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MEJORA DE LA GESTIÓN DEL BINOMIO AGUA-ENERGÍA CON IoT, EN SISTEMAS HÍDRICOS, MEDIANTE LA REDUCCIÓN DE LA HUELLA HÍDRICA Y DE CARBONO. APLICACIÓN EN DIVERSOS CASOS DE ESTUDIO DEL SURESTE DE ESPAÑA

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DECLARACION JURADA

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Y para que así conste, firmo debajo:

En Elche, diciembre de 2020

Fdo: Jesus P. Chazarra Zapata

A mi mujer Rita

A mis hijos Rodrigo y Rita

En memoria de mi Madre que falleció durante la redacción de esta Tesis

Perdón, por el tiempo que no aproveche vuestra maravillosa compañía, paciencia y amor durante estos últimos 6 años, donde mi tiempo de hobbie para investigar, invadió mis horas de familia sin apenas percibirlo.

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INDICE

Pag.

LISTADO DE ABREVIATURAS……………………………………………………….. 3

LISTADO DE FIGURAS Y TABLAS ……………………………………………….. 5

1. INTRODUCCIÓN………………………………………………………………….. 10
   1.1. Antecedentes………………………………………………………………... 10

2. OBJETIVOS……………………………………………………………………….. 14

3. MATERIALES Y MÉTODOS ………………………………………………….…. 17
   3.1. En el caso del RETO 1: …………………………………………………..... 17
      3.1.1. Subsistema de adquisición de datos y balizamiento BLE………………….. 18
      3.1.2. Interfaz de Operador y Subsistema de Gestión de Datos…………………… 20
      3.1.3. Subsistema en la nube en línea…………………………………………….. 21
   3.2. En el caso del RETO 2:……………………………………………………….. 22
      3.2.1. Antecedentes……………………………………………………………… 22
      3.2.2. Climatología, régimen térmico, rasgos agroclimáticos y régimen de precipitación……………………………………………………………… 23
      3.2.3. Necesidades de agua y recursos disponibles……………………………. 24
      3.2.4. Gastos económicos de los consumos eléctricos de diferentes fuentes……………………………………………………………………… 25
      3.2.5. Gasto económico de extracción por medio del Pozo…………………… 25
      3.2.6. Gasto económico de extracción por medios Trasvase Tajo-Segura (TST)……………………………………………………………………… 26
      3.2.7. Extraer los gastos económicos de agua de la EDAR…………………… 27
   3.3. En el caso del RETO 3: ……………………………………………………… 28
      3.3.1. Análisis de necesidades del sistema Smart-Agri………………………… 32
         3.3.1.1. Tamaño medio del paquete……………………………………….. 32
         3.3.1.2. Distribución de hidrantes………………………………………… 33
         3.3.1.3. Espacio geofísico ocupado……………………………………….. 36
   3.4. En el caso del RETO 4………………………………………………………… 37
      3.4.1. Datos de campo…………………………………………………………… 39
         3.4.1.1. Características agroclimáticas……………………………………… 40
         3.4.1.2. Recursos disponibles y demanda de agua……………………….. 40
      3.4.2. Flujo equivalente de CO_2eq a la atmósfera……………………………... 41
      3.4.3. Medidas a adoptar para la reducción de la huella de carbono..……… 42
         3.4.3.1. Minimización de la energía……………………………………….. 42
         3.4.3.2. Análisis de las tecnologías disponibles…………………………... 43
      3.4.4. Sistema solar fotovoltaico………………………………………………… 44
      3.4.5. Huella de agua……………………………………………………………... 45
         3.4.5.1. Reducción directa del consumo por gobernanza……………….. 45
         3.4.5.2. Reducción Indirecta del Consumo (RIC)………………………….. 47

4. RESULTADOS Y DISCUSIÓN………………………………………………….. 49
   4.1. Primer RETO………………………………………………………………….. 49
   4.2. Segundo RETO……………………………………………………………….. 50
   4.3. Tercer RETO………………………………………………………………….. 51
   4.4. Cuarto RETO………………………………………………………………….. 52

5. CONCLUSIONES………………………………………………………………….. 55

6. ANEXO PUBLICACIONES ..…………………………………………….....…………. 57

6.1. Publicación nº 1……………………………………………………………………… 58
6.2. Publicación nº 2……………………………………………………………………… 67
6.3. Publicación nº 3……………………………………………………………………… 88
6.4. Publicación nº 4……………………………………………………………………… 107

7. AGRADECIMIENTOS…………………………………………………………………….. 126

8. BIBLIOGRAFÍA………………………………………………………………………… 128

LISTADO DE ABREVIATURAS

API: interfaz de programación de aplicaciones
App: Aplicación informática (del inglés application), tipo de programa informático diseñado como herramienta, para permitir a un usuario realizar diversos tipos de trabajos
ARM Advanced RISC Machine
BBDD: Base de datos
BLE: Bluetooth de baja energía, Bluetooth Low Energy
CCRR: Comunidad de regantes
CE Consejo Europeo
CM SAF: Instalación de aplicación satelital sobre monitoreo del clima
CNMC: Comisión Nacional de Mercados y Competencia
CO_2: Dioxido de Carbono
CouchDB gestor de bases de datos de código abierto
DIN: Deutsches Institut für Normung —que traducido al español significa **Instituto Alemán de Normalización**
Ed: Producción media diaria de electricidad del sistema dado (kWh)
EDAR: Planta de tratamiento de aguas residuales
Em: Producción media mensual de electricidad del sistema dado (kWh)
FSK: Modificación por desplazamiento de frecuencia
GAP: Generic Access Profile
GATT: Generic ATTribute Profile
GEI: Gases de efecto Invernadero
GHGs: GEI en ingles
GPRS; paquete general de Radio sevicio
GSM: Sistema global para comunicaciones móviles
GUI: Graphic User Interface - Interfaz
Hd: Suma media diaria de irradiación global por metro cuadrado recibida por los módulos del sistema dado (kWh/m2)
Hm: Suma media de irradiación global por metro cuadrado recibida por los módulos del sistema dado (kWh/m2)
ICT: Siglas de TIC en ingles
IDEA: Instituto para la Diversificación y el Ahorro Energético
IE-W: Indice Energía-Agua
IOT: Internet of think, Internet de las Cosas
IRR: Tasa Interna de Retorno
JSON JavaScript Object Notation, (notación de objeto de JavaScript)
LCA evaluación del ciclo de vida
LoRad: baja radiación de campos alternos eléctricos y magnéticos
LowRad: Radio de baja frecuencia
MySQL lenguaje de consulta estructurado de codigo abierto
NBIoT: IoT de banda estrecha
ODS: Objetivos de Desarrollo Sostenible
PC: Personal Computer-Ordenador Personal
PHP Lenguaje Personal Home Page,
PVGIS: Sistema de Información Geográfica Fotovoltaica - Comisión Europea, Centro Común de Investigación
RFID: (Radio Frequency IDentification)
RIC Reducción Indirecta del Consumo

RTU: Unidad terminal remota
SASW: Smart-Agri Scada-Web
SCADA: Control de supervisión y adquisición de datos
SMS: Servicio de mensajes cortos
SoC System on a Chip-Sistema instalado en un Chip de Ordenador
SQLite Sistema de gestión de bases de datos relacional
TEA término de facturación de la energía activa
TIC/TICs: tecnologías de la información y la comunicación
TPA término de facturación de potencia
TST: Transvase Tajo-Segura
UUID identificador único universal o universally unique identifier
Vls Volumen de agua perdidas en el sistema
VlsR Volumen de agua perdidas en el sistema reducidas
WeAA Volumen de agua evaporada Despues de la Acciones
WeBA Volumen de agua evaporada Antes de la Acciones
WeR Volumen de agua evaporada recuperada
WiMAX: Worldwide Interoperability for Microwave Access (interoperabilidad mundial para acceso por microondas
WSN: wireless sensor networks
WUA: Asociación de usuarios de agua
WWTP: EDAR en ingles

LISTADO DE FIGURAS Y TABLAS

FIGURAS

Figura 1. Evolucion precio Barril Brent 2009-2020

Figura 2. Tiempos de inspección detallados por tarea individual para los procedimientos tradicionales frente a los propuestos. Se obtuvieron datos para una ruta que incluye 20 instalaciones que duraron unas 8 h.

Figura 3. Subsistema de adquisición y balizamiento de datos. Izquierda: Diagrama de bloques de la BLE Nano Board e interfaces de comunicación a sensores comunes. Derecha: Las placas electrónicas se montan dentro de un gabinete robusto para aplicaciones industriales antes de su implementación.

Figura 4. Diagrama de flujo de la aplicación de software que se ejecuta en el BLE Nano

Figura 5. Módulos y estructura en capas de la aplicación Android desarrollado para el dispositivo móvil.

Figura 6. Área de regadío de la zona de estudio de la C.R.. Fuente: Confederación Hidrográfica de Segura.

Figura 7. Porcentaje de volumen de agua necesario para cubrir la demanda de acuerdo con la fuente de suministro de agua

Figura 8. Esquema operativo actual de C.R.

Figura 9. Gastos económicos del Pozo. 2016

Figura 10. Gasto económico TST. 2016.

Figura 11. Gasto económico de la EDAR. 2016

Figura 12. Gasto económico total. 2016

Figura 13. Esquema del sistema de automatización en la CCRR de Pliego

Figura 14. Descripción de los sensores en la CCRR de Pliego

Figura 15. Distribución de microparcelas a control remoto en la CR de Pliego.

Figura 16. Distribución de hidrantes a control remoto en la CCRR de Pliego.

Figura 17. Equipo y componentes de Smart-Agri (usuario único en una microparcela).

Figura 18. Hub de radio GPRS (arqueta de sectorización).

Figura 19. El hidrante instalado en una arqueta semienterrada

Figura 20. Duración de la incidencia de la batería según número de comunicaciones

Figura 21. Cultivos en el barranco de Cherro

Figura 22. Producción de análisis de CO_2eq en un sistema agua-energía.

Figura 23. Agua mensual comprada, según la fuente de suministro de agua. Fuente: Elaboración propia

Figura 24. Evolución del índice de transformación de la energía eléctrica en España (kgCO_2eq/kWh) 2015-2019.

Figura 25. % t de flujo de CO2eq a la atmósfera. 2016. Fuente: Elaboración propia.

Figura 26. Consumo anual por fuente (kW). Fuente: Elaboración propia
Figura 27. Instalaciones de Embalses y Solares. Fuente: Propio
Figura 28. Balance de la huella hídrica antes de las acciones. Fuente: Elaboración propia.
Figura 29. TIC utilizadas en esta CCRR. Fuente: Propia
Figura 30. Lámina impermeable en el depósito para reducir la evaporación. Fuente: Propio.
Figura 31. Tiempos de inspección detallados por tarea individual para los procedimientos tradicionales frente a los propuestos. Se obtuvieron datos para una ruta que incluye 20 instalaciones que duraron unas 8 h.
Figura 32. Nuevo esquema operativo CCRR
Figura 33. Flujo Demeter Scada Web

Figura 34. Reducción de CO2eq por huella hídrica después de acciones.

Figura 35. Resumen de los efectos ambientales generados en la CCRR.
Figura 36. Resumen de la nueva reducción futura t CO2eq/a después de las acciones.

TABLAS

Tabla 1. Diferencias entre los procedimientos convencionales y los propuestos

Tabla 2. Suministro de volumen total de los recursos disponibles

Tabla 3. Consumo de batería anual, dependiendo del número de comunicaciones.

Tabla 4. Comparación de potencia del equipo de bombeo.

Tabla 5. Resumen del cálculo de las instalaciones solares fotovoltaicas.

Tabla 6. Resumen de evaporación potencial de agua

Tabla 7. Resumen de la reducción de la huella hídrica después de las acciones.

Tabla 8. Diferencias entre los procedimientos convencionales y los propuestos.

Tabla 9. Resumen de la huella del secuestro de CO2eq por cultivos.

RESUMEN

El binomio agua-energía es uno de los motores de la agricultura y del desarrollo de la civilización. En el levante español, la agricultura sostenible se remonta al pueblo musulmán, los cuáles transmitieron los conocimientos provenientes de Oriente aprovechando la energía del agua para elevarla a las tierras de mayor altitud, mediante el uso de norias y otros ingenios similares. De este modo transformaban las tierras de secano en productivas tierras de regadío.

Toda la cuenca del Segura, en particular los agricultores del Sureste Español han conservado y mejorado las instalaciones hidráulicas que heredaron. Estos agricultores, no se conforman con producir las mejores frutas y verduras de Europa. Mediante modernas tecnologías, como el Internet de las Cosas (IoT) y la innovación mediante el uso de sensores, están desarrollando una agricultura de primer nivel.

En esta tesis se muestran diversos casos de estudio relacionados con recientes avances en aplicación de Tecnologías de la Información y la Comunicación (TIC). Estos avances son aplicados a la agricultura de precisión de manera eficiente, mediante la implementación de un sistema Smart-Agri. Asimismo, este sistema es capaz de utilizar la energía fotovoltaica para la extracción de aguas subterráneas. Adicionalmente, el sistema permite transportar aguas regeneradas de las EDAR de las zonas urbanas a los embalses de cabecera, con el fin de proporcionarle una energía suficiente para su empleo en riego de precisión. Simultáneamente este sistema incluye un análisis de la calidad del agua suministrada en tiempo real. Todo ello garantiza cultivos de calidad sostenible y es respetuoso con el medio ambiente.

Esta tecnología se basa en sistemas de comunicación de bajo coste con radio de baja frecuencia (LowRa). En estos sistemas se aplica una gobernanza enmarcada dentro de los objetivos de desarrollo sostenible (ODS). El fin es reducir la desertificación de estas tierras cultivables que están en peligro de abandono por su baja producción. Como consecuencia se reduce la huella hídrica y de los Gases de Efecto Invernadero (GEI), de la Agenda 2030 de las Naciones Unidas. Estos pulmones verdes artificiales proporcionan, no sólo alimentos para la Unión Europea, sino que también son un sumidero de CO_2 que contribuye a la protección de la capa de ozono.

ABSTRACT

The water-energy binomial is one of the engines of agriculture and the development of civilization. In the Easter Spain, sustainable agriculture dates back to the Muslim culture, who transmitted the knowledge from the East taking advantage of the energy of the water to raise it to the higher lands, using waterwheels and other similar devices. In this way, they transformed rainfed lands into productive irrigated lands.

The entire Segura basin, particularly the farmers of the Spanish Southeast, have conserved and improved the hydraulic installations they inherited. These farmers are not satisfied with producing the best fruits and vegetables in Europe. Using modern technologies, such as the Internet of Things (IoT) and innovation through the use of sensors, they are developing first-rate agriculture.

This thesis shows various case studies related to recent advances in the application of Information and Communication Technologies (ICT). These advances are applied to precision agriculture in an efficient way, through the implementation of a Smart-Agri system. Also, this system is capable of using photovoltaic energy to extract groundwater. Additionally, the system allows the transport of reclaimed water from the WWTP in urban areas to the headwater reservoirs, in order to provide it with sufficient energy for its use in precision irrigation. Simultaneously this system includes an analysis of the quality of the water supplied in real time. All this guarantees crops of sustainable quality and it is respectful with the environment.

This technology is based on low-cost communication systems with low frequency radio (LowRa). In these systems a governance framed within the Sustainable Development Goals (SDG) is applied. The aim is to reduce the desertification of these arable lands that are in danger of abandonment due to their low production. As a consequence, the water footprint and Greenhouse Gases (GHG) footprint of the United Nations 2030 Agenda is reduced. These artificial green lungs provide, they are not only food for the European Union, but they are also a CO_2 sink that contributes to the protection of the ozone layer.

RESUM

El binomi aigua-energia és un dels motors de l'agricultura i del desenvolupament de la civilització. En el llevant espanyol, l'agricultura sostenible es remunta al poble musulmà, els quals van transmetre els coneixements provinents d'Orient aprofitant l'energia de l'aigua per a elevar-la a les terres de major altitud, mitjançant l'ús de sínies i altres enginys similars. D'aquesta manera transformaven les terres de secà en productives terres de regadiu.

Tota la conca del Segura, particularment els agricultors del Sud-est Espanyol, han conservat i millorat les instal·lacions hidràuliques que van heretar. Aquests agricultors, no es conformen amb produir les millors fruites i verdures d'Europa. Por Mitjà de modernes tecnologies, com la Internet de les Coses (IoT) i la innovació através de l'ús de sensors, estan desenvolupat una agricultura de primer nivell.

En aquesta tesi es mostren diversos casos d'estudi relacionats amb recents avanços en aplicació de Tecnologies de la Informació i la Comunicació (TIC). Aquests avanços són aplicats a l'agricultura de precisió de manera eficient, per implementació d'un sistema Smart-Agri. Així mateix, aquest sistema és capaç d'utilitzar l'energia fotovoltaica per a l'extracció d'aigües subterrànies. Addicionalment, el sistema permet transportar aigües regenerades de les ESTACIONS DEPURADORES D'AIGÜES RESIDUALS de les zones urbanes als embassaments de capçalera, amb la finalitat de proporcionar-li una energia prou per a l'ús en reg de precisió. Simultàniament aquest sistema inclou una anàlisi de la qualitat de l'aigua subministrada en temps real. Tot això garanteix cultius de qualitat sostenible i és respectuós amb el medi ambient.

Aquesta tecnologia es basa en sistemes de comunicació de baix cost amb ràdio de baixa freqüència (LowRa). En aquests sistemes s'aplica una governança emmarcada dins dels objectius de desenvolupament sostenible (ODS). El fi és reduir la desertificació d'aquestes terres cultivables que estan en perill d'abandó per la baixa producció. Com a conseqüència es redueix la petjada hídrica i dels Gasos d'Efecte d'hivernacle (GEH), de l'Agenda 2030 de les Nacions Unides. Aquests pulmons verds artificials, no són només aliments per a la Unió Europea, sinó també són un embornal de CO_2 que contribueix a la protecció de la capa d'ozó.

1. INTRODUCCIÓN

El binomio agua-energía tiene una importancia fundamental para las explotaciones agrícolas con sistemas hídricos presurizados en las zonas del área mediterránea. Estas zonas templadas del área mediterránea están sometidas a estrés hídrico durante ciertos períodos anuales, cada vez más prolongados. La disminución de aportaciones de agua debido al cambio climático está obligando a los agricultores del levante español a desarrollar sistemas sostenibles agua-energía que permitan hacer viables sus explotaciones.

Para conseguir explotaciones sostenibles desde el punto de vista medioambiental es preciso reducir la huella hídrica, así como la huella de carbono asociada al consumo energético que precisan.

