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Innovative Eco-Technologies for Resource Recovery from Wastewater

INCOVER

Deliverable D3.4

Smart irrigation systems at demo scale

Work Package 3

Added-value resources production

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Executive summary

The aim of Deliverable D3.4 is to present and discuss the deployment of the smart irrigation systems at demo scale in Barcelona (Agropolis) and Almeria (El Toyo). FINT, the IoT solution developer in charge of these systems, developed a powerful irrigation controller using an embedded system engineering approach along with Cloud Computing technologies. The company worked with two different hydraulic (drip) systems one on surface (Agropolis) and the other one buried under the ground (El Toyo).

The company initially designed, programmed and implemented the hardware part (irrigation controller) that was attached to the electro-valves and validated that they successfully transmit the actuation commands (valve on/ valve off), in real life and from wherever the operator has access to the Internet (Cloud). The other hardware component that hosts the engine that masters the local network constituted of the local things (e.g. sensors, electro-valves) is called FINoT Gateway and also connects the Information and Communication system with the logic of the user. That said, extensive effort to clarify the agronomical logic was put on and extensive research on the last trends of IoT, Data Science and relevant standards' landscape. As a result, FINoT irrigation was built to combine information from any other source (up to a hundred additional sensors, or external open Weather Data) and can correlate them with the locally stored logic of the irrigation system. Part of FINoT Gateway logic stands on the Cloud meaning that an external path can always be followed and adjusted to the users' preferences. All the software modules are responsible for programming each irrigation cycle and its dynamic changes. As a result, INCOVER led to the creation of FINoT irrigation scheduler that follows all commercial weather based standards and along with FINoT irrigation controller is the close-to-market product that FINT will further pilot in commercial farmers.

Last, the different modes for programming irrigation functionality is elaborated below as well as the multiple ways that the user interacts with the system.

1. Info on the Background of the technology used

FINT had designed and implemented an IoT middleware platform to network the required “things” to remotely operate a drip irrigation system and adequately control the “SMART” (context-aware) to decide when, how frequent and volumes to irrigate to optimize water use and improve the production yields . The IoT platform, FINoT© was initially designed to perform Connectivity Management, Device Management Device Certification, Data Collection and Analytics and Application Enablement. As the company matured, FINoT was integrated with FIWARE software components, the so-called Generic Enablers, and additional IoT services are being built. From FIWARE, FINT exploited several mechanisms related to Edge and Cloud layer including Data Security and User Privacy policies.

During INCOVER, FINoT was under development and it now hosts an additional IoT service and offers its value (remote irrigation management) to actors from the Agriculture domain. It is expected that such system can save large amounts of energy and water (up to 50% of the conventional systems) while, at the same time, increase farmer productivity and Agrifood businesses’ digital transformation potential.

2. Specifications of smart irrigation system

2.1. Selecting the appropriate irrigation method for Case Study 1

FINT had to decide the type of the system of irrigation to be implemented (border, furrow, sprinkler, drip) while considering the project objectives (water efficiency and safety when applying reclaimed water), EU legislation and market prospects, current market structure, where FINT is involved and its exploitation plan as well as the global irrigation market trends.

The result of a thorough analysis, the decision was to deploy a drip irrigation system that aligns with INCOVER projects aims and objectives since it achieves the highest application efficiency (more than 85%) when compared to other irrigation methods. Moreover, drip irrigation is an option that guarantees safety to local workers/visitors where reclaimed water is applied, assuming a scaled operation. Furthermore, the market dynamics that the company works within (IoT complex value chain) and the complexity of the irrigation market itself , forced the firm to explore a strategic cooperation with a local equipment manufacturer (OEM)-and global leader- in the drip market with INCOVER project being among its starting points. The irrigation design and conventional system’s specifications are shown in the following figure.

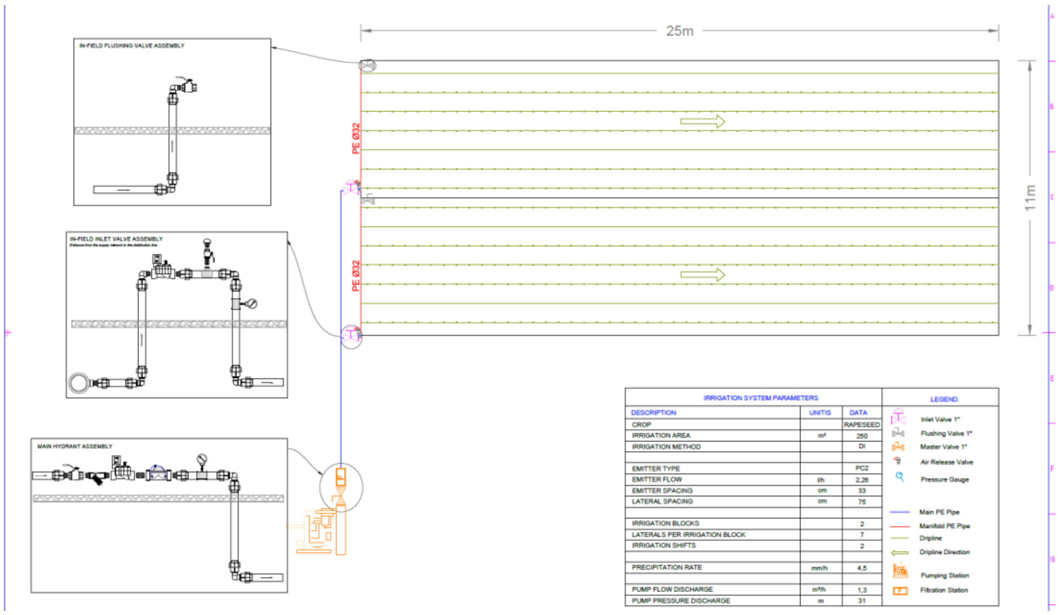

Figure 1. Design blueprint of the case-study 1 for the irrigation system established at Agrópolis (Viladecans, Barcelona).

2.1.1. Crop selection process- Brassica

FINT smart farming unit along with the partners of the INCOVER consortium and the DEMO facilities' owners discussed the appropriate crop to be planted at the Agropolis site. Various criteria and dynamics had to be taken into account for the decision, including:

1. Legislation on reclaimed water used for agriculture at local and European level
2. Water and land availability,
3. Local weather conditions
4. Project's timeline (when to plant is analogous with what to plant)
5. Local agri-production preferences and prospects
6. Available local expertise
7. EU agricultural prospects on the domain
8. INCOVER's (reclaim water) impact on economy's circularity

After discussions with the irrigation service provider partner, and since the initial plot was planned to be of ca 80 to 100 m2 and taking into account the availability of land and resources it was decided to increase the planted surface to 250 m2 to allow setting up a realistic business case. Additionally, the local conditions in autumn favoured the cultivation of cabbage (Brassica oleracea) or a similar fast growing crop such as rapeseed (Brassica napus), which are frequently used by citizens of the EU daily. However, local legislation on the domain (food crops irrigated with wastewater or reclaim wastewater) is stringent and the demands chemical and microbiological control including heavy metals, pathogens, bacteria and others. Hence, water reuse within circular economy imposes new challenges in existing EU competitive model. As an example, bio-diesel (70% of EU bio-fuel production) is a product based on the circular economy context and a special interest for EU, since it is the largest producer in the world (even its dominance is questioned by US entering the market). Furthermore, rapeseed oil is used to produce diesel fuel either directly as bio-diesel or as blended fuel. In fact, brassica is the leading crop (in hectares and tons) for biodiesel production in EU followed by sunflower (Helianthus annuus) fields . Some agronomy related details are presented in the Appendix (field conditions, cultivation practices and tips, water demand and more) that will facilitate FINT and Agropolis team cooperation. It should be stressed that Agropolis' personnel and UPC showed full cooperation and interest in facilitating FINT's work during the establishment phase as they effectively supported FINT on-field operations despite the language barriers and unstable local socio-political situation lived by Cataluña at the time of implantation (early October).

2.2. Selecting the appropiate irrigation method for Case Study 2

As in the first Case Study, FINT selected a drip irrigation system as in INCOVER, but the design went a step forward in the development of the technology, and to innovate and to achieve better efficiency complying with the latest trends; a sub-surface drip irrigation system was selected and installed. Sub-surface drip irrigation is highly suitable for the application of reclaimed water while it achieves the maximum water application efficiency since it directly applies water to the roots, minimizing the water losses due to evaporation. Strategically, it was considered that an IoT enabled sub-surface drip system would open additional go-to-market doors from the complex and competitive Irrigation industry but facilitating FINT's exploitation plan of its INCOVER activities. Figure 2 presents the diagram of the conventional sub-surface system along with the excavation and installation guidelines..

