoT Solutions World Congress 2023, Fruit Logistica Berlin 2023.
     - A visit to the Pilot Greenhouse Park of the University of Thessaly by the Prime Minister https://www.facebook.com/uth.lacec/posts/962160981128401
     - A visit to the Pilot Greenhouse Park of the University of Thessaly by the Member of Parliament of New Democracy https://www.facebook.com/uth.lacec/posts/472418911540416
     - Presentation of a work conducted by UTH at the AgEng2022 Land. Technik conference, in Berlin, Germany on November, 22-23, 2022
3. Press publication:
   - **01 publication by Odin**

   Entities involved in the project: 7 universities, research institutes, agricultural services, 01 agricultural room and farmers of citrus, olives, fruit trees and hydroponics crops from the four countries participating in the project were involved in the project.
4. Meetings organized in the PRECIMED pilot farms: 30 meetings
5. Distribution of Dissemination material
   - Number of leaflets, banners, flyers and posters distributed by PRECIMED: 1917

6. Project newsletters: 02 newsletters inserted in the project website and Facebook, the Social Media of CEBAS-CSIC and in the Miracl research laboratory (OPTIM)

7. Project website: 9345 visitors.
8. Project Facebook: 474 followers.
9. LinkedIn: 75 followers

7. Conclusions of the project

Precision Agriculture, which could be defined as "applying the right treatment at the right place and time" and that is technologically viable with the use of IoT, intelligent services, and decision support systems. In this sense, the IoT offers many solutions. The use of LPWAN networks, such as Sigfox, LoRA and LTE-M/NB-IoT, allows the use of wireless IoT devices in agriculture with low maintenance cost, low power consumption, and long-range wireless coverage. Also, the analysis of IoT data allows to interpret and evaluate processes like irrigation and fertilization, and to improve the development of intelligent services and decision support systems using Big Data processing based AI algorithms, which bring the real-life potential of advanced interoperability between IoT technologies across the full value chain in multiple agri-food operational environments, involving different production sectors like greenhouses and outdoor crops and production systems like conventional and organic, among many others.

Under this scenario, all project partners have contributed to the development and validation of the PRECIMED platform according to their role in the project.

OdinS contributed to the development of the PRECIMED IoT DSS platform, based on open standards to enhance interoperability that integrates the IoT devices deployed in the five pilots of the project, different agronomic advanced services, as well as the DSS solutions developed by the partners.

OPTIM has participated building data-driven algorithms for irrigation recommendations that besides they were not able to be validated under field conditions, it exist a compromise to do it during the next years in some pilot farms, as both models, for open field and greenhouse crops, have been distributed via REST APIs to be integrated in the PRECIMED platform. Thus, the different DSS integrated at the PRECIMED platform, will be open to improvement, fact that will maintain the consortium collaborating after finishing the project.

UTH, CEBAS and INRAA contributed to the identification of users/farmers and their requirements, to the selection of sensors and models to be used for the assessment of crop fertirrigation needs, and to the development of the relevant algorithms for the development of the DSS. The pilot farms deployed at their respective locations have served, and will serve, as a showcase for farmers and other stakeholders (irrigation companies, public administrations or students) to exchange information and be aware of the advantages that the use of these kind of tools can offer to the growers.

In the case of UTH, after calibrating successfully and validating the DSS in real-case scenarios, the performance analysis and the analysis of users' feedback on greenhouse crops and DSS implementation were defined. In general, a good performance of the DSS implementation was recorded for tomato and cucumber soilless crops, highlighting the importance of the integration of such systems in greenhouse crops in the Mediterranean region to improve the water and fertiliser use in soilless crops, as well as the environmental impact of such systems in the agricultural sector. With the integration on the PRECIMED DSS into a greenhouse system, the end-user is provided with a weekly nutrient recipe based on the real nutrient demand of the crop, saving resources and costs.

Regarding open-field crops, the team is satisfied with the development of the PRECIMED platform due to the potential it offers. Besides the different difficulties for the implementation at the pilot farms, in both countries, Algeria and Spain, the partners have made an extra effort to performance the evaluation of the DSS. In the case of INRAA, the international crisis provoked important delays in the deployment of the different devices, which caused the impossibility to use the PRECIMED platform as an irrigation service, issue which is trying to be solved using a different via for the integration of their devices in the platform. At CEBAS, the different irrigation strategies applied to the crop have contributed to calibrate the model developed by OPTIM, validate a new irrigation protocol based on the monitoring of soil moisture sensors to schedule irrigation daily and develop the main interface, as well as the controllers that the platform requires to be use in a friendly way by the end users.

With regard to the dissemination of the results, the project partners have participated in various conferences and workshops, not only in the targeted regions but also in other areas potentially interested on the project results. In addition, the organization of the open days at the pilot farms, the social media channels and the website, have offered the possibility to reach many people

Finally, besides the scientific publications achieved during the project, there are more publications ongoing regarding the validation of the DSS and the effect of the DSS on crop quality and productivity, in greenhouses and open field crops, and they are likely to be published after the end of the project.