Con este fin se ha de promover, por un lado, la reducción del consumo hídrico de las explotaciones junto con el aporte adicional de recursos hídricos de diversas procedencias (aprovechando las aportaciones de lluvias torrenciales mediante captación por tanques de tormenta y tanques ambientales, aprovechamiento de aguas regeneradas, entre otros). Ello permite mejorar la eficiencia de los sistemas de distribución hídrica.

Por otro lado, se debe promover la mejora de la gobernanza. Una herramienta que permite esta mejora es la gestión de los recursos mediante TIC´s en tiempo real. Ello se complementará con el uso de energías alternativas y tendría como fin la reducción de costes y de producción de CO_2.

Simultáneamente, todas estas tecnologías tienen como objetivo la reducción de la huella de carbono asociada a la huella hídrica.

1.1. Antecedentes

-La directiva marco del agua de la Unión Europea 2000/60/CE establece que los recursos hídricos son un patrimonio colectivo y como tales deben ser protegidos, defendidos y tratados. Esta normativa también está contemplada en la legislación española.

La Directiva Marco del Agua, el Plan Hidrológico Nacional y el Plan Nacional de Regadíos consideran el agua como recurso fundamental, y contemplan mejoras en la gestión de los recursos hídricos. Éstos van ligados a los recursos energéticos en la mayoría de los sectores productivos y en particular en el regadío.

Adicionalmente, el ahorro y la eficiencia energética son herramientas básicas, del desarrollo económico de los países de la Unión Europea, y el cumplimiento de sus compromisos frente al cambio climático se han plasmado en una serie de Directivas, Estrategias y Planes de Acción sobre la eficiencia del uso final de la energía y los servicios energéticos”, además de la Estrategia Española de Ahorro y Eficiencia Energética E4 2004-2012. Todo esto es fundamental para la “Directiva 2006/32/CE”.

Por lo expuesto anteriormente, las nuevas estrategias de gestión de recursos hídricos y energéticos en agricultura están orientadas a conseguir el máximo margen bruto junto a la sostenibilidad de los recursos, para alcanzar el máximo rendimiento en la producción.

La estrategia de Ahorro y Eficiencia Energética en España 2004-2012, a través de los planes de acción 2005-2007 y 2008-2012, han impulsado en estos últimos años, una serie de medidas tendentes a favorecer la eficiencia energética de diferentes sectores productivos (Ministerio de Economía, 2003). Para el regadío se concretan en las siguientes actuaciones:

a) Una mejora en la tecnología, gracias a la implantación de éstas, para reducir los consumos de agua, que repercutirán directamente en el consumo de energía.
b) Un cambio de sistema de aplicación del riego por aspersión, a riego localizado, ya que los sistemas de riego más eficientes en el uso del agua pueden conseguir una reducción en la altura de elevación en la cabecera de las redes.
c) Una optimización del dimensionado de las instalaciones, gracias a un diseño óptimo en las redes de riego y estaciones de bombeo, que minimizará los costes totales a lo largo de la vida útil de las instalaciones.
d) Un mantenimiento de las instalaciones, porque un adecuado mantenimiento puede reducir los costes energéticos de explotación.
e) Una mejora en la gestión de los acuíferos, ya que la incorporación de aguas depuradas favorecerá la recuperación de los acuíferos sobreexplotados, facilitando así el bombeo del agua desde una menor profundidad.
f) Una mejora e implantación de sistemas de regulación y control del agua.
g) Un establecimiento de consumos energéticos de referencia.
h) Una mejora de la formación de los regantes en técnicas de eficiencia energética.

En los últimos 10 años se han realizado auditorías energéticas en diversas comunidades de regantes (CCRR) repartidas por todo el territorio español. La realización de estas auditorías ha sido subvencionada por el Instituto para la Diversificación y el Ahorro Energético (IDAE), dependiente del Ministerio de Industria, a través de las agencias de la energía de las diferentes Comunidades Autónomas. En estos trabajos se muestran algunos resultados de auditorías energéticas llevadas a cabo en diversas comunidades de regantes del sureste español. Gracias a éstas, se ha permitido evaluar la situación energética e hidráulica de las comunidades de regantes, y proponer medidas para reducir los consumos energéticos e hídricos.

La presente Tesis Doctoral se centra en el estudio de los consumos hídricos y energéticos de varios casos de estudio de comunidades de regantes en el sureste de España. Adicionalmente se incluyen sus costes, su posible aplicación a otras redes y sus sistemas de gestión y comunicaciones. Estos últimos sistemas son fundamentales para la mejora y modernización de las instalaciones.

Básicamente, el consumo de energía de una red de riego depende de varios factores, entre ellos, el sistema de riego instalado, la topografía del área regable y la procedencia del agua de riego. Las auditorías energéticas permiten evaluar la eficiencia energética e hídrica de una instalación, que dependerá tanto del rendimiento de los equipos de bombeo, como de la eficiencia en la distribución del agua relacionada directamente con la red de riego.

Por otro lado, los costes energéticos e hídricos representan generalmente una parte importante de los costes totales, en función de la dependencia energética de una comunidad de regantes. Estos costes se han incrementado de manera alarmante en los últimos años como consecuencia de las subidas que ha experimentado el precio de la energía. Particularmente subieron a partir de 2008, cuando desaparecieron definitivamente las tarifas especiales de riego. Debido a esta supresión y de su obligatoriedad, según el Real Decreto 809/2006 se debe recurrir a las tarifas generales, y por eso los regantes se están viendo abocados a buscar medidas, para reducir el consumo energético y en definitiva, para poder mejorar la eficiencia energética de sus instalaciones.

Además, el término de facturación de la energía activa (TEA), se ha mantenido a lo largo del mismo período (Orden IET/3586/2011). En la actualidad el mercado es libre. Esto significa que se tiene la posibilidad de tarificar según los peajes de acceso sujetos a diferentes tipos de contratos, y se pueden negociar las tarifas con la compañía comercializadora por parte de las comunidades de regantes.

Por último, en cuanto a los precios de los peajes de acceso, la tendencia del término de facturación de potencia (TPA) fue creciente desde el 2008 hasta la actualidad. Entre 2008 y 2009 se incrementó un 30% y durante los años 2009 y 2010 crecieron un 20%. Desde 2010 hasta la actualidad el incremento ha sido notable.

Las auditorías energéticas e hídricas consultadas de las que se parte en esta Tesis Doctoral, se realizaron según el Protocolo editado por IDAE (Abadía et al., 2008) en varias comunidades de regantes del sureste de España.

Es preciso señalar que las auditorías se realizaron en un intervalo de varios años, con los datos de distintas campañas de riego. Para la realización de estas auditorías se obtuvieron los valores de una serie de indicadores de gestión energética e hídrica. Eso permitió esbozar en grandes cifras, unas ratios de consumo de costes de agua y energía en las comunidades de regantes estudiadas.

El desarrollo de una auditoría en una comunidad de regantes conlleva diversas fases:

- En primer lugar, se realiza una toma de datos de diversa naturaleza.

  -Los datos de funcionamiento ordinario son los que maneja la comunidad de regantes en su proceso habitual de gestión, y son suministrados por los gestores de la misma. Entre ellos se incluyen los datos descriptivos, de funcionamiento interno, de suministro hídrico, y datos de tipo energético.

  -Los datos de infraestructura y manejo de las instalaciones se refieren a la descripción, y características de toda la infraestructura de la comunidad de regantes, así como los referentes al funcionamiento y manejo de la red de distribución de agua. Estos datos también son suministrados por la comunidad de regantes o en algunos casos se toman directamente en campo.

  -Los datos de consumo energético e hídrico específicos, son los referentes al consumo energético e hidráulico instantáneo medidos en los equipos necesarios, para poder calcular la eficiencia energética de su funcionamiento.

  -A partir de los datos medidos en la instalación y de las características de la propia comunidad de regantes, se establecen una serie de indicadores para evaluar la eficiencia energética. Estos indicadores también están relacionados con el coste económico de estos consumos.

- Posteriormente, se calculan los principales indicadores energéticos e hidráulicos, y a partir de ahí se establece una clasificación de la comunidad de regantes, en función del consumo energético. Por último, se establecen las medidas correctoras para mejorar la situación energética e hidráulica.

  Para el caso de las redes de abastecimiento de agua potable se aplica una metodología análoga, y en esta tesis se tratará de implementar nuevas metodologías específicas.

Específicamente, el procedimiento incluye las siguientes fases:

- Primeramente, se evalúa el funcionamiento hidráulico del sistema (White, 1974; Lingiredy y Wood, 1998; White, 2003; Filion et al, 2004; Almandoz et al., 2005; Filion, 2008; Ochoa, 2015; González et al, 2010; IDAE, 2011), teniendo en cuenta el inventario de la infraestructura (obras existentes de captación, depósitos en servicio y su estado, número y tipos de rebombeos (Budris, 2008; NRC, 2008; González, 2010), tipología de tuberías existentes, entre otros).

- Con posterioridad, se realiza un análisis de los caudales a suministrar y demanda del agua, un diseño de acciones de mejora hidráulica y energética de la red (Pelli e Hitz, 2000; CEC, 2005; McMahon et al, 2006; USDE, 2006; EC, 2009; PTE, 2009; Steve, 2009; Stoyan, 2009; Hurtado 2010; ICAEN, 2011; ICAEN, 2011b) y un estudio económico (Colombo y Karney, 2002; Díaz et al., 2005; IEA, 2008; Runge y Mann, 2008) que justifique la solución adoptada.

Este estudio de investigación se basa en los diferentes sistemas de auditoría energética utilizados en el sureste de España. Con este fin, se estableció un marco genérico que puede aplicarse a los sistemas hídricos en general. Se analizan las emisiones generadas, tanto eliminadas como evitables. Adicionalmente se han estudiado diversas tecnologías que contribuyen a la sostenibilidad del binomio agua-energía. Entre ellas, desde pequeños dispositivos a arquitecturas de sistemas. Mediante estas tecnologías se posibilita la Agricultura 4.0 y se cumple con los criterios de sostenibilidad.

2. OBJETIVOS

El objetivo principal de esta Tesis es estudiar la relación del binomio agua-energía en sistemas hídricos agrícolas, buscando cómo optimizar ambos sistemas dentro del marco los Objetivos de Desarrollo Sostenible (ODS) de la Agenda 2030 de las Naciones Unidas, en especial del eje prosperidad. Objetivos 7, 8, 9, 10, 11. Así como otros ODS cuya consecución provocan sinergias de dichos objetivos. Para ello se han desarrollado los distintos artículos contenidos en esta tesis, que muestran las investigaciones realizadas, según diversos objetivos específicos.

La gestión sostenible del agua requiere grandes cantidades de energía que conviene evaluar, para así a partir del análisis efectuado, conocer qué acción coste/beneficio es la más conveniente. Sólo de este modo se darán una adecuada respuesta a las periódicas crisis energéticas, que en las últimas décadas se vienen sucediendo.

Concretamente, en el año 2008 se aproximó el precio del barril de petróleo a los 126 €, (Ver Fig. 1) y aunque en los últimos meses ha bajado debido al efecto de la pandemia del COVID-19, su precio sigue alto oscilando entre los 65-80 euros.

Actualmente, en España sigue existiendo una gran dependencia del petróleo para la generación de energía. Por otro lado, la reducción de las emisiones de gases de efecto invernadero es la única estrategia válida para hacer frente al cambio climático. Ello implica reducir la factura energética.

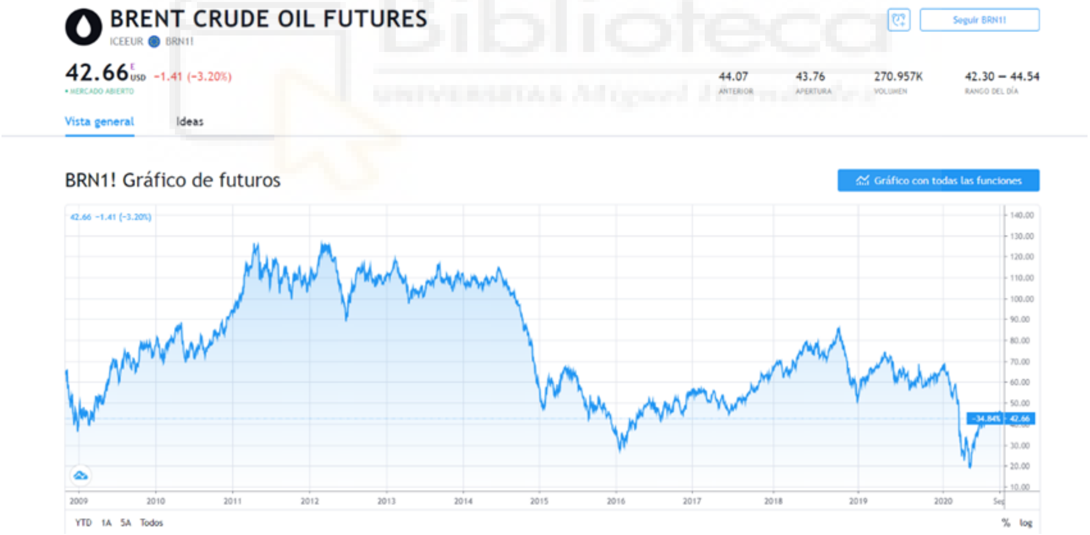


Figura 1. Evolución precio Barril Brent 2009-2020.

A partir de la ecuación integral de la energía y de su adaptación en periodo extendido, se lleva a cabo la auditoría energética de una red de distribución de agua a presión. Con ello se transforma la energía entrante en saliente, (la entregada a los usuarios y la perdida en fugas) más la energía disipada por el rozamiento.

Finalmente, a partir de los precedentes términos energéticos, se definen unos indicadores que permiten valorar tanto las características energéticas del sistema, como las posibilidades de mejora que permite. La realización de una auditoría energética exige haber realizado previamente la auditoría hídrica y disponer del modelo matemático. Así se cuantifica la relación agua-energía en el proceso de distribución del agua.

Con este trabajo se establecen metodologías, parámetros y se aplican a diversos sectores, analizando varios modelos. Esto será muy útil en las empresas y entidades donde se aplique para conseguir una gestión óptima de la energía.

Todo lo expuesto anteriormente, contribuirá a mejorar la eficiencia de las instalaciones de estas organizaciones. Se trataría de buscar la manera de desarrollar y mejorar los citados modelos. Junto a ello, se consigue una gestión más sostenible de las instalaciones mediante la mejora de los métodos y procedimientos.

La presente tesis se basa en la adaptación y evolución de estos sistemas y tecnologías en diversos casos de estudio. Para ello se han desarrollado los distintos RETOS, correspondientes a los diferentes artículos contenidos en ella. Se muestran las investigaciones realizadas que pueden servir de ejemplo a otras regiones, instituciones y entidades para mejorar la sostenibilidad y calidad de vida, entre otros.

El **primer Reto** fue realizar el desarrollo de un dispositivo de bajo coste para mejorar los rendimientos de consumo hídrico y energético en una red colectiva de riego presurizado en una comunidad de regantes. Se concibió un dispositivo instalado en arquetas hídricas de difícil acceso con poca o nula cobertura. Este dispositivo permite leer varias señales procedentes de los instrumentos alojados en las arquetas, y grabarlas en una memoria. Posteriormente se transmite esa información con un *smartphone* o *tablet* convenientemente programados, mediante un sistema de comunicaciones *bluetooth* de baja energía. De este modo, la información será volcada a la nube en cuanto los elementos que captan la señal se ubiquen en zonas de cobertura. No obstante, este dispositivo deberá cumplir varios requisitos:

- Tiene que ser económico de fabricar y de fácil instalación.
- Ha de ser robusto, para que sea capaz de soportar las adversas condiciones ambientales, y presencia de gases, garantizando su fiabilidad y funcionalidad.
- Ha de tener un consumo energético muy bajo, para no tener que estar cambiando las baterías cada poco tiempo. Si tuvieran que estar siendo cambiadas asiduamente, se quedarían fuera de uso con una frecuencia y un coste indeseado y no serían viables.

El **segundo Reto** tiene un objetivo muy preciso, que es reducir el consumo energético de una comunidad de regantes. Como consecuencia se mejora la capacidad hídrica del sistema y se optimizan los equipos de bombeo. Una vez optimizado el sistema, es posible calcular los máximos consumos energéticos previstos. Estos datos servirán para diseñar una planta solar capaz de suministrar la energía requerida para su correcto funcionamiento.

El **tercer Reto** nace dentro de la necesidad de desarrollar un sistema de comunicación con redundancia en una red hidráulica de una comunidad de regantes. Se trata de un dispositivo que sea muy económico, pero que pueda proporcionar la garantía de transmisión de los datos obtenidos de los hidrantes. Adicionalmente debe ser capaz de enviar y recibir datos y accionar determinados elementos de control, generando información fiable. También debe sortear la complicada orografía en la que se implanta el sistema. Por último, debe proporcionar un servicio de calidad suficiente con el consumo mínimo de energía.

El **cuarto Reto** es el diseño de un sistema de comunicación para reducir al máximo el consumo de energía fósil en una red colectiva de riego. Ello se complementa con la implantación de un campo solar fotovoltaico. Junto con ello se analizan la huella hídrica y la de carbono asociadas al manejo de esta red hidráulica.

Todos estos retos citados previamente, están relacionados con los objetivos de desarrollo sostenible – eje prosperidad. El binomio agua-energía juega un papel fundamental para el desarrollo agrícola de países con dificultad de suministro y producción propia de alimentos. Específicamente, se plantean una serie de objetivos de desarrollo sostenible para lograr que las ciudades, regiones y los asentamientos humanos sean:

- Inclusivos ODS-8 (proporcionando una posibilidad de trabajo digno), seguros (se han de buscar producciones agrícolas de productos con mínima garantía de consumo y venta de excedentes).

- Resilientes ODS-7-9 (las infraestructuras de agua para riego gestionada con energía solar de autoconsumo y tecnología colabora a la planificación, y a la garantía de su funcionamiento).

- Sostenibles ODS-11 (respetando el medio ambiente, contribuyendo a generar sumideros de CO_2, frenando la desertificación de regiones que por falta de suministro energético asequible hacen inviables la explotación de tierras fértiles con acceso a agua que precisan energía para su suministro). Para ello precisan de infraestructuras para suministro de agua y energía que sean robustos, autosuficientes en la medida que sea posible y dependan mínimamente de producción energética externa, minimizando el consumo de fuentes fósiles.

La reducción de la desigualdad en regiones de un mismo país y entre distintos países (ODS-10) se puede promover mediante el primer reto. Esto se puede conseguir mediante el uso de energía solar aplicada a zonas rurales, donde el suministro de energía es mayoritariamente fósil (combustibles derivados del petróleo). Las soluciones Smart-Agri, con el diseño de infraestructuras de telecomunicaciones de bajo coste permiten la citada reducción.