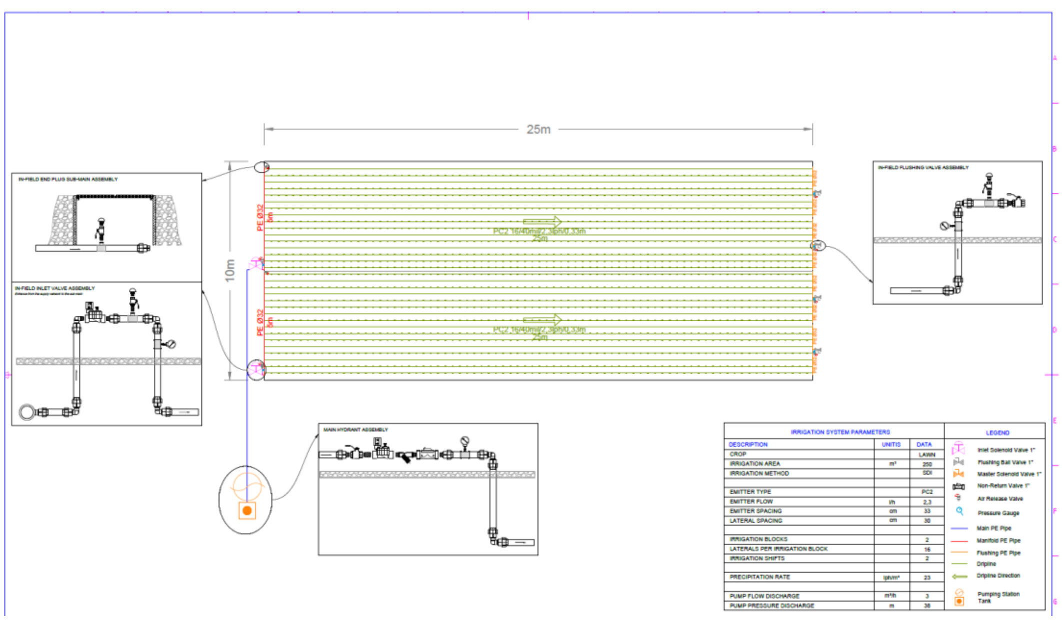

Figure 2. Diagram of case study 2 for the irrigation system established at Almeria, at Aqualia facilities in El Toyo wastewater treatment plant.

2.2.1. Crop selection process- Lawn/ grass

FINT smart farming unit and its partnered entities, along with the INCOVER consortium and the DEMO facilities' owners extensively discussed the appropriate crop selection for the Almeria site. Various criteria and dynamics were taken into account among them:

1. Legislation on reclaimed water for agriculture use at local and at European level
2. Water and land availability,
3. Local weather conditions
4. Project's timeline (when to plant is analogous to what to plant)
5. Local agri-production preferences and prospects
6. Availability of local expertise
7. EU agricultural prospects on the domain
8. INCOVER's (reclaimed water) affect economy's circularity

After discussing with the irrigation service partner, the plot surface was increased to 250 m2 (from 80-100m2) which, although is still small and comparable to a home garden, it is closer to a business case if compared to the original specification. Secondly, local expertise are not available locally, since El Toyo is an industrial site, away from the city and -unlike Agropolis-, there is no agronomy expert that would facilitate on-field operations.

Additionally, the local conditions after July and for the following six months are quite challenging (hot temperatures and windy conditions) for seeding. Furthermore, a recent public consultation on setting an EU Regulatory Framework for stating the minimum quality requirements on the reuse of reclaim wastewater for agriculture and aquifer recharge unveiled a general positive attitude, 60% of the surveyed considered a relevant EU action. Furthermore, a large majority of the surveyed considered the possibility and even the need of using reclaimed water for other types of uses, besides irrigation and aquifer recharge once the EU minimum quality requirements are met. In particular, a consensus was achieved for the irrigation of sport fields and urban green spaces. Therefore, the suggestion of irrigating grass areas that resembling golf courts or urban municipal landscape was finally proposed and adopted.

2.3. System analysis

The systems' smart optimisations are based on a combination of communication equipment that includes hardware and software modules, developed by FINT. The design and the equipment provides the system capabilities such as being remotely monitored, activated/deactivated, adjustable to the end user needs, -inserted rules and context-aware (e.g. the user is notified when certain microclimate or macroclimate thresholds are getting close to be or are actually surpassed). For more details regarding FINoT system, refer to the Appendix section.

In terms of on-field requirements, FINoT system requires a power source, 3G/ WiFi/ ETHERNET coverage and 24V AC or 12V DC control valves. Flow meters can be also easily integrated in FINoT platform but it was decided not to include them in any INCOVER's system since the irrigation designer was unable to suggest a company to supply a product for the low water volumes discharged at the site.

Table 1. Technical characteristics of the smart irrigation system of case-study 1

A/A	Item/ Component	Functionality/ Description
1	Sensors	To measure air (temperature, humidity) and soil conditions (temperature, moisture, EC, salinity, TDS)
2	Irrrigation controller	The unit that contains all the irrigation valves' actuation circuits, controls for the master valve and the two irrigation blocks and will be remotely activated by the end user and taking into account the microclimate data coming from the sensing unit as well as the macroclimate conditions and weather forecast.
3	FINoT Gateway	The router that connects the wireless sensor network that is installed between the sensing and irrigation nodes with the Internet. The device also embeds the required network software layer (network capable application processor that enables two-way and close to real-time communication with the sensors/actuators nodes' transducer electronic datasheets exchanges) and the FINoT Gateway data handling micro-services that enable the smart system back-end interaction with the cloud.
4	Web Monitoring Application	A user-friendly WebApp that enables the farmer to fill-in a profile page with his personal and cultivation characteristics, design the farm, syncronise it with the irrigation system, create flexible irrigation rules and profiles and finally get system's statistics and exportable data formats that he can easily store, re-use and share.

3. Design, implementation and starting operation of irrigation system at case-study 1

The site was planted in the late winter with sufficent water for the plants to germinate and no need for irrigation. Once the weather changed and the plants required irrigation, the irrigation system started operating along with the monitoring.

3.1. UPC's supporting role, Case Study 1

Agropolis team and UPC effectively cooperated and supported FINT's work during the deployment phase as they largely supported FINT on-field operations –especially seeding the brassica and establishing the surface system-despite language barriers and weird socio-political situation (early October).

3.2. Aqualia's supporting role, Case Study 2

Aqualia has supported FINT in the design and implementation of the systems at El Toyo wastewater plant in Almeria.

The buried piping coming from the solar-driven AO that will supply the irrigation system was installed as shown in Fig 9. Addtionally and to support the irrigation system and the smart control Aqualia has designed and installed water pipes (DN25) and electricity (2.5 kWh) for running the system, and supply tertiary treated water from El Toyo WWTP as an alternative water source Figure 7 and 8 present the layout of the installations at El Toyo.

Additionally, Aqualia has also established a health and safety plan for working at the site to reduce risks of accidents and to ensure high quality of the work.

3.3. Implementation and operation of FINoT smart irrigation system

The off-the-shelf irrigation system and its components have been shipped to Agropolis and Almeria and was deployed by local experienced teams. The equipment included all the necessary materials (pump, filters, driplines, valves, cables, adaptors) and will start the operation when water is available.

Hardware

FINT prepared and deployed the following equipment.

Table 2. Hardware deployed at the sites and software developed in INCOVER

<table>
<tr><th>Deployed Hardware</th><th>Case Study</th><th>Short description of the technolgy</th><th>TRL</th></tr>
<tr><td>Barcelona-FINoT Gateway</td><td>Agropolis</td><td rowspan="2">This device enables the creation of a local wireless network for the interconnection of hundreds of FINoT Nodes. Through it, data is delivered on an Internet platform from where a user has bi-directional communication, meaning he can receive data from the nodes and he can send commands to them too. You may think FINoT Gateway as a low power home WiFi router but it significantly differs in the coverage distance (much greater) and the scalability of the connected end-objects (sensors and actuators). It is the critical point where application business logic connects with the infield equipment performance.</td><td>8</td></tr>
<tr><td>AlmeriaFINoT GW</td><td>Almeria</td><td>8</td></tr>
</table>

<table>
<tr><td>Barcelona-FINoTAgriNode</td><td>Agropolis</td><td rowspan="2">This black box acts as the sensor controller and the telecom medium through which data is circulated within the local network that the FINoT gateway created. It can control up to four different objects (you can see one air and one soil sensor in the picture) while it serves network data to its proximate neighborhood node also acting as coverage extender (mesh topology). An IPv6 address was allocated offering its payload (all its sensors/ actuators data) directly on the Net. This is particular interesting for the forth-coming Internet of Things era, when connected objects will directly communicate with each other the same way webpages currently interact. It is called AgriNode because it provides the smart irrigation system with agriculture-related microclimate conditions upon which water irrigation use is optimised.</td><td>8</td></tr>
<tr><td>AlmeriaFINoTAgriNode</td><td>Almeria</td><td>8</td></tr>
<tr><td>Barcelona-FINoT GW+AgriNode</td><td>Agropolis</td><td rowspan="2">Hundreds of sensors and actuators can be connected with each other in the most cost efficient, operationally flexible and application generic way (Telecom-wise).</td><td></td></tr>
<tr><td>AlmeriaFINoT GW-AgriNode</td><td>Almeria</td><td></td></tr>
<tr><td>Barc-FINoT-irrigation controllerB</td><td>Agropolis</td><td>This device also acts as network node and things' controller. In this case, FINoT irrigation controller actuates three different valves: the master valve close to the pump and the two separate irrigation blocks, A and B. The FINoT Gateway also masters it, where the irrigation rules are retained.</td><td>8</td></tr>
<tr><td>Alm-FINoT-Irrigation Controller</td><td>Almeria</td><td>This device also acts as network node and things' controller. In this case, FINoT irrigation controller actuates three different valves: the master valve close to the pump and the two separate irrigation blocks, A and B. The FINoT Gateway also masters it, where the irrigation rules are retained.</td><td></td></tr>
<tr><td>Irrigation Scheduler</td><td>Almeria-Barcelona</td><td>This part of Cloud-hosted software embeds a Complex Event Processor that enables the system to interact with the user and other data sources in to define critical parameters related to climate, soil, crop and hydraulic/electric details of the deployed system. Then, the IoT scheduler defines irrigation frequency while available local input variables (e.g. soil moisture, weather forecast) determine irrigation cycle’s duration.</td><td>7</td></tr>
</table>

4. Establishment of the tech in the sites

4.1. Barcelona- Agropolis

FINT cooperated with UPC INCOVER team and Agropolis' Leader who deployed the hydraulic parts of the irrigation system while the electric and ICT components were connected locally, but activated remotely, from FINT premises in Greece.

Figure 3. Pilot hardware preparations and installed at the Barcelona site.

Figure 4. Drip irrigation System in Barcelona- Rapeseed (*Brassica napus*).

After successfully testing the networked devices, FINT ran a sensor-based, remotely managed, time-scheduled drip irrigation system from November 2017 until October 2018. The agronomists of the local team in Agropolis proceed with the cultivation of Rapeseed (*Brassica napus*) (November-May) and Sunflowers (*Helianthus annuus*) (June-November) and two distinct periods of irrigation were followed.

Figure 5. Drip irrigation in Barcelona- Sunflowers

Later on, after communicating with the local team the company decided to further work on the smart mode irrigation pattern on Almeria's deployment, due to the standard testing cultivation field (lawn) and more challenging climate criteria (the driest region in Europe).

4.2. Almeria- El Toyo

In Almeria, FINT collaborated with a gardening local service provider to prepare the field and deploy the sub-surface drip irrigation system that would irirgate a certain grass specie that is common in the area.

Figure 6. Sub-surface drip, soil transfer and grass rolls deployment (June2018)

After the plot preparation, the communication part was tested and FINT's hardware components responsiveness when commands were sent from FINT's headquarters in Greece.

Figure 7. Testing FINoT Irrigation Controller in Almeria

The system is then ready to kick off its irrigation functionality. The grass parcel was divided in two irrigation zones, each of them controlled by one electro-valve that FINoT irrigation controller masters. Following local and external agronomists' advice FINT system initially followed a standard time-setting irrigation pattern; while in parallel the functionality of the weather based autonomous system was being built up.

Figure 8. Smart Irrigation field in El Toyo, Almeria (September 2018)

4.3. Irrigation WebApp

FINT has develped QUHOMA[1] (QUalitative HOrticulture Marketplace), an agriculture-specific IoT platfrom from where farmers can check, visualise and remotely download sensor data of their farm. For INCOVER irrigation, QUHOMA was enriched with an additional tab (irrigation) that controls the different preferences regarding irrigation schedulling. These are analysed below.

4.3.1. System Features

A QUHOMA user needs to register himself in the app in order to gain permission to enter the platform by the administrator. Assuming both of them have done so, the «farmer» goes to the **irrigation** tab, where the Internet-connected irirgation zones are available (valve 1 and 2 for INCOVER case) and his field's irrigation design (provided by external irrigation designer).

Valve_X menus include; a) the current state of valve (OFF/ON), b) a bar indicating when the valve is in **auto** or **manual** mode, c) the active and stored profile (any profile may run temporarily and if is not stored the older –stored- profile will run, after the former completion) and d)a drop down menu to apply a different but already created and saved irrigation profile.(Figure 9)

[1] Moysiadis, H. et al (2017)

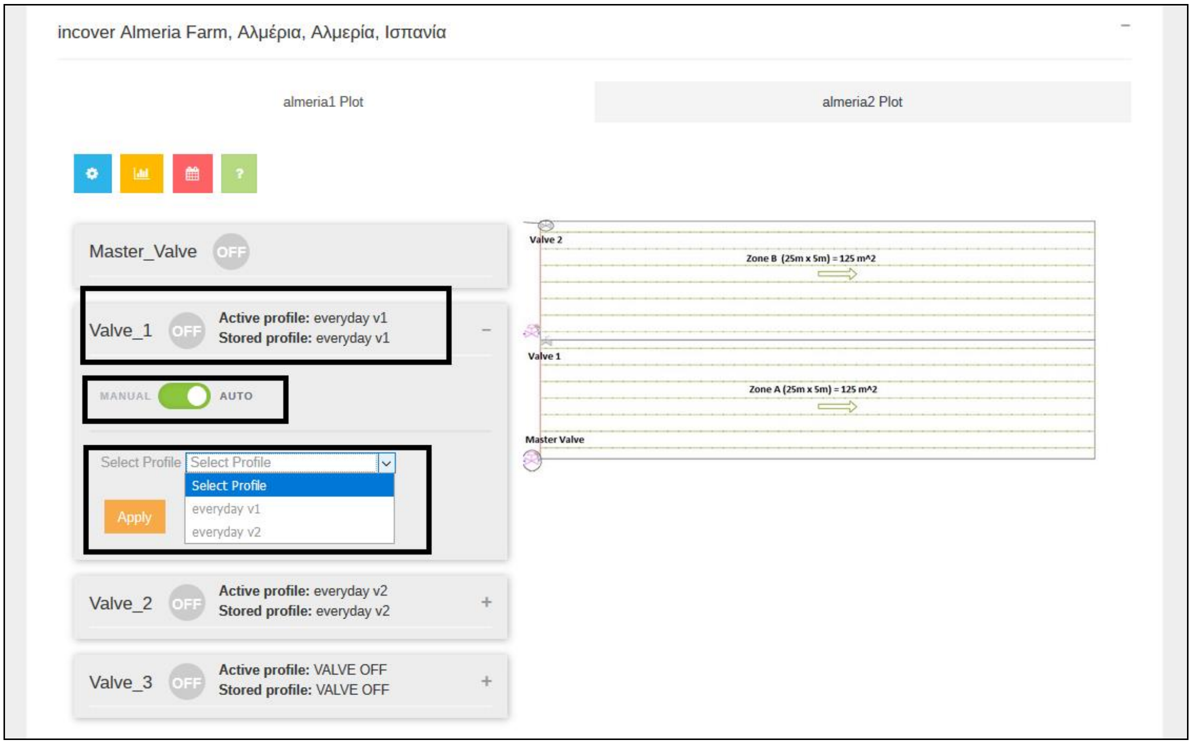

Figure 9. Valves control

On top of the valves' menu, the user finds three additional coloured buttons. The first button (Blue) enables the user to define the hyrdaulic and electrical characteristics of the system that is running and proceed with his preferred irrigation strategy and settings. (Figure 10)

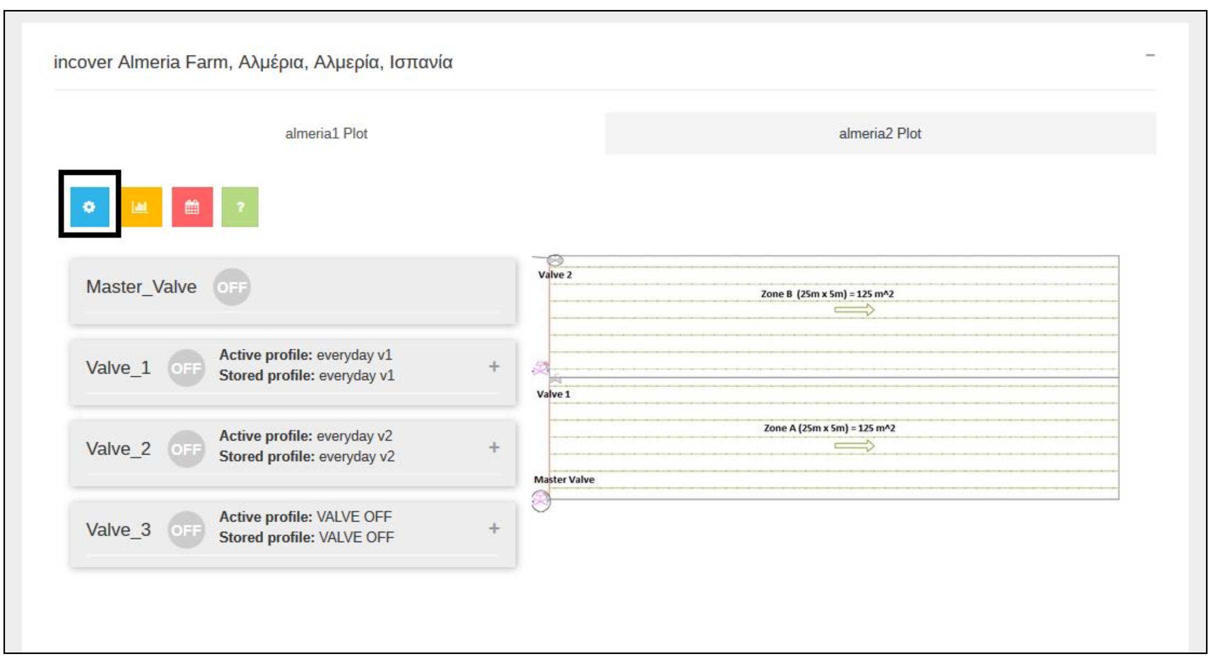

Figure 10. Irrigation Settings

Starting from the former, the user pulses the «sequencial» box when the irrigation designer has specified that irrigation zones cannot run in parallel but only one after the other (in sequence). Following, pump-related details follow where the user specifies pump's capacity, topological and emitters' specifications are requested. All thesedatsa, are already provided by the irrigation consultant/designer/expert that farmer has seek advice from. Next, three green boxes guide the user through the operational logic of the system (detailed explanation follows in the next section). (Fig 11)