El uso de energía solar (RETO 2) garantiza un acceso a energía renovable ODS-7, gestionada con tecnología de bajo coste (RETO 1,3,4). Ello permite el desarrollo de agricultura capaz de producir alimentos saludables y asequible, segura, sostenible y moderna.

Finalmente, y concluyendo es mi deseo, que esta investigación contribuya a incrementar el conocimiento y a mejorar la calidad de vida de la sociedad. Adicionalmente, estas técnicas pueden ser replicables a países en vías de desarrollo y les puede permitir mejorar en comunidad.

3. MATERIALES Y MÉTODOS

Esta tesis se ha basado en la aplicación de diferentes herramientas tecnológicas junto con el desarrollo de auditorías energéticas e hídricas en diferentes casos de estudio localizados en comunidades de regantes del sureste de España. Además, se han realizado auditorías energéticas en depuradoras y sistemas de abastecimiento en alta y distribución.

Gracias a las ideas y conceptos adquiridos, se ha tratado de establecer un marco genérico que pueda ser aplicable a sistemas hídricos, donde se analizan las emisiones generadas, las eliminadas y las evitadas.

En los siguientes apartados se describen los materiales y métodos específicos para cada uno de los retos planteados.

3.1. En el caso del RETO 1:

Para este reto se presenta un caso de estudio aplicado en una comunidad de regantes. Se trata de una plataforma para la gestión de hidrantes basada en dispositivos móviles y motores *Bluetooth* de bajo consumo energético (BLE en inglés). Las ventajas de las redes de sensores inalámbricos (WSN en inglés) en la agricultura de precisión han sido ampliamente documentadas. Las aplicaciones para sistemas de riego inteligentes (Yu et al., 2015; Navarro-Hellín et al., 2015; Coates et al., 2013) o sistemas generales de monitoreo ambiental (Mesas-Carrascos et al., 2015; Shining et al., 2015; Srbinovska et al., 2015) son algunas de las referencias más recientes. Sin embargo, la mayoría de estas aplicaciones requieren la interconexión de los sensores en una malla de área amplia, el uso de módems basados en servicio general de paquetes vía radio (en inglés, GPRS) o tecnologías de interoperabilidad mundial para acceso por microondas (en inglés, WiMAX) para conectarse a nodos centrales, o ambos. Nuestro estudio de caso, sin embargo, difiere de las arquitecturas que se encuentran en la bibliografía en que no hay necesidad de un vínculo directo entre los nodos de los sensores y el *host* central, ya que este enlace es proporcionado por el dispositivo móvil del operador en el momento de la inspección regular. Por lo tanto, en nuestro caso, sólo se necesitan conexiones locales (cableadas) desde el mote BLE Nano®, de tecnología Arduino® a sus sensores circundantes. Este hecho simplifica y abarata la arquitectura del sistema, y no impide incluir algunos nodos especiales con conexión directa en línea si es necesario para una configuración determinada. Con estas premisas, la arquitectura de la plataforma desarrollada tiene tres componentes principales, como se muestra en la Figura 2.

Su comportamiento se describe en los párrafos siguientes.

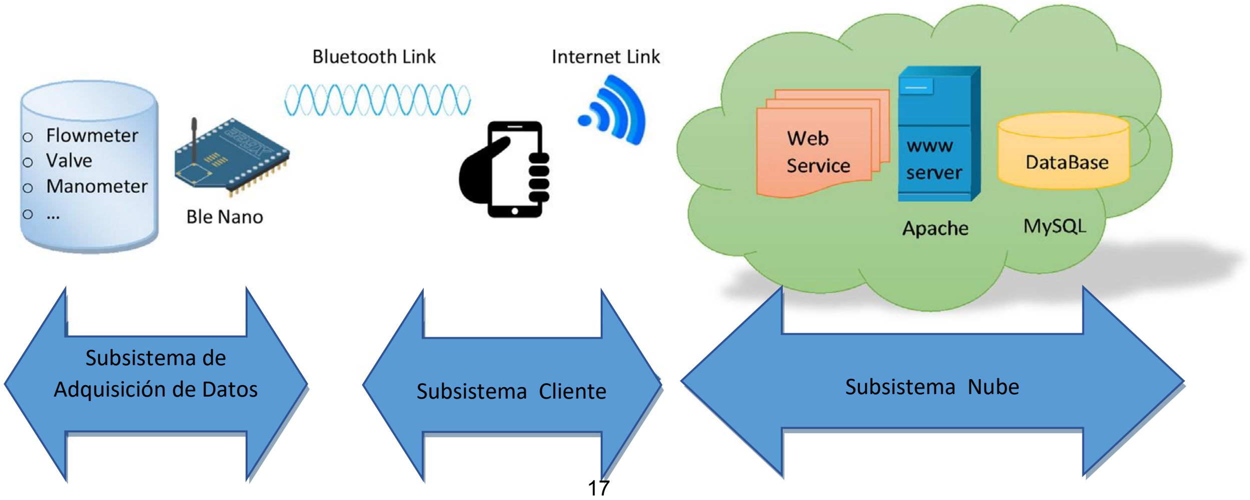
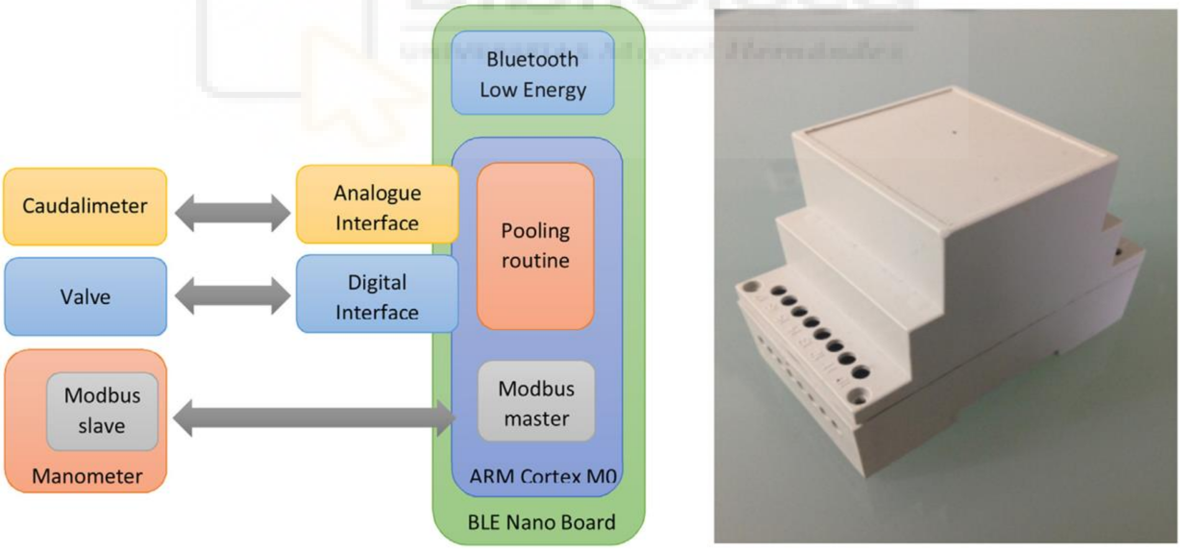


Figura 2. Una visión general de la plataforma desarrollada. El usuario puede detectar, analizar o controlar instrumentos y sensores conectados al BLE Nano desde un dispositivo móvil a través de un enlace BLE. Los datos adquiridos se almacenan en la base de datos local móvil o se transfieren a los servidores en línea cuando hay una conexión a Internet disponible.

3.1.1. Subsistema de adquisición de datos y balizamiento BLE

El mote seleccionado para la plataforma del sensor fue el BLE Nano Kit de Red Bear Company Limited (RedBear, 2016). El Nano es una de las placas más pequeñas habilitadas para BLE, sólo 18.5x21.0mm, y uno de los más baratos, según la experiencia que se ha tenido. Se basa en el chip nRF51822n Nordic®, que incluye un SoC ARM cortex-M0® junto con la radio BLE que funciona a 16 MHz con un consumo de energía ultrabajo, menos de 3 A cuando se alimenta de 1.8V a 3.6V en modo inactivo.

Se muestra un diagrama de bloques del subsistema de adquisición y balizamiento de datos. Incluye la placa Nano y una serie de etapas de acondicionamiento de señal o placas dedicadas según sea necesario. Las placas de PC se montan y conectan a los bloques de terminales a prueba de golpes dentro de un gabinete completamente aislado para rieles DIN® estándar, como se muestra en la Figura 3b.



a) b)

Figura 3. Subsistema de adquisición y balizamiento de datos. a) Diagrama de bloques de la BLE Nano Board e interfaces de comunicación a sensores comunes. b) Las placas electrónicas se montan dentro de un gabinete robusto para aplicaciones industriales antes de su implementación.

Las aplicaciones de software se pueden desarrollar para el Nano utilizando tres entornos diferentes. Para pequeños prototipos, bocetos de Arduino, por medio de la Biblioteca Arduino® para nRF51822® desarrollado por RedBear® es la opción más simple. Para el desarrollo rápido profesional de productos basados en microcontroladores ARM®, una mejor opción es utilizar la plataforma Mbed (plataforma y sistema operativo para conexión de dispositivos por Internet) desarrollada por ARM®.

Por último, para las aplicaciones más exigentes, el SDK nRF51822® proporcionado por Nordic® ofrece acceso completo a la afinación de la característica de cada chip. En este caso, se seleccionó el marco ARM® Mbed, ya que ya incluye acceso estándar a bibliotecas de comunicación avanzadas para BLE, lo que aceleró el ciclo de desarrollo de software. La comunidad en línea activa proporciona también un gran conjunto de módulos como interfaz de programación de aplicaciones (API en inglés) de lenguaje C++® que son gratuitas y están listas para usar.

La aplicación en el BLE Nano consta de dos etapas. La etapa de adquisición es capaz de capturar datos de un medidor de flujo, válvula o sensor de presión utilizando entradas analógicas de 4-20mA, entradas digitales o protocolos industriales típicos como Modbus®, en nuestro caso. Otras interfaces (I2C®, SPI®, RS232®, etc.) se han probado a bordo y podrían implementarse si fuera necesario.

La segunda etapa está dedicada a la comunicación BLE. En comparación con el Bluetooth clásico, BLE consume menos energía y requiere menos tiempo y esfuerzo para emparejar dispositivos, pero proporciona velocidades de conexión más bajas. Esta etapa implementa los perfiles de acceso genérico (en inglés GAP) y el protocolo de atributos (en inglés GATT) en una interfaz privada de alto nivel que se comparte con el dispositivo móvil. El perfil de acceso genérico (GAP) establece el papel periférico para el Nano y configura el modo de publicidad, lo que lo mantiene enviando una señal de baliza regularmente para que pueda ser detectado.

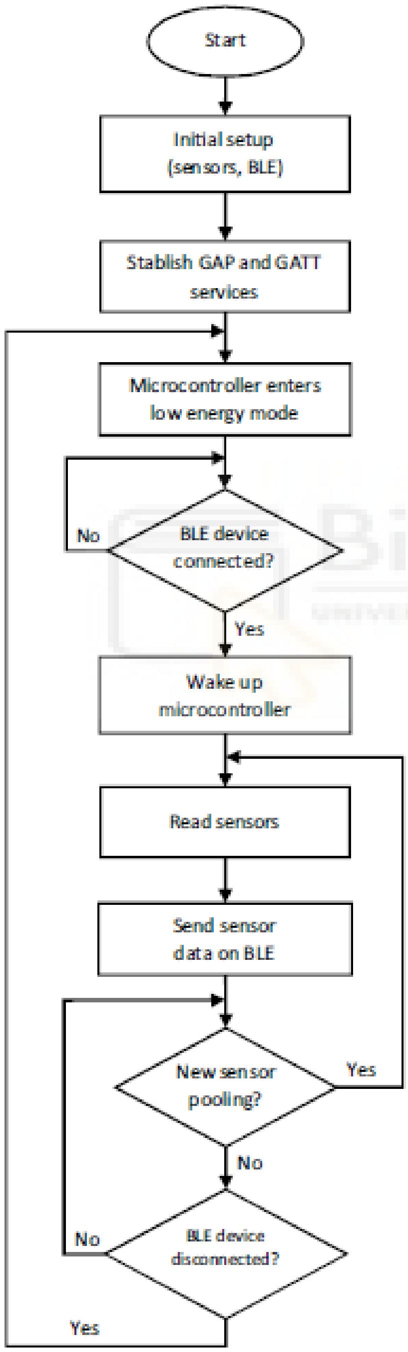


Figura 4. Diagrama de flujo de la aplicación de software que se ejecuta en el BLE Nano

Esto incluye la configuración del intervalo de anuncios, que se puede establecer de 20 ms a 10,24 segundos. En nuestro caso, se seleccionó una brecha de 2 segundos, como un equilibrio adecuado entre la velocidad y el consumo de energía. Vale la pena señalar que mientras que en el modo de radiodifusión (publicidad) no se establece ninguna conexión, lo que permite un ahorro de energía considerable, que se gasta principalmente durante la fase de conexión.

La carga útil de la baliza GAP, encapsulada dentro de la estructura de datos de la publicidad, tiene tres campos: un código de identificación de 16 bytes (UUID), un campo Mayor/Menor de 2 bytes y un byte adicional para el poder del texto. Estos campos podrían utilizarse para la difusión de datos pequeños desde sensores, proporcionando suficiente espacio para la mayoría de las aplicaciones de IoT, como en nuestro caso. Sin embargo, en previsión de futuras mejoras que podrían requerir intercambios de datos más grandes, se decidió incluir un servicio separado del GATT para el intercambio de datos.

El perfil de atributo genérico (GATT) permite a los dispositivos que interactúan adoptar una relación cliente-servidor. Estos roles deben conectarse explícitamente y hacer protocolo de enlace para transferir datos, definiendo un protocolo y algunos atributos. Dado que la mayor parte del consumo de energía tiene lugar durante el proceso de vinculación del dispositivo y, en menor medida, durante la transferencia de datos una vez conectado, la autonomía de los motes no se vería muy influenciada. Para nuestro propósito, el perfil del GATT se definió con un solo servicio que proporcionaba tres atributos de solo lectura que se utilizaban para contener y transmitir los valores leídos de los dos sensores digitales y el analógico. Sin embargo, esta estructura podría ampliarse fácilmente según sea necesario para instalaciones complejas.

Una vez configurados los perfiles GAP y GATT, el microcontrolador ARM® entra en modo de suspensión, interrumpido solo para enviar la baliza BLE con el intervalo especificado. Si un dispositivo móvil intenta conectarse, el microcontrolador sale del modo de suspensión, negocia la conexión y entra en un ciclo de agrupación donde lee los datos de los sensores y los envía al dispositivo móvil. Una vez que se desconecta el dispositivo cliente, el microcontrolador vuelve a entrar en modo de suspensión y se habilita el rol de publicidad. La Figura 4 muestra un diagrama de flujo de alto nivel para el comportamiento propuesto.

3.1.2. Interfaz de Operador y Subsistema de Gestión de Datos

El sistema *front-end* del operador y el subsistema de gestión de datos se ha desarrollado como una aplicación para Android®. Esto permite utilizar cualquiera de la gran cantidad de tabletas y dispositivos de teléfonos inteligentes basados en Android® como la herramienta interactiva del operador. La relevancia de las comunicaciones móviles y la ubicuidad de la plataforma Android® ha llamado la atención de los investigadores y muchas aplicaciones están en desarrollo en varios campos que adoptan esta tecnología (G. Montoya et al., 2013; Rafoss et al., 2010), debido a ventajas adicionales: bajo costo, gran comunidad de desarrolladores, herramientas de desarrollo gratuito y enormes repositorios en línea con bibliotecas listas para usar para casi cualquier aplicación.

La aplicación ha sido desarrollada utilizando una metodología en capas, donde cada capa proporciona ciertos servicios a la capa superior, dando como resultado un software modular y sostenible. Figura 5 muestra los módulos principales que componen la aplicación. La capa de datos se encuentra en el nivel más bajo. Esta capa está a cargo de la gestión de datos dentro de la aplicación. Consiste en un módulo Bluetooth desarrollado bajo el patrón de diseño *singleton* o instancia única (que restringe la creación de instancias de una clase a un objeto) y un controlador SQLite® para proporcionar comunicación con la base de datos interna del dispositivo Android®. La capa de lógica de negocios compone el nivel intermedio. En esta capa, el módulo de servicio Android ejecuta un proceso en segundo plano que se utiliza para escanear constantemente dispositivos BLE. También envía notificaciones al operador que le permiten acceder a los dispositivos descubiertos. También se encuentra en esta capa, el módulo Cloud administra la comunicación con servicios en la nube externos y el intercambio de información con la base de datos empresarial, utilizando el formato de notación de objeto de JavaScript® (JSON en inglés) de estándar abierto para la codificación de objetos de datos. El nivel de presentación forma el nivel superior de la aplicación modular. Esta capa contiene principalmente la interfaz gráfica de usuario (GUI en inglés) y sirve como una herramienta para estructurar la información. La funcionalidad de la GUI permite escanear manualmente los motes BLE, generar informes internos y externos para una instalación determinada, tomar fotografías que se pueden agregar a los informes y enviar toda esa información a los servidores en la nube. Por supuesto, en caso de que no haya conexión a Internet, los datos se almacenarán en una base de datos interna en el dispositivo móvil, y se transmitirán este último cuando se restablezca la conexión.

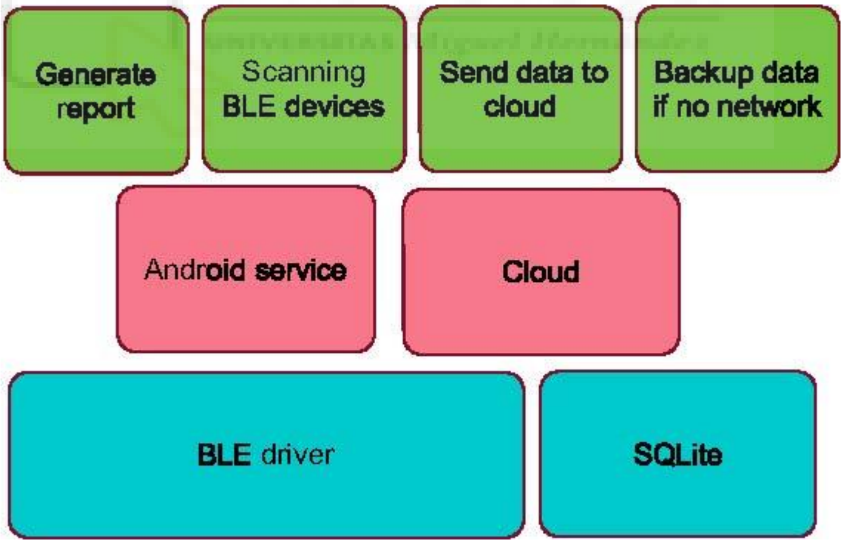


Figura 5. Módulos y estructura en capas de la aplicación Android desarrollado para el dispositivo móvil.

3.1.3. Subsistema en la nube en línea

Los servicios en la nube proporcionan una forma cómoda de hacer que una aplicación sea escalable y distribuida según sea necesario. Para nuestra planta piloto, el subsistema en la nube se compone de una base de datos MySQL® y un servidor

Apache®. La base de datos se administra con la herramienta CPanel® estándar. Una vez implementada la base de datos y en línea, se define un servicio web para la transferencia de datos. Como se mencionó anteriormente, los mensajes enviados y recibidos por la plataforma en línea utilizan el formato de datos JSON. Hoy en día JSON es el formato de datos más común utilizado para la comunicación asíncrono navegador/servidor, debido en parte a su naturaleza estándar abierta y el uso de un formato de texto legible por el ser humano. Esto ha favorecido el hecho de que prácticamente todos los lenguajes de software modernos admiten JSON. En nuestro caso, un conjunto de servicios en segundo plano en el servidor Apache 2 fueron desarrollados en el lenguaje de programación PHP®. Esta capa de servicio se puede ampliar según sea necesario. Algunos de estos servicios son responsables de hablar con el controlador de base de datos para realizar una consulta o encapsular los datos recuperados en un objeto JSON antes de enviarlos de vuelta al dispositivo que realizó la consulta.

3.2. En el caso del RETO 2:

En este caso se planteó la reducción de la huella de carbono de una comunidad de regantes mediante el uso de energía solar. El caso de estudio se sitúa en el sureste de España. Para un análisis correcto de la situación se estudiaron las características agroclimáticas y las necesidades de los cultivos, que a su vez se adaptan a las dotaciones que suministró la organización de cuenca (Confederación Hidrografica del Segura). Se recogieron los datos de las distintas facturas eléctricas de cada punto de consumo, seleccionando los grandes consumos (bombeos principales). Estos datos se trataron separando los diferentes costes de la factura hasta aislar el consumo real de bombeo. Una vez contados estos consumos reales, se obtuvieron como punto de partida, las necesidades energéticas máximas mensuales y las correspondientesemisiones de CO_2, que se generaron durante un año, mes a mes. Se consideraron varias soluciones limpias, como el viento y la generación de turbinas aprovechando las diferencias de calibre (Mérida García, A.; et al., 2018). Pero su uso no garantizaba un suministro suficiente de energía para las diferentes demandas mensuales. Sólo la energía fotovoltaica fue capaz de garantizar la energía necesaria durante cualquier época del año. La posibilidad de implementar otras energías de manera complementaria fue descartada debido al alto costo de su instalación asociado a la necesaria inversión del transporte de energía a los puntos de consumo y pérdidas durante el transporte. Una vez que se conocían los días de máxima energía requerida, la planta fotovoltaica se dimensionó y se obtuvieron las emisiones potencialmente evitadas. Esta metodología ayudó a alcanzar los objetivos de GDS (Da Silva I., et al., 2020) y contribuir a alentar a otras comunidades de usuarios a utilizar esta fuente de energía.

3.2.1. Antecedentes

La Comunidad de Regantes(CC.RR.) de la zona del estudio se encuentra en la Región de Murcia (España). El área de riego es de 373,59 ha (Figura 6). Esta CCRR ha sido constituida a partir de la unión de diferentes grupos y asociaciones de riego.

Esta CC.RR. incluye dos explotaciones naturales: Pozo (W) y Trasvase Tajo-Segura (TST). Además, una tercera explotación proviene de la Planta de Tratamiento de Aguas Residuales (WWTP) en la zona del caso de estudio (Pijoan, J. & Prat, Narcís., 2008).

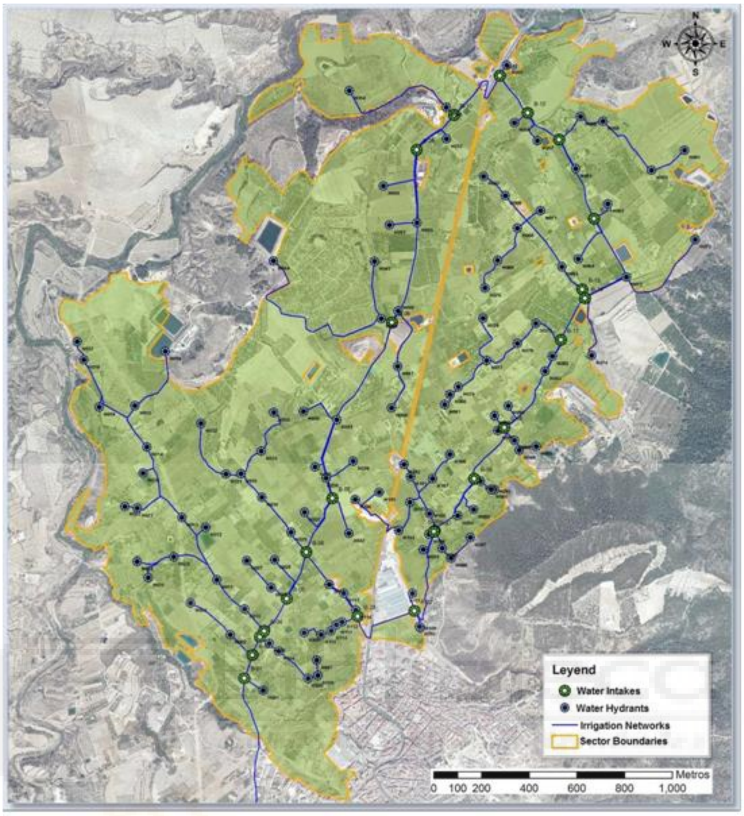


Figura 6. Área de regadío de la zona de estudio de la CC.RR.. Fuente: Confederación Hidrográfica de Segura.

3.2.2. - Climatología, régimen térmico, rasgos agroclimáticos y régimen de precipitación.

Los siguientes detalles de los factores climáticos y térmicos de la zona de estudio:

- **Clima:** El análisis climático de la zona de riego está condicionado por los siguientes factores:
  - Posición latitudinal, que determina la intensidad de la radiación solar. La superficie se encuentra entre los 37° 57' y 37° 01' paralelos, siendo responsable de las altas temperaturas en verano.
  - Posición altitudinal, que determina la intensidad de las precipitaciones y los vientos predominantes de la zona.
  - Condiciones específicas de la zona de riego con respecto a la rugosidad vegetal y presencia de agua.
  - Circulación atmosférica general que atraviesa la región. La presentación del anticiclón será el acondicionamiento de la circulación atmosférica, aunque será atemperada por la estructura de relieve existente, que

condicionará la distribución de la precipitación durante todo el año.

- Las condiciones atmosféricas de la zona de estudio son los determinantes del clima característico de la zona, esto se caracteriza por una disminución en el contenido de humedad de las masas de aire que, junto con el sistema de montaña bética, producen el efecto de la pantalla y dan lugar a tipos de clima seco, templado y claro, tanto en invierno como en verano.

- **Régimen térmico y rasgos agroclimáticos:**

  - La temperatura media del mes es más fría entre 8 y 11ºC; la temperatura media mínima de 4 y 7ºC. Por lo tanto, el riesgo de heladas es bajo.
  - Las temperaturas medias de las más cálidas son entre 26 y 28ºC, con promedios de máximos entre 32 y 34ºC.
  - La precipitación es de 200-300 mm al año. El período seco dura 7-11 meses, según las estaciones.
  - Las condiciones térmicas permiten el cultivo de cereales y algodón.
  - El tipo climático de la zona subtropical mediterránea cálida o semi-cálida.
  - El área de pertenencia, debido a su ardedura e higrocontinentalidad a la formación fisiognomica Durilignosa en transición a Siccideserta.

- • **Régimen de precipitación**: En el análisis de la precipitación, debido a su tipo térmico árido termomediterráneo, el régimen térmico indicado en la sección anterior, y otros factores climáticos producen registros pluviométricos muy débiles que rara vez superan los 350 mm, en toda la zona de la región.

3.2.3. Necesidades de agua y recursos disponibles

Actualmente, con una provisión de 10 años, la CC.RR. tiene 3 usos con una asignación anual de 3.629.361 m^3 (Tabla 1).

Tabla1. Suministro de volumen total de los recursos disponibles.

Exlotation	Capital Flows		Annual apropiation (m³)	Regulating rafts (m3)
	QD (l/s)	Q (m³/h)		
Well	95	342	2.326.158	45.000
Tajo- Segura Transfer (summer)	300	1.080	1.140.000	230.000
WWTP	40	144	163.203	39.464
		TOTAL	3.629.361	

La forma en que se utilizan las aguas de riego consiste en bombear desde las diferentes fuentes a sus propios estanques de regulación (Tabla 2), que son propiedad de la CC.RR., y desde allí a través de conductos hasta los puntos de consumo de acuerdo con las necesidades de agua de cultivo. La extracción por medio del bombeo se lleva a cabo en los períodos más económicos de la tarifa eléctrica contratada.

Según la Figura 7, las necesidades de agua han sido cubiertas:

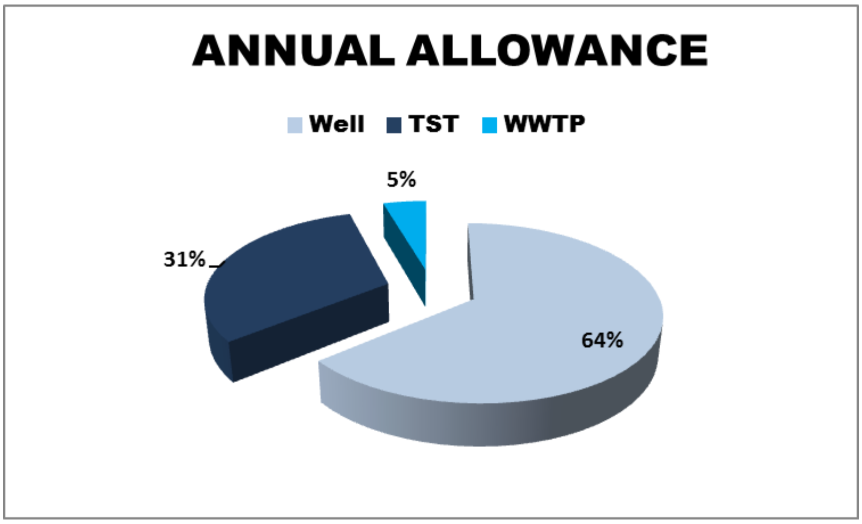


Figura 7. Porcentaje de volumen de agua necesario para cubrir la demanda de acuerdo con la fuente de suministro de agua.

3.2.4. Gastos económicos de los consumos eléctricos de diferentes fuentes.

Se registraron los consumos eléctricos durante 2016 dependiendo de la fuente de agua de riego de extracción. Los gastos económicos, de acuerdo con la potencia facturada y la energía consumida, se analizaron según el esquema operativo actual real (Figura 8).

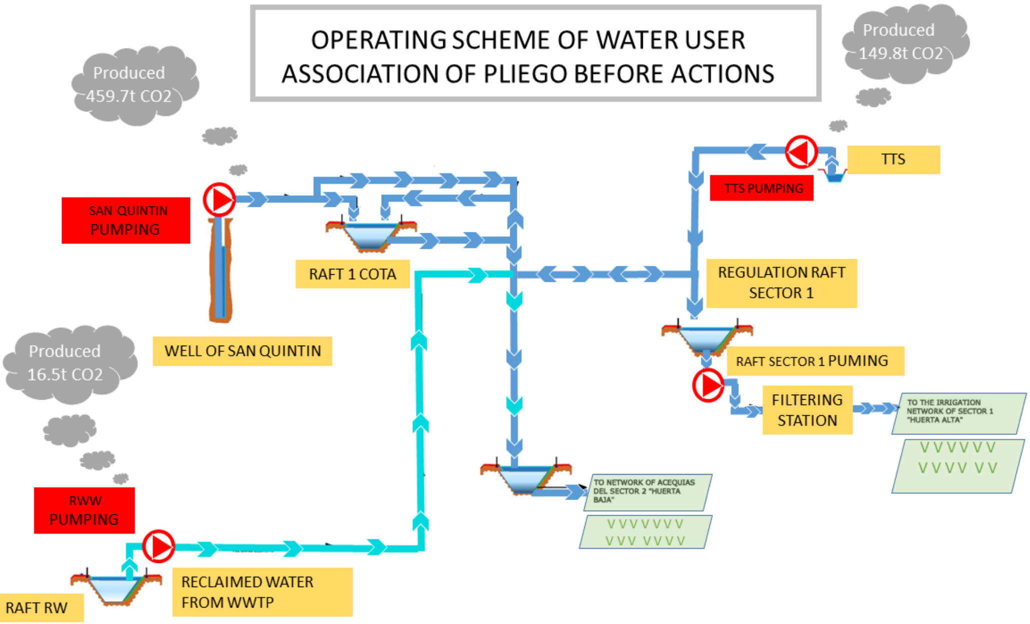
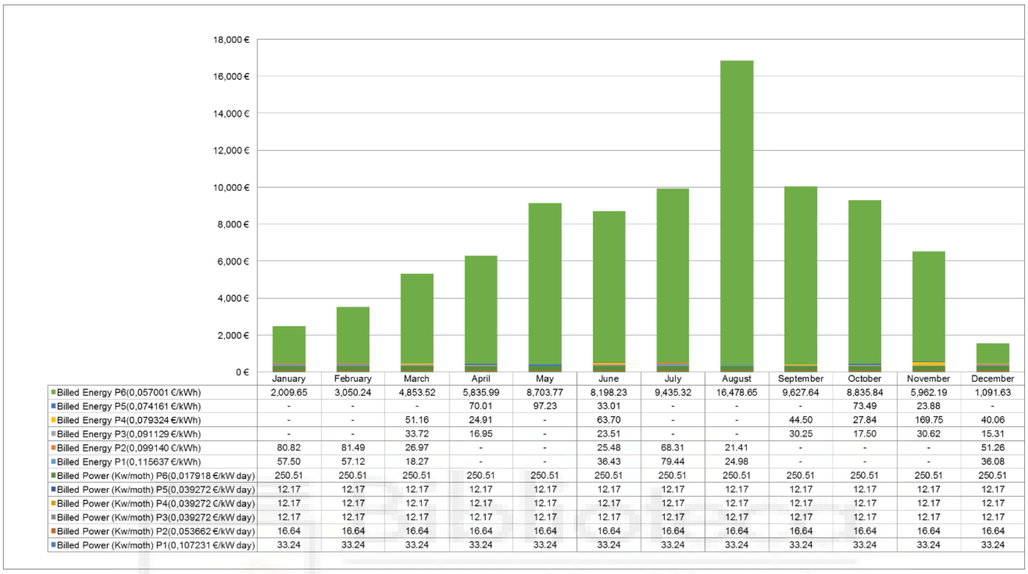


Figura 8. Esquema operativo actual de CC.RR.

3.2.5. Gasto económico de extracción por medio del Pozo

Para la extracción mediante bombeo de agua subterránea desde el pozo de la instalación se contrató la tarifa comercial T6.1 (normativa española). Esta tarifa incluye alta tensión y una potencia de más de 15 kW en 3 períodos: P1 a 10 kW; P2 a 10 kW; P3 a 10 kW; P4 a 10 kW; P5 a 10 kW; P6 a 451 kW. El gasto mensual se puede mostrar en la Figura 9. Está claro que el CC.RR. estaba utilizando principalmente la bomba del pozo durante el período por hora menos costoso, de acuerdo con la tarifa P6.

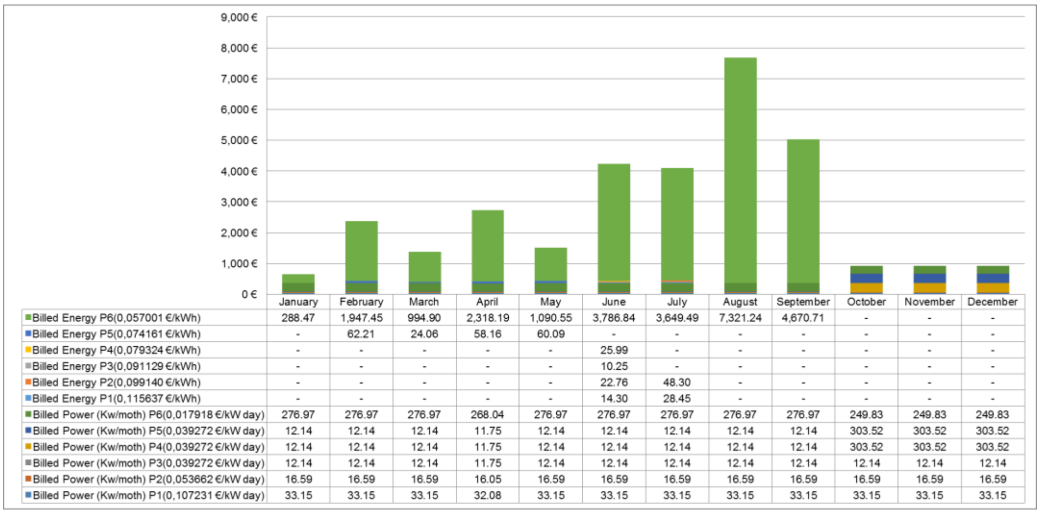


	January	February	March	April	May	June	July	August	September	October	November	December
■ Billed Energy P6(0,057001 €/kWh)	2,009.65	3,050.24	4,853.52	5,835.99	8,703.77	8,198.23	9,435.32	16,478.65	9,627.64	8,835.84	5,962.19	1,091.63
■ Billed Energy P5(0,074161 €/kWh)	-	-	-	70.01	97.23	33.01	-	-	-	73.49	23.88	-
■ Billed Energy P4(0,079324 €/kWh)	-	-	51.16	24.91	-	63.70	-	-	44.50	27.84	169.75	40.06
■ Billed Energy P3(0,091129 €/kWh)	-	-	33.72	16.95	-	23.51	-	-	30.25	17.50	30.62	15.31
■ Billed Energy P2(0,099140 €/kWh)	80.82	81.49	26.97	-	-	25.48	68.31	21.41	-	-	-	51.26
■ Billed Energy P1(0,115637 €/kWh)	57.50	57.12	18.27	-	-	36.43	79.44	24.98	-	-	-	36.08
■ Billed Power (Kw/moth) P6(0,017918 €/kW day)	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51
■ Billed Power (Kw/moth) P5(0,039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
■ Billed Power (Kw/moth) P4(0,039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
■ Billed Power (Kw/moth) P3(0,039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
■ Billed Power (Kw/moth) P2(0,053662 €/kW day)	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64
■ Billed Power (Kw/moth) P1(0,107231 €/kW day)	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24

Figura 9. Gastos económicos del Pozo. 2016.