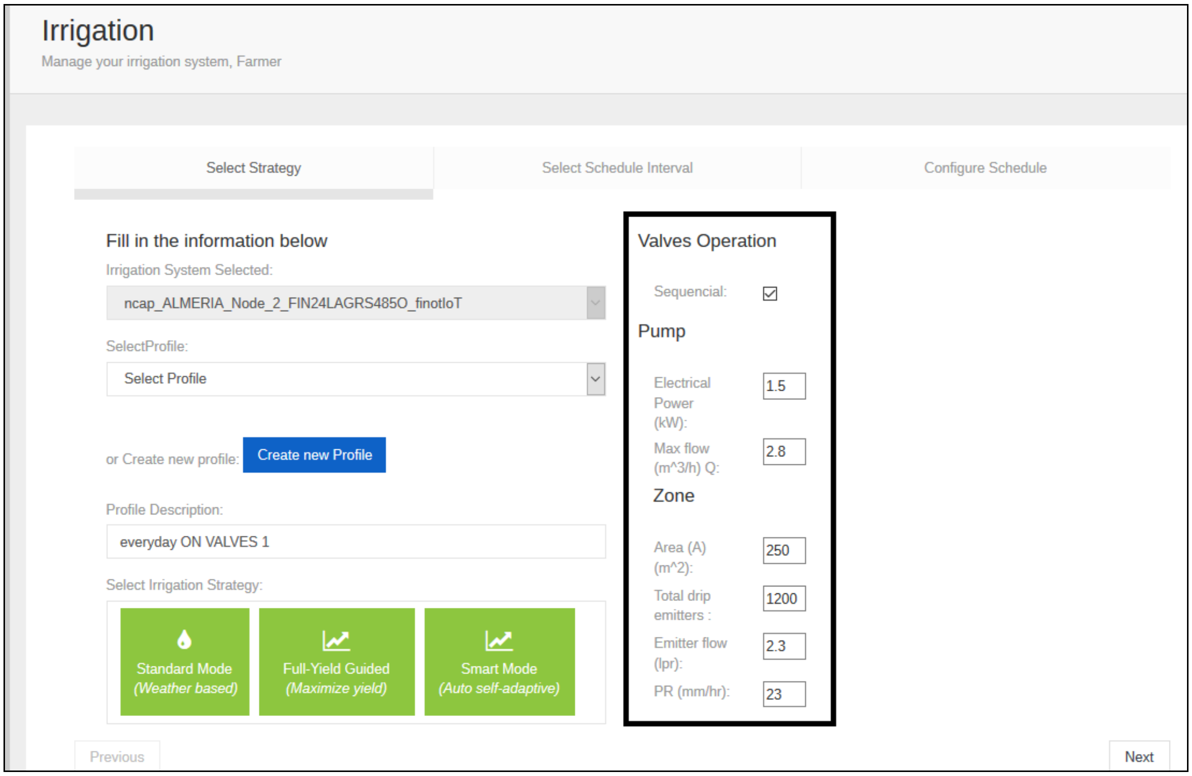

Figure 11. Hydraulic and Electric system specifications

4.3.2. Operational logic of the system

Selecting a Cloud-based Irrgation Strategy

INCOVER's irrigation system as implemented by FINT and its QUHOMA platform for Smart and Collaborative Farming encapsulated three different and interconnected irrigation strategies.

Firstly, the user can select the weather-based irrigation strategy in which he needs to define specific thresholds for soil moisture and rain precipitation over which the system will stop its operation in order to save water. For instance, if the operator has previously checked that soil moisture of 16% keeps its cultivation adequately healthy then he should insert this figure in the relevant field of the User Interface and then; a) the irrigation cycle will not start if moisture is over 16% and/or b) the irrigation cycle will stop when 16% is achieved. After doing so, the user will then select his preferred recurrent irrigation programme by time-programming the applications either by selecting a calendar-based or interval-based frequency. In general, weather-based irrigation is selected, when the ultimate scope of landowner is water savings from the irrigation infrastructure (Figure 12).

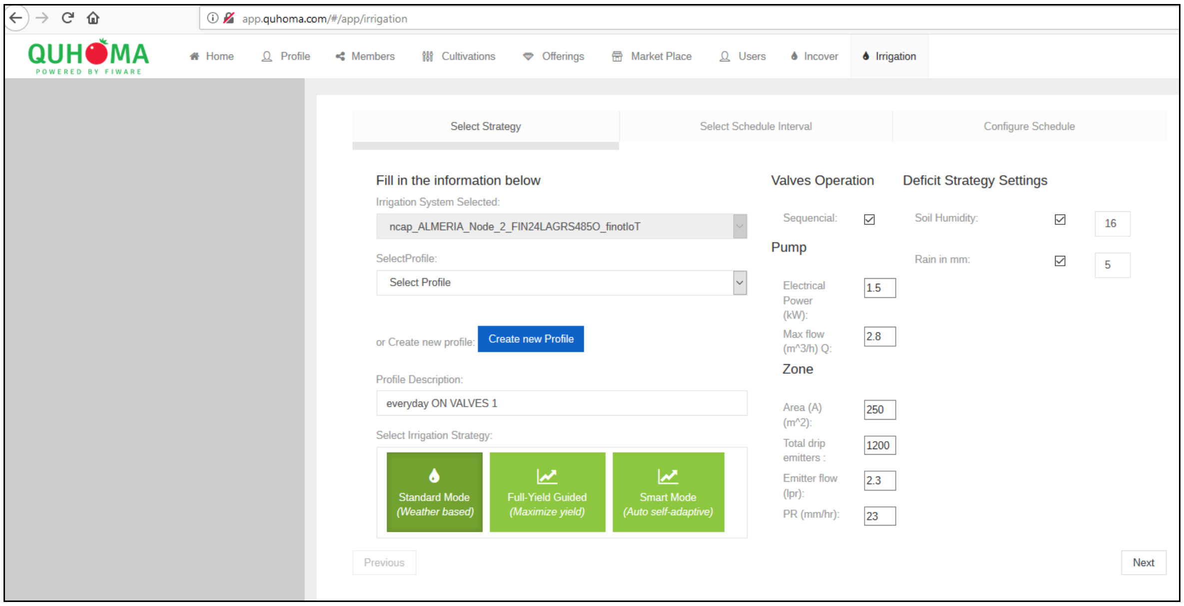

Figure 12. Weather-based irrigation settings

For the user that is mostly interested in achieving maximum crop yield and not water savings, full-yield irrigation strategy shall be selected. The strategy, and assuming the appropriate hardware is installed (e.g. flow meter), the system selects the proper conditions and notifies the user if anything goes wrong, for example leakages. In that case, the user will set the value of the flow meter top-right in his screen and has to also include the preferred irrigation depth in millimetres, his hydraulic system irrigation efficiency (e.g. for drip irrigation system efficiency is over 80%) in order to INCOVER scheduler automatically estimate irrigation cycle's duration. Once done, the platform feedbacks with information of the minimum irrigation frequency and duration conditions in order to support his decisions (Figure13).

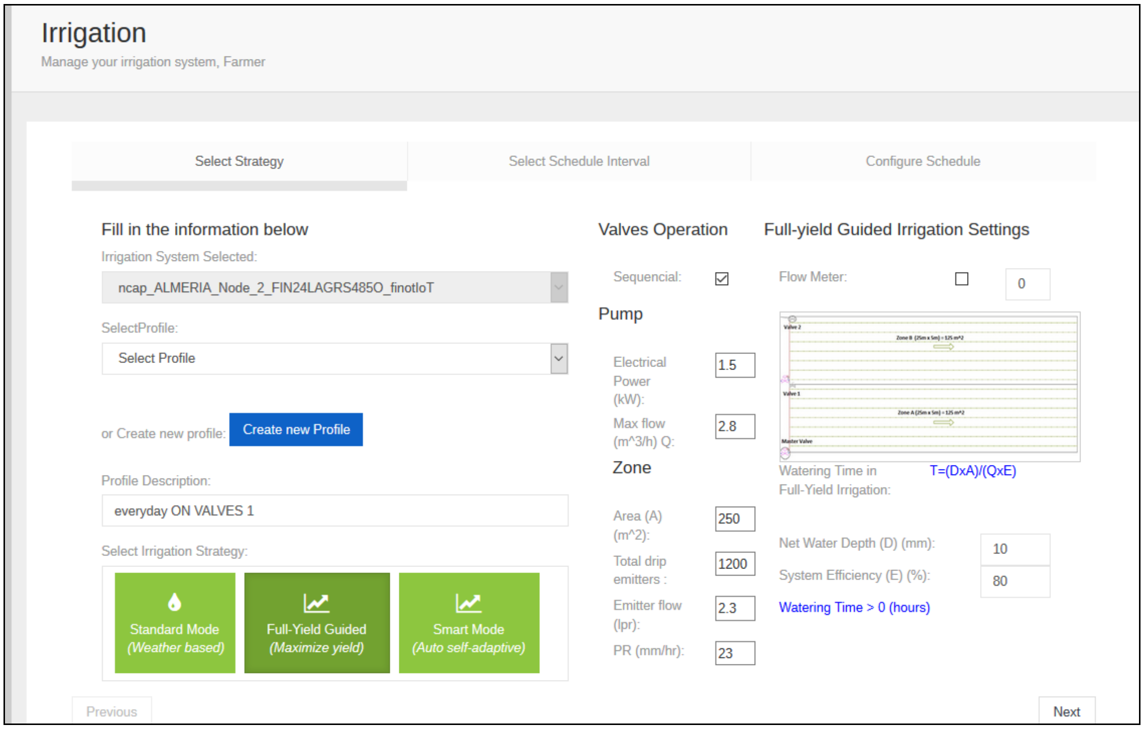

Figure 13. Full yield Irrigation strategy

Last, the user can select the smart mode feature for irirgation. This strategy's main cornerstone is the estimation of crop evapotraspiration (ETc), meaning that the water losses is calculated from the soil and plant for each day (mm/day) information. Various methods for calculating water loss are available in the literature. In the INCOVER project, FINT selected to work with two of them and develop the backend software tools and interconnections that host the algorithms and enable their quantification (Complex Event Processor, CEP). In the manual method, the user knows the reference evapotranspiration ETc and the crop coefficient (Kc)- a variable used to later estimate the water losses for the especific crop at a certain cultivation stage (initial, crop development, mid season, late/ harvest)-so he inputs the information and the system calculates the watering frequency to be applied. In the statistical/literature method, the irrigation operator is guided through an explanation of which climate is considered as humid, semi-arid and dessert and he selects the proper one. In the Blaney-Criddle method, which is used when on-field data – though limited- exists and that has been proved as the most accurate[2,3,4] ETc is estimated daily, via real time sensor measurements. As a result, frequency is automatically estimated and registered as a system's actuation command. Last, when sufficent data exists, the user can also select the most precise formula according to FAO, Penman-Monteith model. The second required irrigation schedulling parameter is the duration of each irrigation cycle, which is calculated from the soil conditions. Hence, the system requires basic soil texture information like salt content, loamy or sandy soil conditions; the slope of the parcel, soil's water intake capacity (field capacity), allowable surface

[2] Hafeez, M., & Khan, A. A. (2019)

[3] P, Rajasekhar & Siddhharrdha, Ragav & Prasad, Mynepally & Pitta, Sundara & Nagam, Raghavendra. (2015)

[4] Abdrabbo, Mohamed & El Afandi, Gamal. (2015)

accumulation and the available water content. If the user doesn't precisely acknowledge them, FINT's agronomists can support by after the field visit for the irrigation controller deployment.

Eventually, the system can self-define, both the amount (duration) and frequency of the irrigation cycle, for this zone by having information of the water holding capacity of the soil. More specifically, the total amount of water necessary to bring the soil up to field capacity is calculated by using the effective rooting depth of the crop and the soil's water holding capacity. Another important feature of the system is that the user can manually register the water budget ranging from 80% to 120%, so that he respects the previous system results (by the default 100%) or increases/decreases them, based on the crop stage and how important this is for the final volume of harvest. Last, it should be also noted that even in the irrigation's smart mode, the soil moisture and rain sensor continues to monitor the relative humidity and the effective rainfall rates. As a result, further water efficiency is realized by suspending irrigation cycles when the soil water is at field capacity (Figure 14).

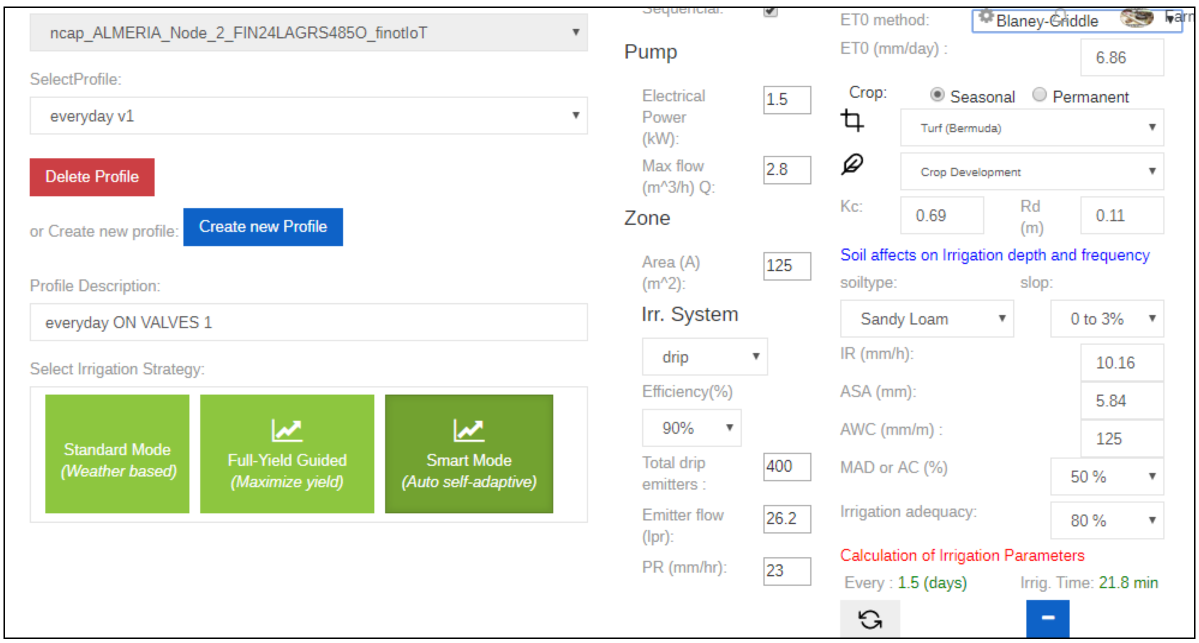

Figure 14. Smart-mode irrigation strategy

Manually Setting Irrigation Controller's schedule interval

QUHOMA app enables the user to create irrigation profiles directly on the non-volatile memory of FINoT Irrigation Controller. This is critical in cases where network connection is not available at the moment or when the gateway's power supply is temporarily off. Assuming Irrigation Controller is on power (off grid, energy autonomous Irrigation Controller is already designed) and despite any loss of signal between this device and Gateway the standard stored irrigation profile will run smoothly in all irrigation zones. There are two manual ways to define a static time-based irirgation profile either on a calendar basis or interval-based as explained before (Figure 15). The operator can select the prefererred option as shown below.

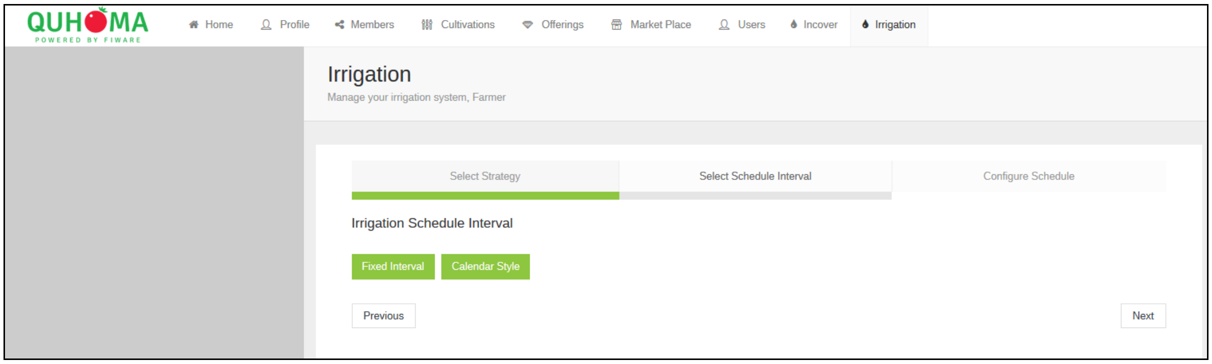

Figure 15. Selecting time-based irrigation cycles

In case of fixed interval is selected (Figure 16), the user selects the frequency that the system will periodically run, the exact starting time and the duration of the cycle. A important feature of the software, especially within INCOVER demonstration of Almeria, is the possibility to repeat the cycle unlimited times within a day. This is very helpful during periods when water availability is scarce and/or soil quality does not favor water retention.

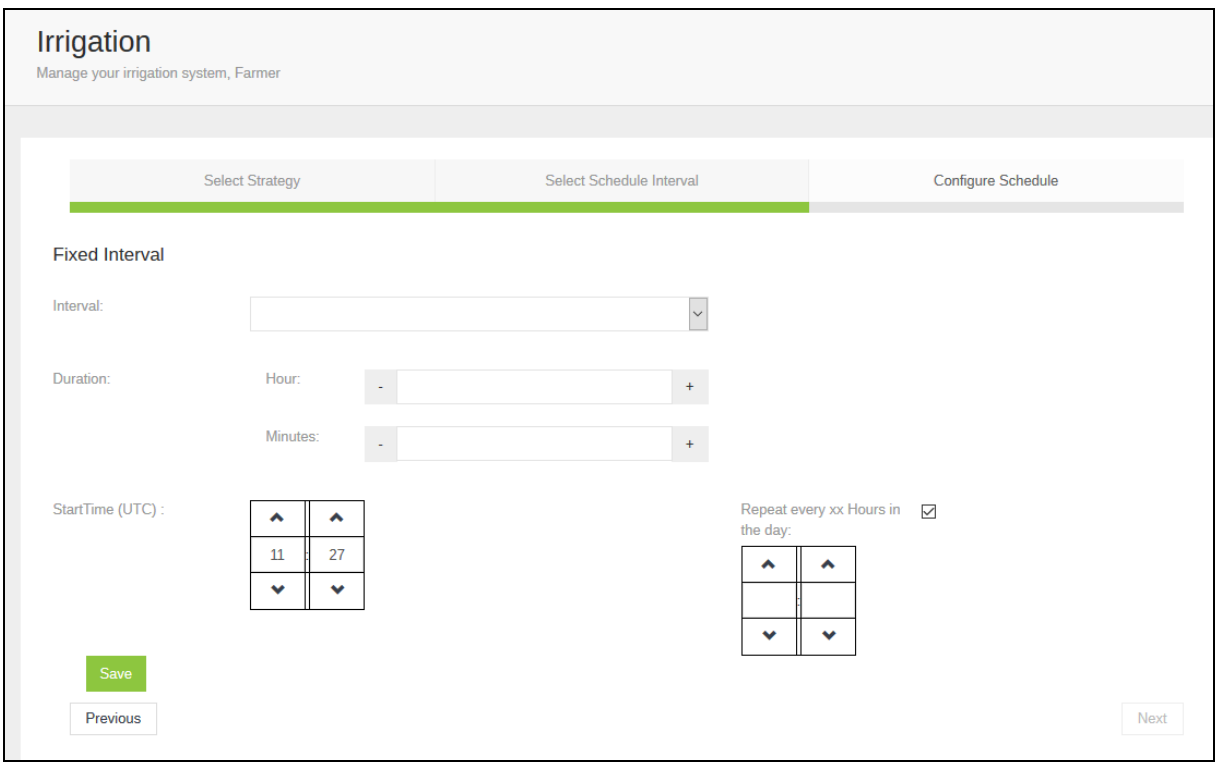

Figure 16. Setting regularly periodic irrigation applications

For example, the grass rolls in Almeria were deployed in mid-June, when local evapotranspiration reaches its highest level. Simultaniously, the amount of demanded water by the plants equals 3m^3/d approximately, but the available disinfected water for the AO system was limited to 175L/h. This can be explained by the system's auto-repeatability that the grass finally received the amount of irrigation that it was needed because FINoT Irrigation Controller was applying less water, but in more cycles to allow the disinfection system the time to provide the necessary to produce the water needed (figure 17).