3.2.6. Gasto económico de extracción por medios Trasvase Tajo-Segura (TST)

Para la extracción de bombeo de agua del agua TST, se ha contratado la tarifa comercial T6.1. Este arancel se detalla en 2.1. El gasto mensual se observa en la Figura 10.

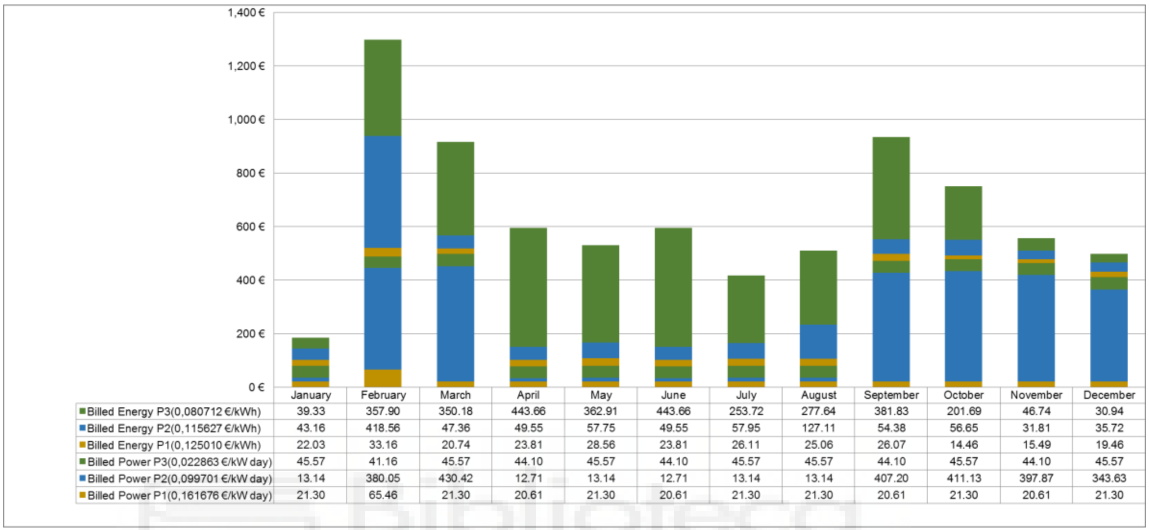


	January	February	March	April	May	June	July	August	September	October	November	December
■ Billed Energy P6(0,057001 €/kWh)	288.47	1,947.45	994.90	2,318.19	1,090.55	3,786.84	3,649.49	7,321.24	4,670.71	-	-	-
■ Billed Energy P5(0,074161 €/kWh)	-	62.21	24.06	58.16	60.09	-	-	-	-	-	-	-
■ Billed Energy P4(0,079324 €/kWh)	-	-	-	-	-	25.99	-	-	-	-	-	-
■ Billed Energy P3(0,091129 €/kWh)	-	-	-	-	-	10.25	-	-	-	-	-	-
■ Billed Energy P2(0,099140 €/kWh)	-	-	-	-	-	22.76	48.30	-	-	-	-	-
■ Billed Energy P1(0,115637 €/kWh)	-	-	-	-	-	14.30	28.45	-	-	-	-	-
■ Billed Power (Kw/moth) P6(0,017918 €/kW day)	276.97	276.97	276.97	268.04	276.97	276.97	276.97	276.97	276.97	249.83	249.83	249.83
■ Billed Power (Kw/moth) P5(0,039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	303.52	303.52	303.52
■ Billed Power (Kw/moth) P4(0,039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	303.52	303.52	303.52
■ Billed Power (Kw/moth) P3(0,039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	12.14	12.14	12.14
■ Billed Power (Kw/moth) P2(0,053662 €/kW day)	16.59	16.59	16.59	16.05	16.59	16.59	16.59	16.59	16.59	16.59	16.59	16.59
■ Billed Power (Kw/moth) P1(0,107231 €/kW day)	33.15	33.15	33.15	32.08	33.15	33.15	33.15	33.15	33.15	33.15	33.15	33.15

Figura 10. Gasto económico TST. 2016.

3.2.7. Extraer los gastos económicos de agua de la EDAR

Para la extracción de bombeo de agua de EDAR se ha contratado la tarifa comercial T3.1 (normativa española). Se trata de alta tensión y la potencia de más de 15 kW en 3 períodos: P1 a 5 kW; P2 a 5 kW; P3 a 75,636 kW. El gasto mensual se puede observar en la Figura 11.



	January	February	March	April	May	June	July	August	September	October	November	December
🟩 Billed Energy P3(0,080712 €/kWh)	39.33	357.90	350.18	443.66	362.91	443.66	253.72	277.64	381.83	201.69	46.74	30.94
🟦 Billed Energy P2(0,115627 €/kWh)	43.16	418.56	47.36	49.55	57.75	49.55	57.95	127.11	54.38	56.65	31.81	35.72
🟨 Billed Energy P1(0,125010 €/kWh)	22.03	33.16	20.74	23.81	28.56	23.81	26.11	25.06	26.07	14.46	15.49	19.46
🟩 Billed Power P3(0,022863 €/kW day)	45.57	41.16	45.57	44.10	45.57	44.10	45.57	45.57	44.10	45.57	44.10	45.57
🟦 Billed Power P2(0,099701 €/kW day)	13.14	380.05	430.42	12.71	13.14	12.71	13.14	13.14	407.20	411.13	397.87	343.63
🟨 Billed Power P1(0,161676 €/kW day)	21.30	65.46	21.30	20.61	21.30	20.61	21.30	21.30	20.61	21.30	20.61	21.30

Figura 11. Gasto económico de la EDAR. 2016.

En el caso de la EDAR, la CC.RR. está utilizando principalmente la bomba de extracción en los períodos menos costosos. Esto ocurre con los aranceles P1 y P2. La CC.RR. está utilizando esta fuente de agua para satisfacer las necesidades de agua de cultivo según la hectárea tipo, durante febrero y marzo y desde finales de verano hasta finales de año.

Adicionalmente, la CC.RR. de la zona estudiada se enfrentó a una factura de 81.949,10 euros (impuestos incluidos) en 2016, como se muestra en la Figura 12.

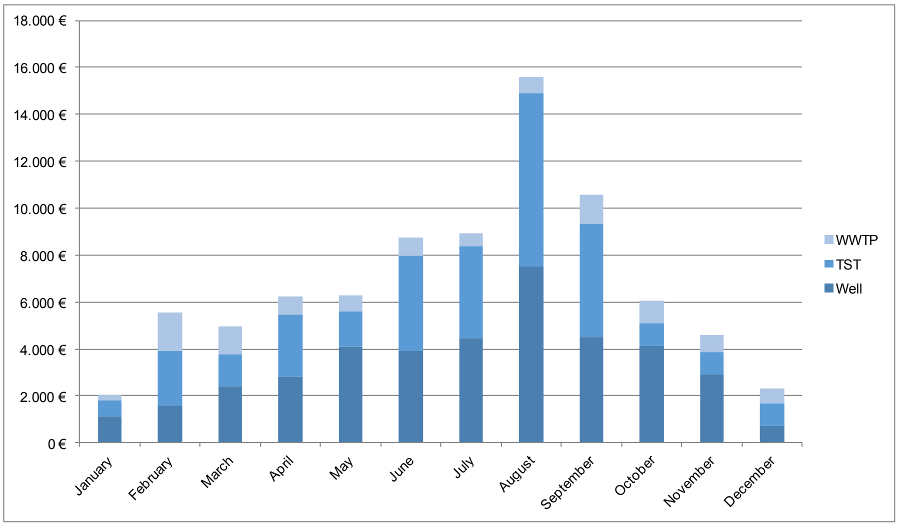


Figura 12. Gasto económico total. 2016.

Como se citó anteriormente, debido a la ubicación de la CCRR en una zona semiárida, el máximo de los gastos económicos es durante el máximo de la demanda de agua en los meses de verano.

3.3. En el caso del RETO 3:

Se trata de un caso de estudio sobre la aplicación de las TIC en la CCRR de Pliego (Murcia). El objetivo principal de esta investigación fue conseguir la integración de dos tipologías de explotación. Una nueva en el Sector 2 de la citada CCRR, con parcelas de mayor tamaño, cuya nueva implementación permitía el uso de hardware comercial pero que requería un número mínimo de control de 16 parcelas para ser viable económicamente. Por otra parte, otra tipología de explotación del Sector 1 de la CCRR, de menor tamaño y con orografía más abrupta, capaz de dar servicio a micro-parcelas con unidades de transmisión remota independientes.

El esquema principal del sistema de automatización se describe en la Figura 13. Los datos proporcionados por los distintos sensores que registran según su grado de importancia donde a mayor importancia mayor frecuencia de lectura, se vuelcan a las unidades terminales remotas (RTU) que son capaces de almacenar en unidades internas hasta 6 meses. Cuando los puertos de comunicación se abren, lanzan una señal de baja radiación de campos alternos eléctricos y magnéticos (LowRa) que es recogida por la concentradora más próxima y esta identifica la estación de comunicación y etiqueta la fecha de la comunicación, compara si los datos recibidos son más recientes que los que tiene almacenados y si es así los graba, (en caso contrario no los almacena) este proceso se duplica a dos concentradoras como mínimo para garantizar las comunicaciones. A su vez si estas concentradoras tienen nuevas instrucciones que han sido enviadas desde la aplicación (APP) por los usuarios o el administrador las devuelven durante la ventana temporal de comunicación (repitiéndose el proceso de verificación) y pueden así reprogramar las unidades RTU para modificar las programaciones (como apertura y cierre de las válvulas, incremento de la frecuencia de lectura en un contador, si se ha detectado alguna anomalía, etc.). Finalmente, tras cerrarse el ciclo de comunicación que en nuestro caso se limitó cada dos horas para prolongar la duración de las baterías (se puede modificar si existen problemas), los datos se suben a la red y son grabados en un disco duro físico y opcionalmente en la Nube, para posteriormente visualizarse en el escada y la APP de los usuarios. Esto no significa que no exista actualización del escada en dos horas, sino que la totalidad de los datos proporcionados por los sensores de toda la CCRR del sistema se completa cada dos horas. Paralelamente en los puntos críticos (Red Primaria y algunos en la Secundaria) se leen en tiempo real y se actualizan en la APP y en el Scada instantáneamente.

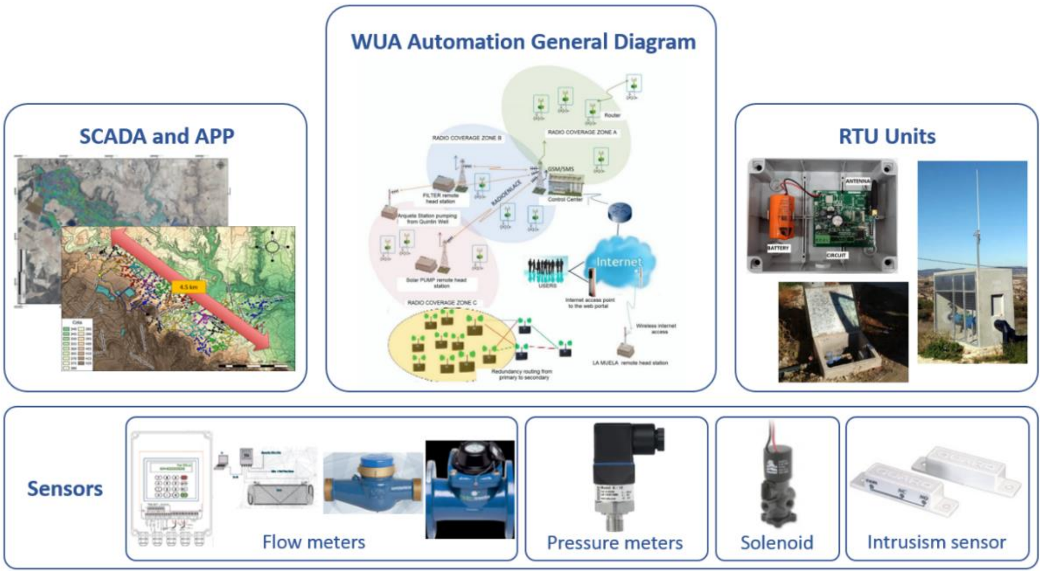


Figura 13. Esquema del sistema de automatización en la CCRR de Pliego.

La investigación se ha centrado en el desarrollo del nuevo hardware y software diseñado expresamente para resolver los problemas de comunicación y facilitar la gestión tanto de las programaciones de riego por parte de los usuarios como facilitar al administrador el control de todo el sistema, con la particularidad de disponer de información suficiente para tomar las decisiones que sean más beneficiosas, y para esto se requiere satisfacer tres funciones principales:

1. Consulta del sistema: sirven al administrados para poder controlar el funcionamiento del sistema a tiempo real (número de hidrantes abiertos caudales consumidos, presiones en puntos de control, …) .
2. Adquisición de datos históricos: permiten al administrador y los usuarios conocer y consultar los datos ya registrados (consumos, presiones, estados de apertura y cierre de válvulas,…)
3. Lectura o actuación a demanda: Proporciona el último dato registrado y permite la interacción con los elementos conectados.

Teniendo en consideración estos requisitos se diseñó el sistema, y por ello vamos a describir los principales dispositivos integrados en este sistema de automatización (Figura 13). Existen dos niveles de automatización aparte del sistema de pantallas para consultoría y gestión (SCADA, APP, entre otros). El primer nivel consta de unidades de transmisión remota (RTU). En las RTU, se pueden distinguir, en primer lugar, los concentradores. Este dispositivo es al mismo tiempo concentrador de comunicaciones y RTU con entradas y salidas. Además, puede comunicarse con un servidor central mediante tecnología de comunicaciones de servicio general de paquetes vía radio (GPRS), o radio de banda libre, y puede funcionar de forma continua durante 6 meses en ausencia de comunicaciones sin pérdida de información. Este dispositivo es un equipo totalmente autónomo. Los concentradores funcionan con baterías y, como soporte adicional, puede gestionar su carga a través de un pequeño panel solar. Además, estos dispositivos incluyen la posibilidad de reprogramar *firmware* inalámbrico. El equipo más básico es capaz de controlar hasta cuatro hidrantes, una entrada digital y una salida y dos entradas analógicas, aunque este número puede ampliarse mediante expansiones de entrada/salida (E/S). Pueden funcionar como un punto final de radio o GPRS y como un centro de comunicaciones mixto GPRS / Radio. Estos dispositivos recopilan y concentran las comunicaciones de una subred de radio y las retransmiten a través de GPRS.

El otro tipo de RTU es el esclavo. Estos dispositivos pueden comunicarse con un servidor central mediante tecnología GPRS, o radio en banda libre, pudiendo funcionar de manera continua durante 6 meses en ausencia de comunicaciones sin pérdida de información. Estos dispositivos son completamente autónomos. Se alimentan de una sola batería de litio que le confiere una autonomía superior a los 3 años en su versión GPRS y a los 10 años en la versión radio (24 comunicaciones diarias). Puede controlar un hidrante y una entrada digital, y puede funcionar como "punto final" GPRS o como radio. En este caso, existe la posibilidad de reprogramar firmware inalámbrico. El consumo es de 35uA en ausencia de comunicaciones. Mientras que los consumos se incrementan en función del número de comunicaciones por hora y de la duración de estas. Tal y como se puede ver en la Tabla 2.

Tabla 2 . Consumo de batería anual, dependiendo del número de comunicaciones.

		Número de comunicaciones diarias							**Siempre conectado (1 comunicación horaria)**
		1	**2**	**4**	**6**	**8**	**12**	**24**	
Entrada de lecturas analógicas en intervalo de 4-20 mA (min)	**60**	7,85	7,64	7,44	7,25	7,44	7,25	6,73	0,11
	30	4,37	4,31	4,24	4,18	4,24	4,18	4,00	0,11
	15	2,32	2,30	2,28	2,26	2,28	2,26	2,21	0,10
	10	1,58	1,57	1,56	1,55	1,56	1,55	1,53	0,10
	5	1,21	1,21	1,20	1,20	1,20	1,20	1,18	0,10

Las RTU incluyen antenas para evitar la falta de cobertura debido a la topología. Los concentradores tienen una antena en un mástil de 4 m de altura. Los concentradores controlan simultáneamente los puntos de venta del sector. Las RTU incluyen antenas para evitar la falta de cobertura debido a la ubicación.

Los sensores incluidos en este sistema son los siguientes. Inicialmente, se instalan 1.300 unidades de un contador de chorros múltiples de calibres variables con emisor de pulsos. Además, se incluyen 20 unidades de medidor Woltmann®, con un diámetro de 150 mm con emisor de pulsos. Finalmente, el proyecto incluye 6 unidades de caudalímetro ultrasónico no invasivo. Están conectados a un PLC Siemens® en bombeo solar y también se pueden conectar a los remotos descritos anteriormente. Este PLC está integrado en el sistema. Las válvulas de todo el sistema de riego están controladas por aproximadamente 1.320 unidades de pestillo solenoide de 3 vías. Finalmente, la presión es controlada por 28 unidades de transductores de presión de 0-10 bar.

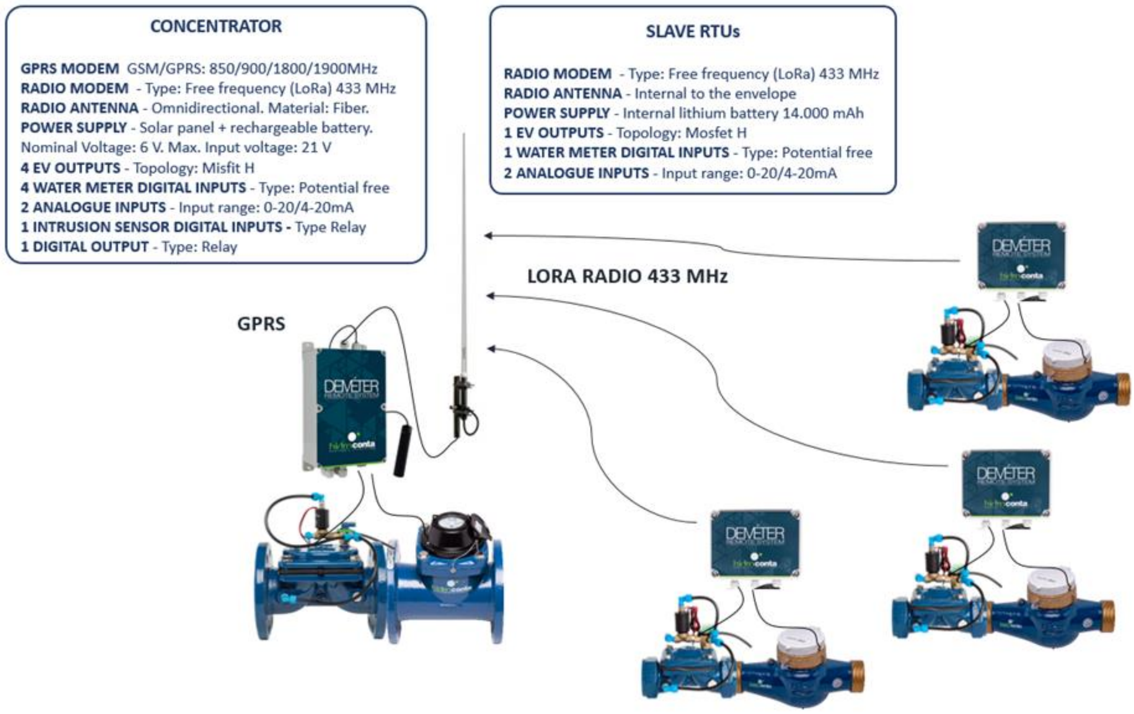


Figura 14. Descripción de los sensores en la CCRR de Pliego.

En primer lugar, para la elaboración de este estudio se obtuvieron del inventario de cultivos de la Región de Murcia 2016-2017 los datos de Pliego, localidad de la Región de Murcia (España) y el censo de agricultores del Sector I de Pliego de las CCRR. Esto se ha analizado con el fin de orientar los sectores, según el tipo de cultivo previsto. La intención de todo ello es aprovechar las diferentes necesidades hidráulicas, según los meses del año de cultivo.

En segundo lugar, cabe señalar que la instalación de un sistema de control remoto en la CC.RR. de Pliego ha sido un desafío, tanto técnica como económicamente. Las principales características que se han tenido en cuenta son las siguientes. Para la elaboración de este estudio se han analizado datos sobre el consumo de agua en los diferentes hidrantes. Este análisis se desarrolló con el fin de conocer la demanda actual en función del tipo de cultivo, en el terreno, con base en el censo del CR Sector I Pliego. Para ello se han estudiado las facturas de los últimos 5 años de cada microparcela. Además, se han estudiado las principales redes existentes, capaces de sectorizar y telecomando desde la red y los diferentes recursos hídricos (pozo, embalses, agua regenerada de la depuradora (Fernández-Ahumada, L.M., et al., 2019), sistemas de estaciones de bombeo). Los datos que suministran al sistema (caudales, parámetros de calidad del agua y presión de la red), cada hora en el caso de los caudalímetros de los monohidrantes, y a tiempo real en puntos críticos de control de la red primaria y algunos de la red secundaria. Éstos se analizan para mantener los niveles de presión en un valor en torno a los 25 metros de columna de agua.

Había que resolver varios desafíos. Principalmente, la automatización de una red existente y ofreciendo a los usuarios la posibilidad de seleccionar la programación de riego en su microparcela. Además, la ubicación en un terreno escarpado implica grandes dificultades de comunicación. Todo lo anteriormente citado debe gestionarse de forma que sea económica y medioambientalmente sostenible (Rodríguez-Robles, J., et al., 2020). Para ello, se evaluaron las diferentes tecnologías disponibles hasta la fecha (Pérez Hernández, F., et al 2017; Melián Navarro, A., et al., 2016; Giannakis, E., et al., 2016) y su posible uso, analizando los pros y contras que supondría cada una de ellas.

El objetivo de esta investigación fue diseñar un sistema de control remoto barato, escalable, fácil de implementar y mantener, con la capacidad de adaptarse a la brecha de las topologías de redes hidráulicas existentes. Para ello se pretende brindar soluciones a cualquier CCRR independientemente de su extensión, topografía, concentración de hidrantes o cobertura. Este sistema brindaría una solución, no solo a las CCRR con buenas condiciones (extensión, topografía, concentración y cobertura de hidrantes), sino a otras CCRR que, por sus especiales características, dificultaban la automatización con tecnologías existentes hasta ahora. En este caso, el precio de cada dispositivo por cada toma de usuario es de 298 € frente a los 1.300 € que costaría la alternativa de instalar un mando. En cuanto a la facilidad de mantenimiento, la mayor ventaja es que son baterías estándar y fáciles de reemplazar. Finalmente, el control remoto se logra gracias a la funcionalidad del dispositivo para conectarse a través de Internet.

3.3.1. Análisis de necesidades del sistema Smart-Agri

Para definir completamente el sistema Smart-Agri®, se deben analizar cinco aspectos:

La CCRR de Pliego incluye tres características que son, primero, un desafío técnico para la instalación de un sistema de control remoto y, segundo, que es económicamente aceptable (Barnes, A.P., et al., 2019). Son el tamaño medio de las parcelas, la distribución de los hidrantes y el espacio geofísico en el que se ubica.

3.3.1.1. Tamaño medio del paquete

La superficie incluida en el sector abordado, Huerta Alta (Sector I), alcanza las 373,59 ha. Tenga en cuenta que 1.949 usuarios (Figura 15) están registrados, tiene un tamaño promedio de parcela menor a 0.2 ha por parcela. Esto implica una atomización extrema del riego que hace de esta CR un caso excepcional, dificultando el mantenimiento y amortización de equipos, ya sean hidráulicos o electrónicos, por área de servicio. La parcela utilizada para la redacción del mismo se ha obtenido de tres fuentes fundamentales:

- Censo de la CR de registros de propagación.
- Mapeo oficial del Catastro
- Zona de riego reconocida por la Cuenca del Segura.

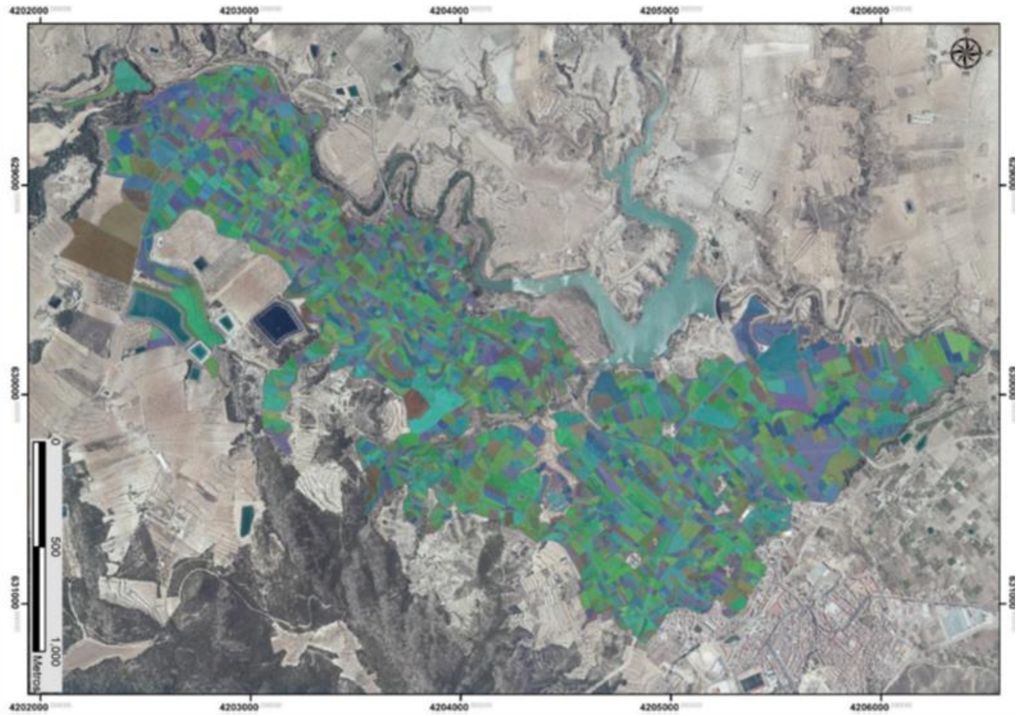


Figura 15. Distribución de microparcelas a control remoto en la CR de Pliego.

3.3.1.2. Distribución de hidrantes.

El principal inconveniente en este punto viene dado por la dispersión de los hidrantes. La red baja, que era preexistente, consta de arquetas monohidrantes distribuidos en cada una de las parcelas, en contraposición a la distribución más favorable de los arqueta multihidrantes. Esta característica, en combinación con la gran cantidad de usuarios, hizo imprescindible la instalación de una gran cantidad de terminales remotos (Figura 16).

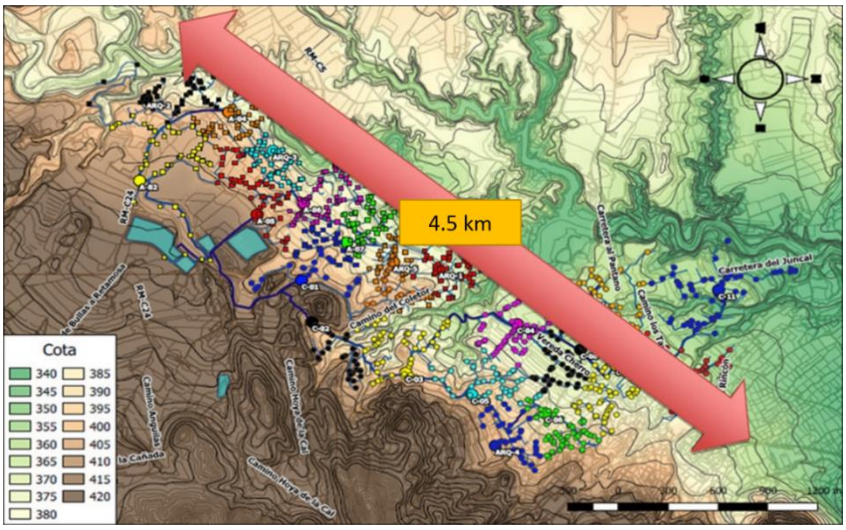


Figura 16. Distribución de hidrantes a control remoto en la CCRR de Pliego.

Esto significa un rendimiento de un equipo por cada 0,2 ha, lo que requiere una gran economía en varios niveles. En cuanto a la inversión, se hizo indispensable la existencia de equipos de muy bajo costo y muy fácil instalación. Se logró con un dispositivo que incluía las entradas y salidas estrictamente necesarias, permitiendo la lectura de un contador y la apertura y cierre de una válvula; y con un consumo de energía limitado, evitando expandir los costos en los sistemas de almacenamiento de energía.

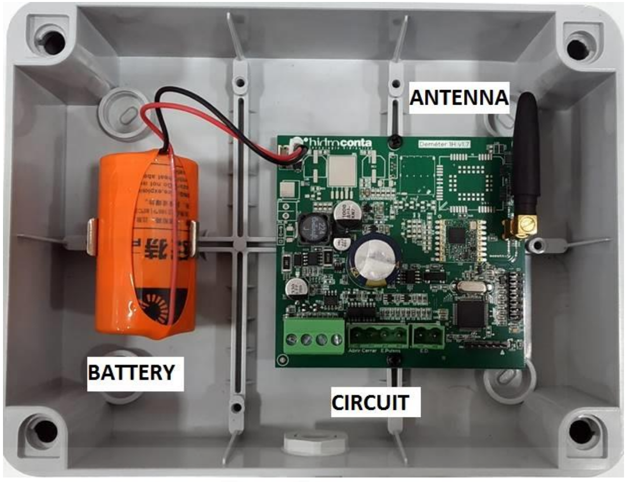


Figura 17. Equipo y componentes de Smart-Agri (usuario único en una microparcela).

La instalación se resolvió mediante un protocolo simple, pero a la vez tan completo que incluyó pruebas in situ de comunicación y funcionamiento de los componentes de hardware de todos los terminales (Figura 17). En términos de operación y mantenimiento, el sistema tenía que ser robusto y duradero, y emplear un sistema de comunicaciones asequible. Esto descartó el uso de comunicaciones GPRS de forma indiscriminada, lo que llevó al uso de un sistema mixto de radio GPRS.

Para ello, los concentradores ya descritos, que incorporan una antena de radio de alta ganancia que asegura la recepción de las comunicaciones, en el caso ideal de visión directa entre antenas, a distancias que alcanzan los 5 km (Figura 18). Esta distancia no debe valorarse en términos absolutos sino en relación al tamaño de las antenas equipadas tanto en el equipo emisor como receptor, siendo en este caso 270 cm en el *hub* y 5 cm en la RTU esclava.

Figura 18. Hub de radio GPRS (arqueta de sectorización).

En ciertas ubicaciones extremadamente difíciles, las comunicaciones correctas se lograron instalando una antena externa de 40 cm en el equipo esclavo. Esta medida fue necesaria en 8 arquetas, lo que, considerando que se instalaron un total de 1205 terminales de radio (Figura 19), representa una incidencia menor al 0,7%. La figura 8 incluye un hidrante. Consiste en un caudalímetro con regulación de presión para conectar el sistema de riego por goteo del agricultor.

Figura 19. El hidrante instalado en una arqueta semienterrada.

Para reducir los costos de mantenimiento de los equipos, se utiliza una batería de litio con una duración estimada de 10 años (Figura 20). Además, la simple instalación antes mencionada excluyó anclajes fijos y tornillos innecesarios, permitiendo la posibilidad de mover el equipo para una inspección y operación rápida y eficiente. La vida útil de la batería depende de diferentes factores (precisión del voltaje de flotación, frecuencia de descargas, número de descargas, tasa de descarga máxima, profundidad de las descargas, límite de voltaje final, temperatura de funcionamiento, cantidad de corriente de ondulación y voltaje permitido, tanto durante la carga como la descarga. Este es un régimen muy estricto que debe seguirse con mucha precisión para lograr la vida útil del diseño. No muchas instalaciones pueden mantener ese nivel de control. En cuanto a la temperatura, el estándar es 25 ° C (77 ° F) la temperatura interna de la batería. La vida de la batería se reduce a la mitad por cada 10 ° C por encima de 25 ° C. Otros factores que dependen son el ciclo de trabajo (frecuencia con la que se carga y descarga la batería), así como evitar ambientes corrosivos, entre otros.

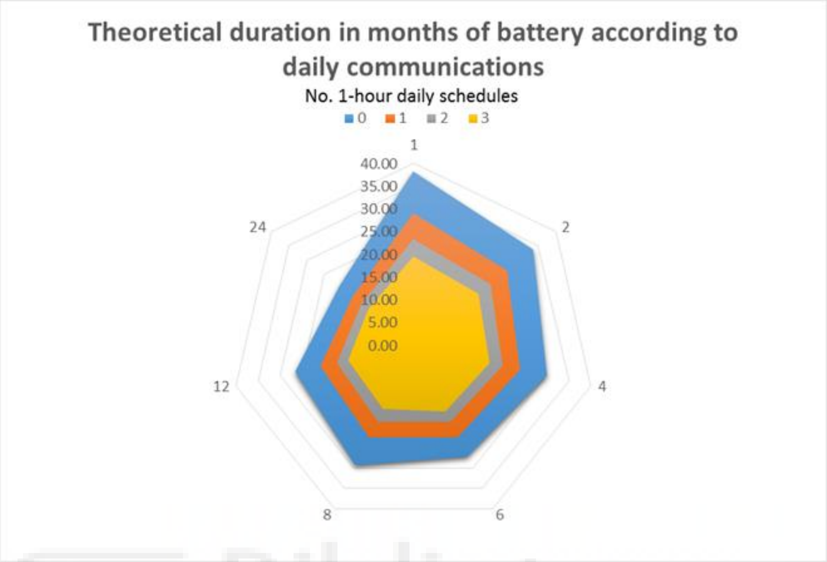


Figura 20. Duración de la incidencia de la batería según número de comunicaciones.

3.3.1.3. Espacio geofísico ocupado.

La tercera de las características que dificultan el buen funcionamiento del sistema de control remoto es el entorno natural en el que se distribuye el sector Huerta Alta. Se encuentra en la vertiente norte de Sierra Espuña, en un entorno con una orografía a tener en cuenta, en el que son habituales pendientes de más de 1/2 y donde los cultivos llegan al cauce del barranco del Cherro (Figura 21) y otros de menor entidad.

Por otro lado, se trata de un entorno altamente antropizado, que llega a la población de Pliego e incluye parcelas urbanizadas y fincas residenciales de temporada. Tanto la orografía como la existencia de construcciones en altura representan complicaciones por el uso de las radiocomunicaciones requeridas por las condiciones descritas anteriormente. Para lograr la robustez de comunicaciones deseada, fue necesario realizar un estudio de cobertura previo a la distribución de los hubs GPRS-Radio. Estas dificultades se ven potenciadas por las características de los arquetas a contener en el equipo, que son de muy reducidas dimensiones como consecuencia de la distribución monohidratante y el pequeño calibre de los elementos hidráulicos necesarios. Se trata de la emisión de radiocomunicaciones con los equipos instalados a escasos centímetros del suelo, por lo que las construcciones y elementos de poca altura pueden ser un obstáculo. Otro beneficio del sistema de redundancia es la posibilidad de mantener las comunicaciones activas incluso con la aparición de obstáculos específicos como vehículos e instalaciones temporales.