PROJECT: INCOVER
SITE: ALMERIA
SYSTEM: F-INT IRRIGATION SYSTEM

Irrigation Type: SDI

Net Irrigation Area: 0,025 Ha or 250 m^2
Blocks: 2
Laterals per block: 16 Laterals Spacing: 30 cm
Emitter flow rate: 2.3 lph Emitter Spacing: 33 cm
Water consuption per block: 2800 lt/h
Pump Flow (Q): 3 m^3/h Pump Pressure Discharge: 38 m

Date: 28/7/2018

Depth Formula: D=(Q*T)/A where T=1h
Irrigation Depth: 12 mm

Input		
System:	AUTARCON	
Produce:	175	lt/h
INPUT		
t(min)	Vol(lt)	
1	2,92	
10	29,17	
15	43,75	
20	58,33	
25	72,92	
30	87,50	
60	175,00	
1440	4200,00	

Output for 1 Zone					
Pump flow rate:	3	m^3/h			
Water Cons:	2800	lt/h	Wait Time :	16	
Output			to reproduce		
t(min)	Vol(lt)		for 1 ZONE	t(min)	hours
1	46,67			16	0,27
10	466,67			160	2,67
15	700,00			240	4,00
20	933,33			320	5,33
25	1166,67			400	6,67
30	1400,00			480	8,00
60	2800,00			960	16,00

Site Limits in time		
Wait Time :		Zones
to refilling	for ZONEs:	2
min	hours	
32	0,53	
320	5,33	
480	8,00	
640	10,67	
800	13,33	
960	16,00	
1920	32,00	

QUHOMA FINOT			
Valid selections for more than one irrigation in a day			
Duration	Irrigation	every h/d	
t(min)	Schedule	min	max
10	everyDay	6	12
15	everyDay	8	12
20	everyDay	11	12
25			
30			
60			

Note: (1) This restriction is not applied in any other irrigation schedule which is not use more than one irrigation in the same day.
(2) At the beginning the tank must be full

Figure 17. System safety administration rules

In the calendar-based profile-setting, the user creates rules for the days of the week of every month that he wishes (or he is allowed) to irrigate. The user needs to create one rule to open the electrovalve at the exact preferred (or allowed) time and another rule to close it. This method of programming allows the farmers that have permanent cultivations (olives, vineyards), since they already know the different cultivation stages and any potential seasonal/ time limitations so it is more convenient than the interval based time-based scheduling (figure 18).

**When the Smart mode is selected the user can only define the start time of the first irrigation cycle, since the irrigation frequency and duration is derived from the equations used automatically.

Figure 18. Monthly/ weekly irrigation cycles

4.3.3. Irrigation charts and reports

Within INCOVER project timeline, the information requirements of the irrigation system's end-user were also discussed with several farmers in various contexts (interviews, fair/exhibition visits, email exchanges). Such discussions led to the assumption that information on the water quantity and electricity consumption is needed. As a result, a new option was developed; the orange button on top of the initial valves' menu was created and sends the user to a separate menu where he only sets the date from which he looks for the system operations. Then, different diagrams for different irrigation zones are displayed in a downloadable format (csv).

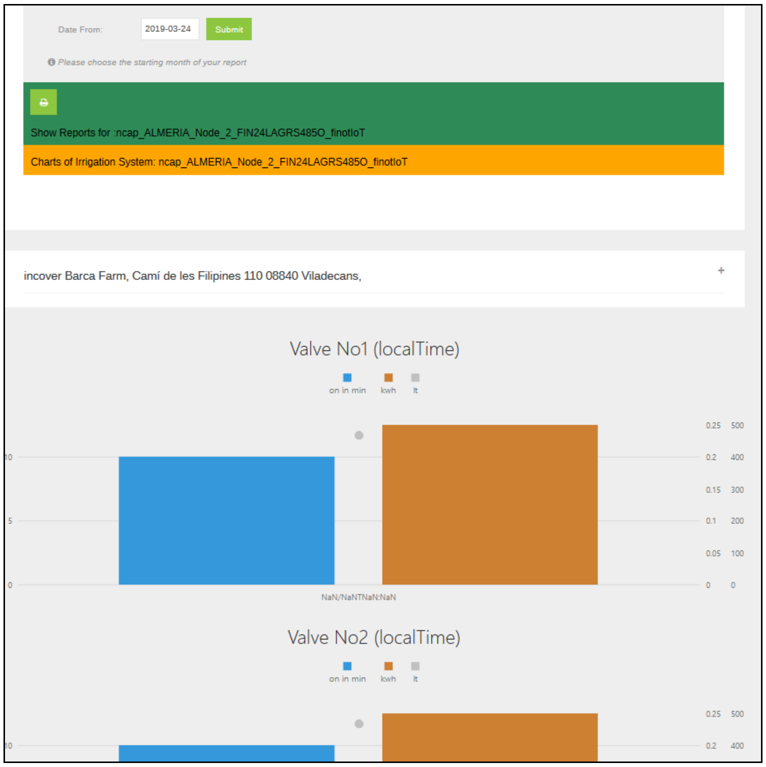

Figure 19. Valve-specific graphs

In addition, an IoT controller needs to self-report itself when abnormal conditions occur, described in INCOVER's smart irrigation system as alarms or events. Additionally, FINT's irrigation controller is programmed to gather data from a third party weather data provider through an open API (Weather Underground) therefore a specific rule has been set to register a relevant notification when these two different vendor systems do not interoperate. Other criteria include notifications when irrigation cycles are being suspended, the IoT system's gateway cannot read agrinodes' data (soil, air depending on the deployment) and an alarm when connection with the irrigation node is not achieved.

Date From: 2019-03-24 Submit

Please choose the starting month of your report

List of alarms/events

#	Date-Time	Source	Node	Alarm/Event	Reason
1	2019-03-01T00:18:02.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
2	2019-03-01T01:18:02.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
3	2019-03-01T02:18:02.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
4	2019-03-01T03:18:02.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
5	2019-03-01T04:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
6	2019-03-01T05:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
7	2019-03-01T06:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
8	2019-03-01T07:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
9	2019-03-01T08:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
10	2019-03-01T09:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
11	2019-03-01T10:18:03.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
12	2019-03-01T11:18:04.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
13	2019-03-01T12:18:04.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
14	2019-03-01T13:18:04.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
15	2019-03-01T14:18:04.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last update:Sat, 16 Feb 2019 22:12:56 GMT
16	2019-03-01T15:18:04.000Z	wScheduler	ALMERIA_Node_2_FIN24LAGRS485O	forecastOutDated	No communication with WU server,Last

Figure 20. System's self-reporting alarm and events

5. Data and results during the trial

5.1. Data

This section discusses the smart irrigation data and results during Almeria pilot trials under a challenging scenario of irrigating urban landscape in Europe's driest region[5] and due to pilots' continuity over a long

[5] https://www.independent.co.uk/news/world/europe/almer-a-how-the-region-in-southern-spain-could-soon-look-more-like-west-africa-as-desertification-a6763891.html

period of time. INCOVER's smart irrigation started after the establishment of the pilots were finalised (excavation, soil transfer, drip emitter systems, hydraulic hardware deployment, electrical connections, soil moisture re-position) by a local service provider. The installation took place at the end of June 2018, while the next couple of weeks were used for testing system's performance, exploring treated water availability and aligning the flow and quality with the irrigation field's requirements.

After that, FINT defined the irrigation schedule, according to the plan needs the calculated flow was of approximately three cubic meters of water per day on the test field during extreme arid conditions. As a result and due to limited water availability, FINoT Irrigation Controller applied reclaimed water every eight hours for 10 minutes to each of the irrigation zones. This program continued until the end of summer and during the period the soil moisture was between 15% to 25%.