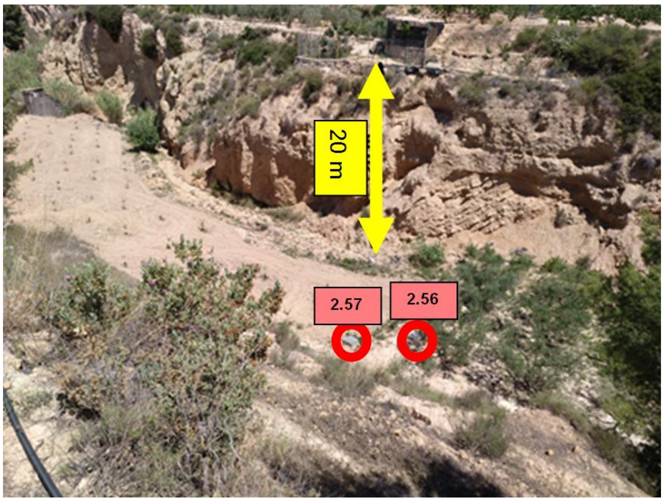
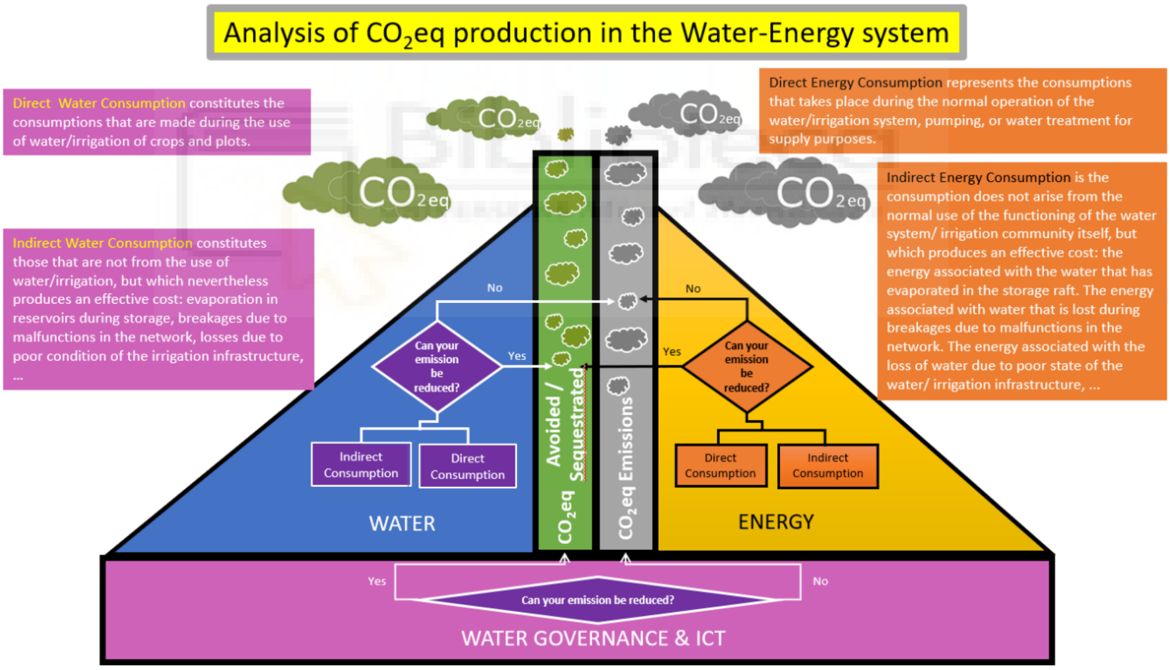


Figura 21. Cultivos en el barranco de Cherro.

Cabe agregar que, dado el espectro de banda utilizada, y la cantidad de comunicaciones requeridas por equipo. Otro aspecto a considerar para asegurar la robustez de las comunicaciones es la cantidad de equipos asociados a cada hub, los cuales tienen un canal propietario único. Para satisfacer la cantidad de información a transmitir, sin sacrificar la economía de operación y mantenimiento de la instalación, se llegó a una solución de compromiso en la que el número de terminales de radio esclavos por concentrador de radio GPRS se limitó a un máximo de 80.

3.4. En el caso del RETO 4

Para este reto se planteó la reducción de la huella de carbono en el binomio agua-energía mediante la gobernanza y las TICs. Este estudio se basa en los diferentes sistemas de auditoría energética utilizados en el este de España (Camacho, E., et al., 2017; Fernández-Pacheco, D. et al., 2015; Melián-Navarro, A. et al.,2017). A tal fin, se ha establecido un sistema que puede ser aplicable a otros sistemas de agua, que analiza las emisiones generadas, tanto evitables como no evitables. La Figura 22 muestra un diagrama que evalúa diferentes acciones en función de su relevancia y eficacia. En una primera fase, se debe examinar el sistema total de unidades de agua (sistema de riego) y evaluar el consumo de componentes de energía localizados (Daccache, A., et al., 2014), teniendo en cuenta tanto la reducción del agua como la huella de carbono. Para lograr un resultado global, la facturación de la energía ha sido estudiada en los últimos años junto con el consumo de agua por los sectores existentes. El diagrama muestra el papel de la gobernanza del agua (Figura 22, zona púrpura), que es similar a un sistema de gestión de control remoto. Debería establecerse una demanda máxima por hectárea porque no se deben plantar nuevos cultivos en determinados sectores para no colapsar el sistema. En cuanto a los problemas de agua (Figura 22, zona azul), este estudio examinó cómo sectorizar la comunidad de regantes agrupando sectores por niveles de altura manométricos similares, porque el exceso de presión puede causar fugas en los puntos de riego (Jackson, T.M., et al., 2010). Además, se estudian diferentes escenarios que son capaces de suministrar agua según la demanda mediante la combinación de diversas fuentes (es decir, pozos, transferencias, agua regenerada), sin comprometer la viabilidad. También es necesario localizar cualquier fuga para repararlas o determinar el funcionamiento anormal de los elementos hidráulicos, complementándolo con el uso de agua regenerada (Jiménez Beltrán, D. 1981), tal como lo hacen los astronautas (Grigoriev, A., et al., 2011; Nicolau, E., et al., 2014); Pickett, M.T., et al., 2020). Estos procesos se logran a través de un equilibrio energético en el que las tomas de agua y las emisiones de CO_2eq están bien establecidas. Una vez completados estos pasos, es necesario estudiar las partes del sistema que consumen energía (Figura 22, zona naranja) y generar emisiones (Rothausen, S.G., et al., 2011). El consumo de energía necesario para sustituirlas por energías renovables debe analizarse (Schilardi, C., 2019), o reducir el consumo aplicando medidas y sistemas inteligentes. Además, deben examinarse las pérdidas de agua debidas a la evaporación porque, en este caso, las pérdidas causadas son significativas y conducen a un desperdicio de energía y a emisiones evitables. Además, este estudio buscó visualizar el secuestro de CO_2eq por las plantaciones agrícolas (los pulmones artificiales del sur de Europa), (Sandoval Estrada, M., et al, 2003). Varias publicaciones han sido revisadas y utilizadas como método de cálculo, el secuestro de CO_2eq por masa verde se ha diferenciado del cultivo y el suelo dependiendo del tipo de cultivo y la superficie, así como sus emisiones durante la respiración en la fase nocturna y las emisiones producidas



Direct Water Consumption constitutes the consumptions that are made during the use of water/irrigation of crops and plots.

Indirect Water Consumption constitutes those that are not from the use of water/irrigation, but which nevertheless produces an effective cost: evaporation in reservoirs during storage, breakages due to malfunctions in the network, losses due to poor condition of the irrigation infrastructure, ...

Direct Energy Consumption represents the consumptions that takes place during the normal operation of the water/irrigation system, pumping, or water treatment for supply purposes.

Indirect Energy Consumption is the consumption does not arise from the normal use of the functioning of the water system/ irrigation community itself, but which produces an effective cost: the energy associated with the water that has evaporated in the storage raft. The energy associated with water that is lost during breakages due to malfunctions in the network. The energy associated with the loss of water due to poor state of the water/ irrigation infrastructure, ...

Figura 22. Producción de análisis de CO_2eq en un sistema agua-energía. Fuente: Elaboración propia.

Este estudio analizó el consumo mensual de todos los puntos de consumo en la Comunidad de Regantes (CCRR) en los últimos 10 años (alrededor de 216.360 registros). Estos datos se procesaron en Excel para determinar el volumen de negocios de energía para el año 2016 (considerado el año de referencia). Además, se recogieron todos los insumos y el consumo de agua durante 2016 para determinar un valor real de kWh de la energía asociada a cada m^3 de agua consumida. Con el cociente kWh/m^3 obtenido anualmente, se calcularon los valores de CO_2eq asociados con el consumo de energía, para determinar la huella de carbono generada por una CCRR. Más tarde con este valor kWh/m^3, y después de aplicar las TIC, las medidas de gobernanza y las reducciones de consumo, es posible calcular cuánta energía se desperdicia. También se calculan las emisiones de CO_2eq evitadas. Posteriormente, para mostrar los beneficios de la gestión de cultivos, se realizó un estudio sobre la evolución de los cultivos a lo largo de 10 años en los dos términos municipales asociados a esta CCRR, basando este trabajo en los estudios del CEDEX (Centro de Estudios y Experimentación y Obras Públicas en España) sobre el CO_2eq secuestrado por estos cultivos, según su especie, se determinó el CO_2eq secuestrado.

La metodología aplicada se ha incluido en varias publicaciones. Sadegh et al. en 2020 citan un aspecto general sobre la evaluación del nexo de alimentos, energía y agua. Esto se encuentra en EE.UU. Otra publicación trata sobre la determinación de la huella hídrica y la demanda primaria de sistemas de arroz en China (Xu, Q. et al, 2020). Este documento incluye el cálculo de la huella de carbono (HC), la huella de nitrógeno (HN) y la demanda de energía primaria (PED) de diferentes sistemas de producción de arroz. Otro estudio de caso se localizó en España (Chazarra-Zapata, J. Parras-Burgos, D.; et al; 2020). El estudio estaba desarrollando la reducción de la huella hídrica y el consumo de energía (en las bombas que presurizan la red, como en la optimización de la solución propuesta, mediante el uso de baterías que se comunican en baja radiación de campos alternantes eléctricos y magnéticos (LoRad), General Packet Radio Service (GPRS), o IoT de banda estrecha (NB-IoT), o energía limpia). El estudio de caso fue sobre los sistemas de riego. Algunos aspectos sobre los equilibrios energéticos y las emisiones de gases de efecto invernadero en las zonas agrícolas de China (Yan, Z.; Hou, F.; et al, 2020) se citan en otro documento. En este estudio, el objetivo era evaluar la diferencia de los cultivos y productos ganaderos con respecto a los equilibrios energéticos, las emisiones de gases de efecto invernadero (GEI), la eficiencia económica del carbono y la eficiencia del uso del agua utilizando una metodología de evaluación del ciclo de vida (LCA) en las granjas en tres subsosas dentro del Oasis Shihezi de China. Además, algunos autores de este artículo incluyeron un estudio adicional sobre la reducción de la huella de carbono en una asociación de usuarios de agua en España (Chazarra-Zapata, J.; Molina-Martínez, J.M., et al., 2020). En este caso, se analiza el uso de la generación fotovoltaica para la contribución en la reducción de las emisiones de gases de efecto invernadero (GEI). Además, se presenta la huella de agua y energía para este sistema. Estas metodologías se han incluido en el presente documento.

3.4.1. Datos de campo

La CCRR de la zona en estudio se encuentra en la Región de Murcia (España). La superficie de riego es de 799,71 ha: SECTOR I "HUERTA ALTA" (373,58 ha) y SECTOR II "HUERTA BAJA" (426,03 ha). Esta CCRR es una combinación de diferentes grupos de riego y asociaciones con más de 1.400 agricultores. Esta CCRR tiene la suerte de poder elegir tres fuentes de agua de diferentes fuentes (agua regenerada de la planta de tratamiento de aguas residuales (WWTP) en el pueblo del caso de estudio, agua del Trasvase Tajo-Segura (TST), y un pozo en la propiedad). Los costes asociados son proporcionales a la energía necesaria para bombear el agua y transportarla a las parcelas que requieren el agua y elevarla a la altura aplicable a los cultivos. La gobernanza y planificación del agua desempeña un papel fundamental en la consecución de los objetivos de análisis del ciclo de vida a largo plazo (LCA) (nuestro estudio de caso LCA puerta a puerta). Las acciones en la agricultura no son instantáneas; requieren un mediano plazo para ser eficaces y alcanzar objetivos significativos. El uso de la energía está asociado con una huella de carbono que debe reducirse para alcanzar los objetivos de desarrollo sostenible (ODS) y reducir el impacto en el medio ambiente. Además, la huella hídrica se asocia con la gobernanza del agua, ya sea reduciendo sus pérdidas mediante la mejora de las tuberías de distribución, la mejora de la gestión a través de sistemas automatizados que identifican fugas y, en última instancia, la optimización de los sistemas de riego.

3.4.1.1. Características agroclimáticas

Es importante tener en cuenta las características agroclimáticas clave de esta CCRR en relación con nuestro estudio: un clima subtropical mediterráneo cálido o semi cálido característico, con altas temperaturas durante el verano determinadas por su latitud, alcanzando valores de 32-34 ºC, escasas precipitaciones (200-300 mm por año), aunque intensas en años de inundación (por ejemplo, pueden producirse lluvias torrenciales, superando los 350 mm). Por estas razones, la capacidad de suministro de agua debe garantizarse durante los meses más secos, en los años de la mayoría de las precipitaciones.

3.4.1.2. Recursos disponibles y demanda de agua

Para determinar las verdaderas necesidades de la CCRR, se analizaron los regímenes operativos de las diferentes fuentes disponibles y se utilizó un año de referencia, que se adaptó más al consumo medio de los últimos 10 años. Estos datos (Figura 23) proporcionaban una instantánea de las necesidades por mes. Dado que estas necesidades son estacionales, (es decir, el suministro varía con los meses del año, dependiendo del clima y el estado de almacenamiento de la cuenca del Tajo), se requiere del suministro de los embalses que están en servicio y los diferentes recursos disponibles.

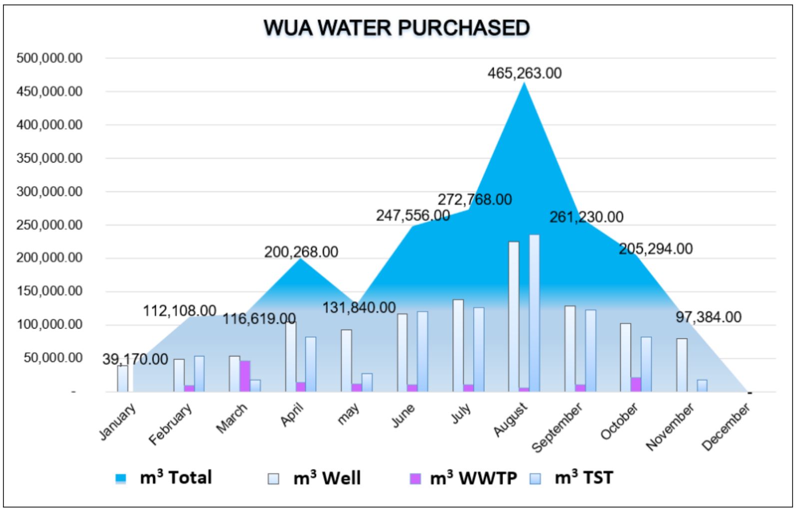


Figura 23. Agua mensual comprada, según la fuente de suministro de agua. Fuente: Elaboración propia.

La cantidad anual de agua disponible es de 3.629.361 m^3, lo que garantiza la supervivencia de los cultivos. Utilizando estos valores como punto de partida, es importante analizar y proponer acciones para comparar y cuantificar las posibles mejoras asociadas. Para ello, se debe establecer un escenario inicial, con datos específicos que se pueden evaluar más adelante. Este estudio consideró 2016 como el año de referencia.

3.4.2. Flujo equivalente de CO_2eq a la atmósfera

Si se analiza la cantidad de kWh consumido para el suministro de agua de riego, el importe total para 2016 fue de 2.032.471 kWh. Para calcular la huella de carbono generada es importante conocer la tasa de transformación de este valor. Los valores de las horquillas de los estudios investigados oscilan entre 0,0413 kgCO_2eq/kWh en un estudio realizado en Brasil según Cardozo et al. (2016)., hasta 0.947 kgCO_2eq/kWh registrados por China en los dos estudios investigados por Li Cheng et al. (2013) y Wan et al. (2012) alcanzaron un valor de 0.780, 0.608 y 0.166 kgCO_2eq/kWh en Irán (Khoshnevisan, B.; Rafiee, S. et al., 2014) y en España (Carrillo Cobo, M.; Camacho Poyato, E. et al., 2014; Nugent, D.; Sovacool, B.K., 2014), respectivamente.

Los valores utilizados en este estudio se basaron en las tasas de transformación anuales denominadas "factor de mezcla eléctrica (kgCO_2eq/kWh)", determinadas por la Comisión Nacional de Mercados y Competencia (CNMC, www.gdo.cnmc.es). Los últimos 5 años se consideraron para calcular el valor medio (Figura 24).

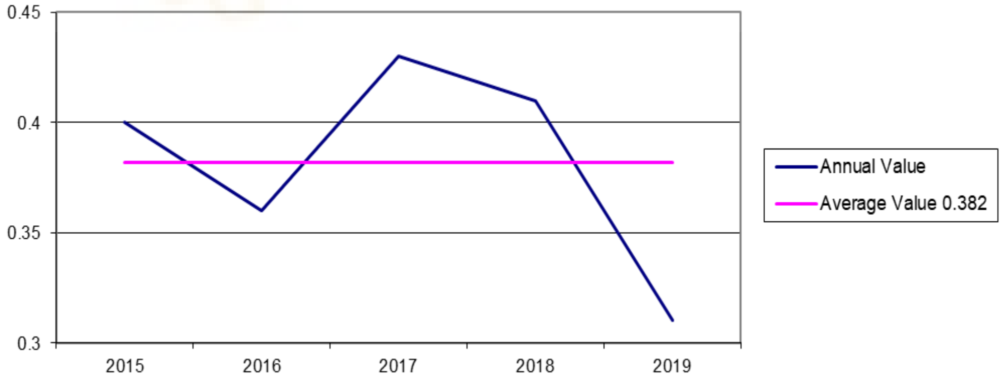
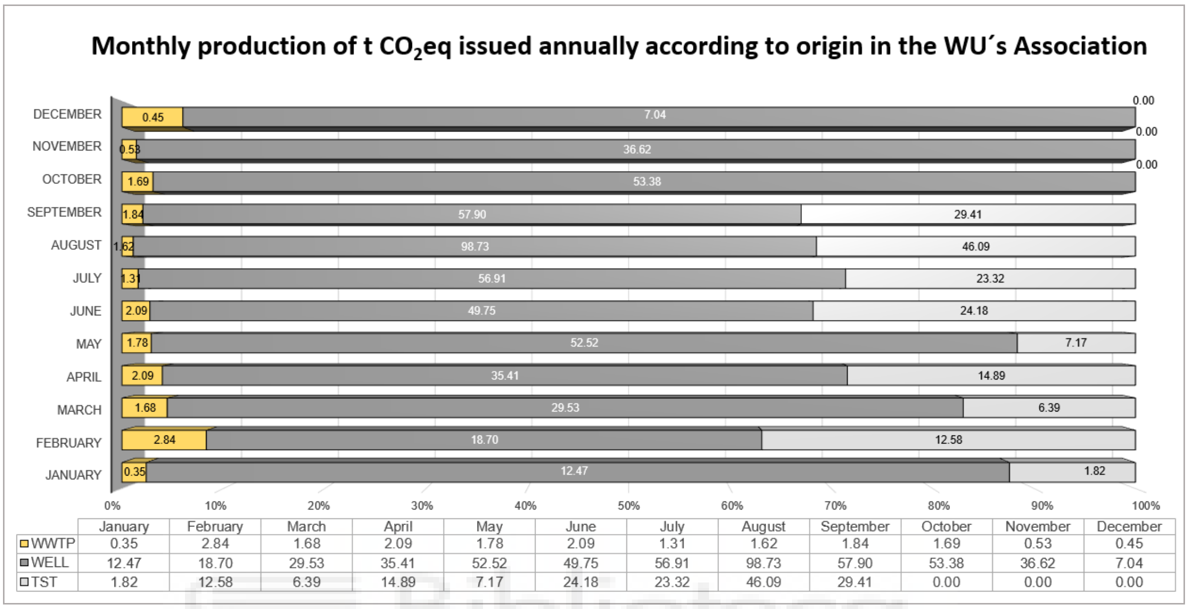


Figura 24. Evolución del índice de transformación de la energía eléctrica en España (kgCO_2eq/kWh) 2015-2019. Fuente: Elaboración propia, basada en datos oficiales de la CNMC (España) (www.gdo.cnmc.es).