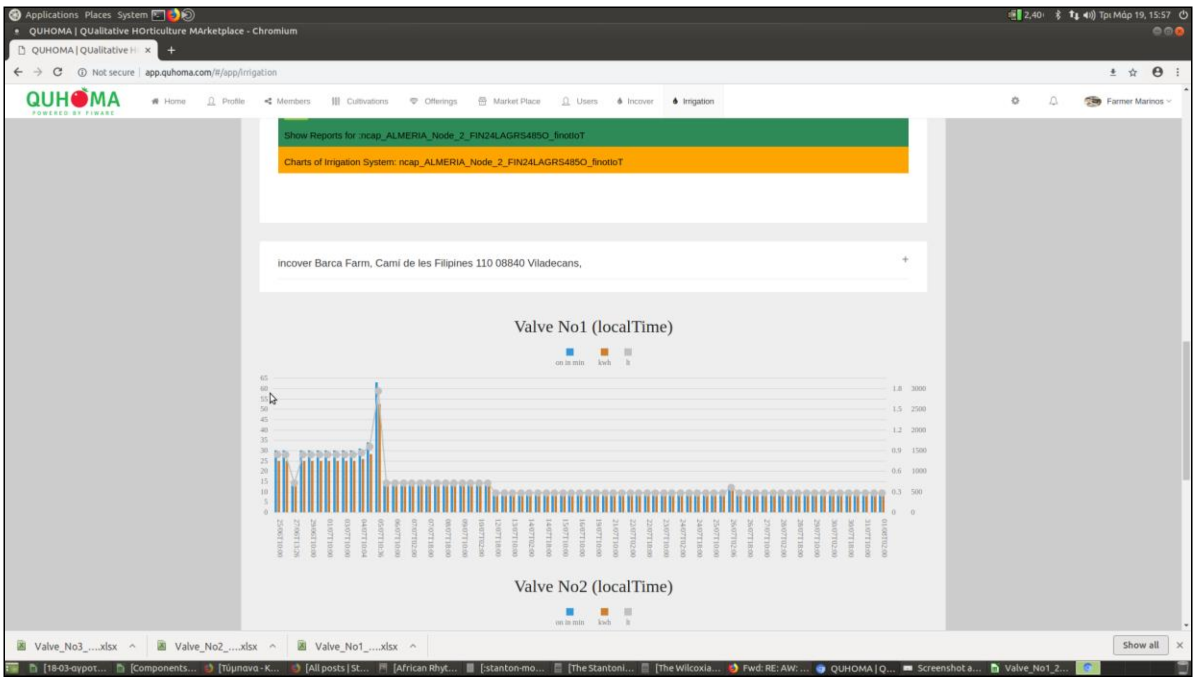

Figure 21. Agrregated irrigation applications for irrigation zone 1

In autumn, and since the temperatures dropped, it was decided to eliminate one cycle and irrigate the field two times per day for ten minutes while different time slots were chosen in order to assess grass responsiveness. Since no major differences occured and the grass was healthy, autumn's irrigation schedule was set to run every twelve hours for every irrigation zone for ten minutes. Soon after, the change of settings in the irrigation parameters, the sensor readings started lowering their values while simultaneously FINT's team in Greece was in direct contact with Aqualia personnel and discussing and exchanging photos of the grass field. The objective of the test was to identify the range at where the humidity reached to satisfy the irrigation needs while simultaneously save water. During winter, and most specifically, the last week of November, smart irrigation was of-line, due to electrical works were taking place at the wastewater treatment premises, during this period the sensor was balancing water to around 10% and still seems acceptable threshold as the grass still looked good.

	A	B	C	D	E	F	G	H	I
1	**dateTime**	**on**	**lt**	**kwh**		**dateTime**	**on**	**lt**	**kwh**
457	09/02T09:00	10	467	0,25		28/02T09:00	10	467	0,25
458	09/02T21:00	10	467	0,25		28/02T21:00	10	467	0,25
459	10/02T09:00	10	467	0,25		01/03T09:00	10	467	0,25
460	10/02T21:00	10	467	0,25		01/03T21:00	10	467	0,25
461	11/02T09:00	10	467	0,25		02/03T09:00	10	467	0,25
462	11/02T21:00	10	467	0,25		02/03T21:00	10	467	0,25
463	12/02T09:00	10	467	0,25		03/03T09:00	10	467	0,25
464	12/02T21:00	10	467	0,25		03/03T21:00	10	467	0,25
465	13/02T09:00	10	467	0,25		04/03T09:00	10	467	0,25
466	13/02T21:00	10	467	0,25		04/03T21:00	10	467	0,25
467	14/02T09:00	10	467	0,25		05/03T09:00	10	467	0,25
468	14/02T21:00	10	467	0,25		05/03T21:00	10	467	0,25
469	15/02T09:00	10	467	0,25		06/03T09:10	0	0	0
470	15/02T21:00	10	467	0,25		06/03T21:00	10	467	0,25
471	16/02T09:00	10	467	0,25		07/03T09:00	10	467	0,25
472	16/02T21:00	10	467	0,25		07/03T21:00	10	467	0,25
473	17/02T09:00	10	467	0,25		08/03T09:00	10	467	0,25
474	17/02T21:00	10	467	0,25		08/03T21:00	10	467	0,25
475	18/02T09:00	10	467	0,25		09/03T09:00	10	467	0,25
476	18/02T21:00	10	467	0,25		09/03T21:00	10	467	0,25
477	19/02T09:00	10	467	0,25		10/03T09:00	10	467	0,25
478	19/02T21:00	10	467	0,25		10/03T21:00	10	467	0,25
479	20/02T09:00	10	467	0,25		11/03T09:00	10	467	0,25
480	20/02T21:00	10	467	0,25		13/03T21:00	10	467	0,25
481	21/02T09:00	10	467	0,25		14/03T09:00	10	467	0,25
482	21/02T21:00	10	467	0,25		14/03T21:00	10	467	0,25
483	22/02T09:00	10	467	0,25		15/03T09:00	10	467	0,25
484	22/02T21:00	10	467	0,25		15/03T21:00	10	467	0,25
485	23/02T09:00	10	467	0,25		16/03T09:00	10	467	0,25
486	23/02T21:00	10	467	0,25		16/03T21:00	10	467	0,25
487	24/02T09:00	10	467	0,25		17/03T09:00	10	467	0,25
488	24/02T21:00	10	467	0,25		17/03T21:00	10	467	0,25
489	25/02T09:00	10	467	0,25		18/03T09:00	10	467	0,25
490	25/02T21:00	10	467	0,25		18/03T21:00	10	467	0,25
491	26/02T09:00	10	467	0,25		19/03T09:00	10	467	0,25
492	26/02T21:00	10	467	0,25					
493	27/02T09:00	10	467	0,25					
494	27/02T21:00	10	467	0,25					

Εικόνα 22. Extracted data from irrigation zone 1 in Almeria, February-March 2019

In total, FINT's IoT irrigation controller applied 918516 litres of INCOVER- reclaimed water while the electric pump that powered the conventional hydraulic system consumed 492 kWh from 1-7-2018 to 15-7-2019. FINoT devices (Gateway, Irrigation Controller, soil sensor) consumed around 35kWh respectively. In addition, FINoT IC hosts unlimited number of profiles for each controlling valve when the calendar and interval based irrigation modes are on. Addtionally, there are no restrictions on daily irrigation applications a feature that critically influenced INCOVER irrigation field, since the irrigation inlet (disinfected water) ther was not sufficent quantity and thus, multiple daily cycles had to be programmed.

When ETo methods were input to the system then estimations on the water saving potential were assumed. After INCOVER's two-month extension and selecting June and July as the months of comparisons, FINT worked with different irrigation scenarios. The first one was applied after local irrigation designers consultation, one based on the historical data of the region as encountered in literature and the last one that exploited Blaney-Criddle formula. Remarkably, when crop is in peak demand (summer period) the system estimated that it would need 5 fewer irrigation applications instead of watering everyday (emprirical) or even more increasing cycles' duration (statistical) to keep the lawn healthy. This would result to 20 cubic meters less of applied water for this specific (small) landscape parcel in June, a 17% decrease and savings of 30 euros for this month. Consequently, the savings in multiple distributed locations would be even higher also taking into account the system's remote scheduling capability meaning less energy input for on-site visits.

Table 3. Budget savings for irrigation (1,59€/m^3)[6] and electricity (0,22€/kWh)[7] costs

14/6 till 13/7 2019 results	Evapotranspiration (ref) Method, peak demands	ET0	Monthly Irrigation Frequency	Monthly Water Applications	Irrigation Quantity (m3/month)	Monthly Water Costs for Irrigation	Monthly Electricity consumption (kWh)	Monthly Electricity Costs for irrigation
	empirical	7,63	1,00	30,00	128,76	204,73	68,99	15,18
	literature / manual	8,00	0,95	31,58	135,54	215,50	72,63	15,98
	blaney criddle method	6,51	1,18	25,53	109,57	174,22	58,71	12,92

Last, it should be noted that due to the standard communication protocol that FINT implements and is exploited in dense IoT applications (industrial sector included) each gateway can connect easily one hundred controllers that each one of them controls four irrigation zones. Therefore, scalability at a substantially profitable cost-benefit ratio is realised since the same product (gateway) can control up to 400 irrigation (or fertigation) valves.

5.2. Discussion

Taking into account the assumptions that derived from the first six months of Almeria's testing period and since now the Smart irrigation back-end developments are being finalised, FINT will set a soil moisture threshold of 20% for the summer period, 15% for autumn, spring and 10% for winter period when defining Almeria's deficit irrigation strategy. Considering soil moisture data from the first irrigation period it is expected that next year, from thirty and up to fifty percent of water reduction application could be achieved.

On the other hand, when the irrigation mode of FINoT Irrigation Scheduler is"Smart" and irrelevant of the soil moisture data the system would by default save close to 20% of water and electricity. This is due to the daily estimation of ETo which is based on real-time air temperature data as compared to historical data or the empirical way of having things done. In INCOVER, FINT proveed that when a farmer invests in low-cost IoT technologies can have significant results in irrigation and be part of the emergent need

[6] https://www.spanishsolicitors.com/what-is-the-price-of-the-domestic-water-in-spain/

[7] https://www.expatica.com/es/living/household/energy-costs-108518/

for Agrifood's digitisation. As a result, the next farming generations will be prepared to take rational decisions while respecting humanity's limited common pool of resources. The same applies to distributed urban landscape fields that a local council provides to its citizens: it can use reclaim and disinfected water in highly efficient hydraulic systems (drip and subsurface drip irrigations systems) by further increasing their efficiency by remote operation, dynamic schedule alterations and timely notifications when abnormal climatic events are detected.

6. Lessons' learned and road ahead

6.1. FINT's IoT (FINoT) devices' optimisation

As INCOVER advanced, new insights, new information, requirements and corporate goals were formatted regarding FINT's smart irrigation/agriculture technologies and value propositions. For example, the company decided to offer a portable sensor to its customers under an «economy of sharing» approach. Therefore, the customer can rent for few euros a credible portable soil sensor, to define the thresholds that his irrigation system will (or not) operate. The user will input the values in the fields described in the above section (4.3.2). FINT built the adapter that provides USB compatibility to its data acquisition interface, which is connected to the soil sensor. Using the adapter, the user can connect the soil sensor to a mobile device (smart phone or tablet) only if the device supports USB OTG (On The Go). Both the adapter and the soil sensor are powered from the mobile device through USB. Using a suitable application on the mobile device, we are able to acquire sensor readings with configurable sample rates, allowing in-situ measurements to the points of interest in the field (figure 23).

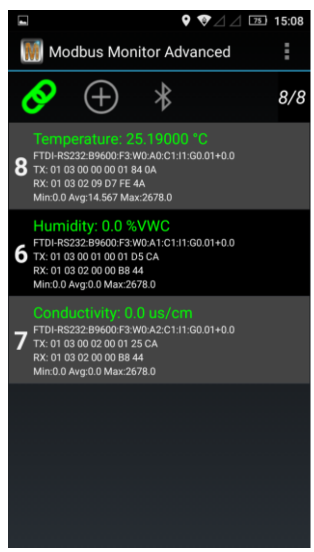

Figure 23. FINoT portable sensor setup and extracted data

As a result of the experience gathered through the INCOVER project, FINT will quickly move into the next version of FINoT Irrigation Controller that will be powered by batteries and a small PV panel. This will provide additional operational flexibility; it will minimize system complexity and add further assurance to the farmer for the cases in case of electricity blackouts occur. The new Irrigation controller can modularly be added on the current FINoT AgriNode, the node that now acquires only sensor data) or be completely standalone. Specifications and preliminary design of the former now follows in Table 4 presented below:

Table 4. FINoT PV powered irrigation controller and full sensor kit

Communication Specifications	**Sensor specifications**
IEEE 802.15.4 - based, 6LoWPAN mesh network. Channel hopping functionality eliminates interference issues at the 2.4GHz ISM band.	- Air temperature: Range: -40 °C to 125 °C; Resolution: 0.1 °C; Accuracy: better than ±0.4 °C
Hop-by-hop AES128 coupled with end-to-end encryption. Typical range of 200m, line-of-sight.	- Air relative humidity: Range: 0 - 99.9% RH; Resolution: 0.1% RH; Accuracy: ±2%
Over-The-Air (OTA) upgradable. Solar powered, autonomous operation.	- Wind speed: Range: 0 - 80 m/s ; Resolution: 0.01 m/s; Accuracy: < 1%
Expandable with an irrigation control module for 12V DC latching solenoids. Pole mounted with configurable height for each component.	- Wind direction: Range: 0 - 360; Resolution: 1; Accuracy: 2
IP66, polycarbonate enclosure.	- Solar radiation: Accuracy: < ±1.8%; Spectral range: 285 - 3000nm; Stability: < 1% per year
Operating temperature range: -25 °C to +50 °C	- Rain gauge: Resolution: 0.2mm; Accuracy: ±4%

That mentioned, and according to INCOVER's WP4 LCSA and LSA analysis, this new version of the FINoT irrigation controller must be prioritised to be marketed as a single device to provide additional economic and environmental benefits for the operator. A new version that also embeds a profile for incorporating a soil, air and rain sensor (optionally) minimises material usage but increases energy usage on the other hand. However, and due to the communication protocol exploitted by FINT (6LoWPAN, IPv6 for Low-power Wireless Personal Area Network) the overall energy consumption is expected to produce a marginal increase.

6.2. FINoT platform optimisation

It is known, that the current ongoing discussions, skepticism and money flow around the concept of IoT and how it differs from conventional telemetry solutions due to the associated technologies (Cloud, BigData, Artitifical Intelligence) are taking place. In fact, a major shift that affects on the global weather data availability has taken place recently. In fact, more and more companies seek ways to make value and money out of data. This major shift also affected the global open weather data availability recently. FINT's IoT platform, which exploits FIWARE generic enablers and acquires IoT devices data that later presents and manipulates- QUHOMA- was also using an open API to receive WeatherData from an external service provider, Weather Undreground[8]. However, IBM that acquired Weather Undergorund in 2015, decided to stop offering the suite of open APIs from the end of 2018[9]. FINT did so because its core technology is marketed as a platform for the IoT and there is no real platform unless it hosts data from external systems (similarly to the case in which QUHOMA hosted AUTARCON's water disinfection system). Secondly, it did not make sense for FINT nor its customers to re-invent the wheel and re-measure conditions that are more or less not that much micro-climate dependent and are already measured by a proximate Weather Station. So now, FINoT platform has to proceed with the neccessary business or technical customisations, if it finally decides to move to another weather and forecast data provider.

Last, FINT will further work on a data marketplace that has encapsulated in its platform that enables data-sharing As a Service within QUHOMA community. A first marketplace version was initially built upon FIWATE Business Chapter but since this has become obsolete by the engineering community other solutions must be explored. Thus, the company will replace it with a more modern solution that will enable Agrifood stakeholders to exchange data and information on their cultivation practices and/ or their final products luring end consumers on their resourcefulness and products' quality.

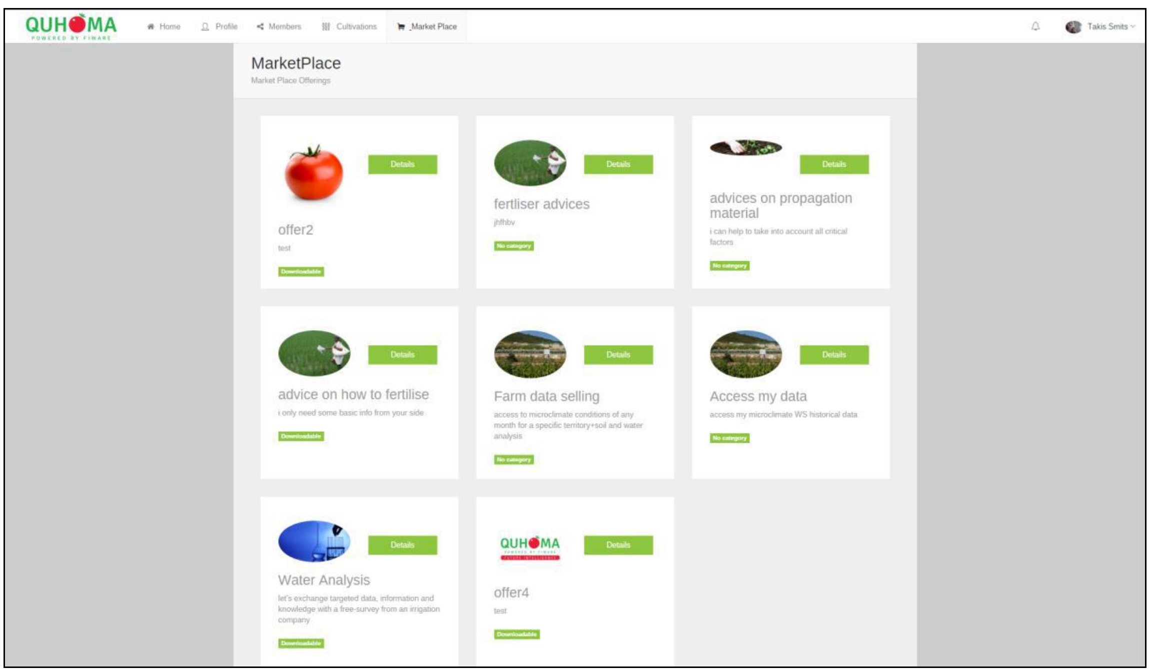

Figure 24. QUHOMA WebApp for data sharing

[8] https://www.wunderground.com/

[9] https://www.programmableweb.com/news/weather-underground-api-retiring-end-2018/brief/2018/09/27

7. Innovation workshop

During M38 Project meeting, where all the aprtners, the advisory board and the innovation board where present, and FINT by CEO, Harris Moysiadis had the opportunity to present in the field the characteristics and operational benefits of the system established by FINT under INCOVER. Addtionally, feedback was proveidded by both of the Boards.

Figure 25. Harris Moysiadis presenting the results of the system established at El Toyo plant, Almeria

8. Final remarks

Regardless of the difficulties demanded by working in a country and establishing the two sites in a different country, the FINT smart Irrigation system was succesfuly installed. The two systems installed at the UPC Barcelona and Aqualia Almeria plant, were established with out major difficulties and came intom operation as planned within the scheduled tiame frame. The communication hardware and software was installed by FINT, while local suppliers installed the irrigation equipment in both sites and contractors suggesting that even though the smart irrigation is a step forward in irrigation mangment it is user friendly enough that local supplier can install it. Once the system came into operation FINT went on to develop more options and even beyond the planned activities. The new options included more software alternatives that willm redound in better energy and water management as well as in better crop yields. In regards to the field and due to the enviromental conditions at the Almeria site, FINT innovated by installing the irrigation systems under the surface not exposed to the atmosphere to reduce the evapotranspiration and directly water the roots. In a large-scale system, the establishment of the irrigation operating under these conditions will improve the use of water, as well as reducing the use of nutrients if fertiirigation is used.

The system installed by FINT has proven effective and as explain in this document is also versatile and can be extended to meet the needs of considerable size plantations regardless of the local climatic conditions and different crops planted. Furthermore, the SMART irrigation system can be updated as new technologies are developed.

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