En el caso de la energía eléctrica, la tasa de transformación varió entre 0,041 y 0,947 kgCO_2eq/kWh, debido a la mezcla de generación utilizada en cada área de estudio. Este ha sido un factor clave en el cálculo de las emisiones de gases de efecto invernadero (GEI) de la gestión del agua en el riego, y por lo tanto es importante profundizar este aspecto, analizando y considerando las variaciones en la tasa de transformación de la electricidad, para calcular con mayor precisión las emisiones de GEI generadas.

En total, 74 gCO_2eq/kWh se dedujo del coste de emisiones implicados en la generación e instalación de placas fotovoltaicas según datos obtenidos del Cuadro 8 (Nugent, D.; Sovacool, B.K., 2014), dando como resultado el 0,308 kgCO_2eq/kWh de este estudio que se ajusta a los valores expuestos anteriormente (teniendo en cuenta la relación: 1 kWh corresponde a 0,308 kg de CO_2eq) equivalía a un importe total de 626 t de CO_2eq (Figura 25).



	January	February	March	April	May	June	July	August	September	October	November	December
▨WWTP	0.35	2.84	1.68	2.09	1.78	2.09	1.31	1.62	1.84	1.69	0.53	0.45
▨WELL	12.47	18.70	29.53	35.41	52.52	49.75	56.91	98.73	57.90	53.38	36.62	7.04
☐TST	1.82	12.58	6.39	14.89	7.17	24.18	23.32	46.09	29.41	0.00	0.00	0.00

Figura 25. % t de flujo de CO2eq a la atmósfera. 2016. Fuente: Elaboración propia.

3.4.3. Medidas a adoptar para la reducción de la huella de carbono

Después de analizar el sistema, las decisiones enmarcadas deben aplicarse dentro del ámbito de la gobernanza del agua, con el fin de eliminar cualquier limitación del sistema y mejorar su explotación aprovechando los recursos disponibles y considerando los puntos débiles. Éstos podrían referirse a los embalses donde la explotación no contribuye significativamente al sistema y conduce a la pérdida de agua a través de la evaporación. Para aprovechar la superficie, se podrían introducir plantas fotovoltaicas (u otras plantas viables) para generar energías limpias.

3.4.3.1. Minimización de la energía

Los objetivos de la propuesta del Parlamento Europeo sobre el clima respaldaron el objetivo de la UE de alcanzar las emisiones netas de gases de efecto invernadero para 2050 en su resolución de 14 de marzo de 2019 sobre el cambio climático 4 ((EU) 2018/1999 (European Climate Law)). Es necesario actuar sobre las fuentes de consumo de energía de la CCRR. Después de analizar las facturas relevantes, los puntos de mayor consumo son los sistemas de bomba de captación, en este caso hay tres (Figura 26).

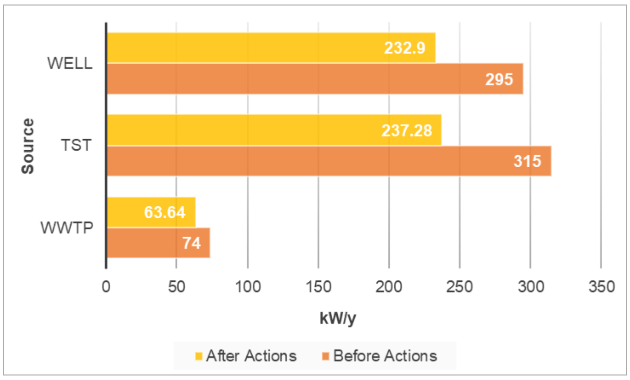


Figura 26. Consumo anual por fuente (kW). Fuente: Elaboración propia.

El primer objetivo para reducir las emisiones de gases de efecto invernadero fue mejorar la eficiencia de la elevación del agua. Por esta razón, se llevó a cabo un estudio del estado de funcionamiento de las bombas, comparándolo con los requisitos óptimos del equipo para su uso en condiciones reales. Esto reveló que todas las bombas debían ser reemplazadas y que se requerían inversores de frecuencia (Tabla 3). El segundo objetivo era sustituir el uso de energía convencional por energía renovable. Esto permite la reducción del consumo, junto con las emisiones asociadas.

Tabla 3. Comparación de potencia del equipo de bombeo. Fuente: Elaboración propia

	Current Pump	Future Pump
	Power (kW)	Power (kW)
Well	295	232,9
TST	315	237,28
WWTP	74	63,64

3.4.3.2. Análisis de las tecnologías disponibles

Después de un análisis detallado de las diferentes tecnologías disponibles, la generación fotovoltaica se identificó como la opción óptima. Esto se debió a la madurez de la tecnología, la disponibilidad de zonas, la irradiación elevada en la zona y la proximidad entre las zonas de generación y consumo. Otras opciones consideradas y rechazadas fueron:

- Energía eólica: después del examen y según los mapas eólicos, la conclusión principal fue que la potencia disponible insuficiente. Sería necesario complementar el mismo con otras fuentes de energía alternativas y seguras, para evitar períodos sin suministro de energía.

- Energía del agua: el diseño de la red de riego aprovecha las sobrepresiones existentes en varios puntos del sistema para generar energía eléctrica. Tras un estudio técnico, se evaluó la incorporación de esta tecnología. La solución fue la incorporación de dos micro turbinas conectadas a las válvulas de reducción de presión existentes. Además, las potencias instaladas eran de 10 y 7,5 kW. Esta opción se descartó debido a la baja potencia disponible. Además, la gran distancia entre la generación de energía y el consumo más cercano (casi tres kms de distancia al sistema de filtrado) puede generar pérdidas importantes debido a la energía utilizada durante el transporte.

3.4.4. Sistema solar fotovoltaico

Para calcular la energía generada en cada uno de los sistemas fotovoltaicos, se utilizó la base de datos del Mecanismo de Aplicación por Satélite sobre El Seguimiento del Clima (CM SAF) perteneciente a la Organización Europea para la Explotación de Satélites Meteorológicos, y como herramienta de cálculo, se utilizó el PVGIS (Sistema de Información Geográfica Fotovoltaica) (Šúri, M.; Huld, T.A.; et al. 2007), (Rosas-Flores, J.A.; Zenón-Olvera, et al. 2019) y PVWatts (Huld, T.; Müller, R.; Gambardella, A., 2012) proporcionó bases de datos de radiación solar en la web para calcular el potencial fotovoltaico en varios países. Este software utiliza todos los valores climáticos (irradiación, temperatura, entre otros) y valores geográficos de la zona. Esto permite obtener la energía generada por cada una de las plantas fotovoltaicas. Para diseñar el sistema, se consideró la separación entre filas y módulos y la inclinación óptima de los paneles en función de la latitud.

El sistema está diseñado para utilizar depósitos de acumulación para satisfacer las demandas instantáneas, evitando así el uso de baterías que deben renovarse y, en última instancia, generar una huella de carbono durante la producción y posterior eliminación. El bombeo se alimentará desde el campo fotovoltaico, programando los inversores de acuerdo con los niveles en los depósitos existentes y el nivel de producción requerido.

Las plantas fotovoltaicas se calcularon utilizando el software PVGIS de la base de datos CM SAF, obteniendo la producción diaria y anual de electricidad suministrada por cada una de las plantas calculadas (Psiloglou, B., 2020) (véase la Tabla 4). La optimización de los paneles solares fue diseñada teniendo en cuenta su posición, inclinación y orientación.

Tabla 4. Resumen del cálculo de las instalaciones solares fotovoltaicas.

Photovoltaic installation	Projected power (kW)	Annual generated energy (kWh)	Units of 250 Wp, c/u
Pumping Well	232,9	543,200	1,400
Pumping TST	237,3	360,971	1,400
Pumping WWTP	63,64	108,640	280,000

Es importante tener en cuenta que los períodos de funcionamiento mensual de la bomba deben adaptarse a la curva de generación mensual de una instalación fotovoltaica, redistribuyendo el consumo máximo en los meses consecutivos y aprovechando la existencia de depósitos para la regulación y la cuota que funciona como sistemas para la acumulación de energía potencial, por lo tanto, se ignora la instalación de baterías de condensadores , lo que equivale a un ahorro significativo para aumentar la eficiencia de las instalaciones solares (Figura 27).

Figura 27. Instalaciones de Embalses y Solares. Fuente: Propio.

3.4.5. Huella de agua

Una vez calculadas las acciones del componente eléctrico del sistema, se debe estudiar el valor de la huella hídrica, analizando los balances del agua comprada para riego y el coste real de la misma para los agricultores (Figura 28). La diferencia es igual a las pérdidas en el sistema y se ajusta a la huella hídrica, dividida de la siguiente manera: (1) las pérdidas debidas a la evaporación durante el almacenamiento en los depósitos y (2) las pérdidas debidas al estado de la red hidráulica.

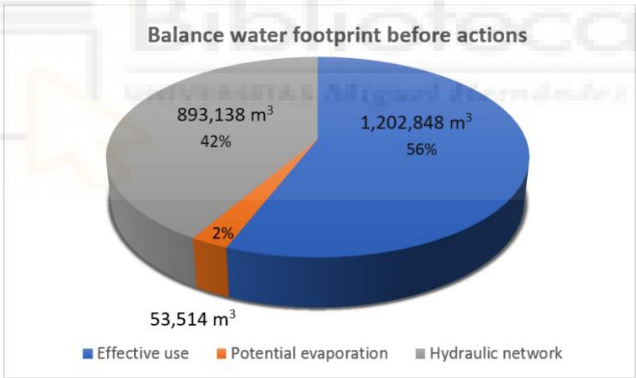


Figura 28. Balance de la huella hídrica antes de las acciones. Fuente: Elaboración propia.

3.4.5.1. Reducción directa del consumo por gobernanza

Después de evaluar estas pérdidas, se pueden tomar varias medidas para reducir la huella hídrica. En primer lugar, se analiza el sistema, sobre la base de los principios de la gobernanza eficiente del agua (véase el área azul del diagrama, Figura 1). Para ello, se debe avisar a los agricultores en relación con los cultivos admisibles, así como las dotaciones máximas por parcela, y los cambios establecidos que están vinculados a las alturas manométricas de las parcelas en ambos sectores. Para que esto sea viable, es necesario utilizar las TIC que nos proporcionan información en tiempo real, como permitir la posibilidad de cambiar los programas de riego en función de los datos proporcionados por las estaciones meteorológicas (ver cita de artículos), o el ajuste del agua suministrada a la parcela, aplicando los datos del lisímetro de pesaje (ver referencia) (se puede añadir el tobogán de audio del funcionamiento del lisímetro de pesaje), y completando esto con la información proporcionada por los sensores de humedad del suelo (ver cita del artículo) (Figura 29).

Figura 29. TIC utilizadas en esta CCRR. Fuente: Propia.

También es posible programar el riego para que se detenga si ciertos valores de humedad están delimitados en el terreno. Todas estas acciones conducen a un ahorro en cuanto al consumo directo de agua (que, en nuestro caso, equivalía aproximadamente entre el cinco y el 10% del agua consumida real). Este ahorro se cuantifica por no desperdiciar agua que no beneficie al cultivo. A su vez, esto conduce a una pérdida de energía indirecta asociada con el agua, que requiere energía del sistema para extraer, distribuir y utilizar el agua en una parcela, aunque con la presión mínima, para que los sistemas de riego localizados funcionen (ver cita de artículo). Además, es importante evaluar y cuantificar el efecto sobre la huella de carbono. La eficiencia en la aplicación representa el agua que utilizan los cultivos, en comparación con la aplicada a la parcela. Esto dependerá del sistema de riego utilizado y de las pérdidas causadas por la percolación profunda, la escorrentía y la falta de uniformidad. La evaluación se llevó a cabo para toda la comunidad de regantes, estableciendo la media ponderada, sobre la base de la distribución proporcional de los sistemas de riego utilizados por la superficie, y considerando los siguientes valores (Tabla 5) (Valores obtenidos de las eficiencias en las zonas de regadío consideradas en ORDER ARM / 2656/2008, de 10 de septiembre, aprobando la planificación hidrológica de la instrucción (BOE-A-2008-15340).

Tabla 5. Eficiencia del uso del agua según el tipo de Sistema de Riego. Fuente: Ministerio de Medio Ambiente y Asuntos Rurales y Marinos (España).

Type of irrigation system value	% of efficiency
Irrigation by surface with total coverage (blanket), with good management	60
Irrigation by surface with partial coverage (by furrows), with good management	60-90
Irrigation by sprinkling, with good management	80
Irrigation by dripping on the surface, with good management	90
Irrigation by underground drip, with good management	95

La red actual cuenta con un sistema de riego superficial con cobertura total (riego a manta) de las dotaciones de zanjas. Esto proporciona un valor de eficiencia en la aplicación del 60% o, en algunos casos, con riego por goteo en la superficie y una buena gestión la eficiencia se establece en el 90%. Esto significa que la reducción por consumo indirecto equivale a, al menos el 35% del agua realmente consumida (1.020.848,10 m^3).

3.4.5.2. Reducción Indirecta del Consumo (RIC)

La reducción de la huella hídrica por pérdidas por consumo directo se ha diferenciado en dos secciones:

· RIC por potencial de evaporación: pérdidas debidas a la evaporación en la superficie de los estanques durante el almacenamiento (estos representan las pérdidas asociadas con el aislamiento recibido por las superficies de láminas de agua de los estanques y cuyo valor se ha estimado en 0,5 m^3/m^2) (Molina-Martínez, J.M. et al, 2006). Para estimar esto, las pérdidas iniciales deben evaluarse primero con las balsas disponibles antes de aplicar las acciones reductivas. Después de aplicar estas acciones, se calculan las nuevas superficies expuestas. Las balsas y otras dos han sido cubiertas con una lámina de polipropileno TPO reforzada con malla de poliéster en su interior, que se estima que se reduce en un 95%. Con la diferencia en el volumen de agua evaporada WeBA 53,514 m^3 antes y después de las acciones correctivas WeAA a 27.492 m^3, la huella hídrica que se genera se ha cuantificado, obteniendo un valor de WeR 26.022 m^3 que representa el volumen de agua que se ahorra anualmente cubriendo balsas y la reducción de la superficie expuesta a la insolación, eliminando dos de las balsas y transformándolas en plantas fotovoltaicas (Tabla 6).
RIC para mejoras de agua: la nueva mejora introducida en el sistema como la duplicación de las tuberías permitió una explotación más adecuada y la distribución en conductos abiertos se ha eliminado frente a tuberías presurizadas mientras que se han instalado sistemas de control remoto con válvulas solenoides controladas. Los solenoides y contadores en el cabezal de riego permiten un equilibrio de entradas y salidas de agua que ayuda a aclarar qué sectores y redes sufren de pérdida de agua, y requieren reparación.

Tabla 6. Resumen de evaporación potencial de agua.

By evaporation reduction								
				Before actions (W_{eBA})		After actions (W_{eAA})		
	Surface (m^2)	Volume (m^3)	Manometric eight (m.c.a.)	Annual Evaporation m^3 ($0.5\ m^3/m^2$)	Source	Annual Evaporation m^3	Source	Actions
Raft 1 “Cota” San Quintin Well	7,534	45,000	440	3,767	Well	75	Well, TST, WWTP	
Raft 2 Anguilas Cherro 1	7,667	24,000	415	3,834	Well, TST	-		Solar sector 1
Raft 3 Anguilas Cherro 2	6,731	26,400	410	3,366	Well, TST	-		Solar Well
Raft 4 Regulation Huerta Baja	30,878	237,675	411	15,439	Well, TST	309	Well, TST, WWTP	
Raft 5 Regulation Huerta Alta	45,929	317,380	413.55	22,965	Well, TST	22,965	Well, TST, WWTP	
Raft 6 La Esperanza	5,761	12,000	424	-		-		Eliminated
Raft 7 WWTP Pliego	8,285	39,464	372	4,143	WWTP	4,143	Well, TST	
TOTAL POTENTIAL WATER EVAPORATION					**53,514**			**27,492**

Este tipo de mejora reduce el volumen total de pérdidas (VIs 946.651,90 m^3) en aproximadamente un 30%, lo que a su vez reduce la huella hídrica para la mejora del agua del sistema (VIsR a 283.995,57 m^3). Por último, el valor de la reducción de la huella hídrica se basa en la reducción por consumo directo (por gobernanza y TIC) y el consumo indirecto (por evaporación y por acciones hidráulicas) (Figura 30), que equivale a una cantidad total de 731.014,41 m^3, desglosado según el resumen que figura en la Tabla 7.

Figura 30. Lámina impermeable en el depósito para reducir la evaporación. Fuente: Propio.

Tabla 7. Resumen de la reducción de la huella hídrica después de las acciones. Fuente: Elaboración propia.

Origin of the consumption		**Water footprint reduction after actions (m^3)**
Direct consumption	By governance & ITC	420,996.84
Indirect consumption	By evaporation	26,022.00
	By hydraulic actions	283,995.57
	TOTAL	**731,014.41 m^3**

4. RESULTADOS Y DISCUSIÓN

A continuación, se exponen los resultados obtenidos de los distintos RETOS que han conformado esta Tesis.

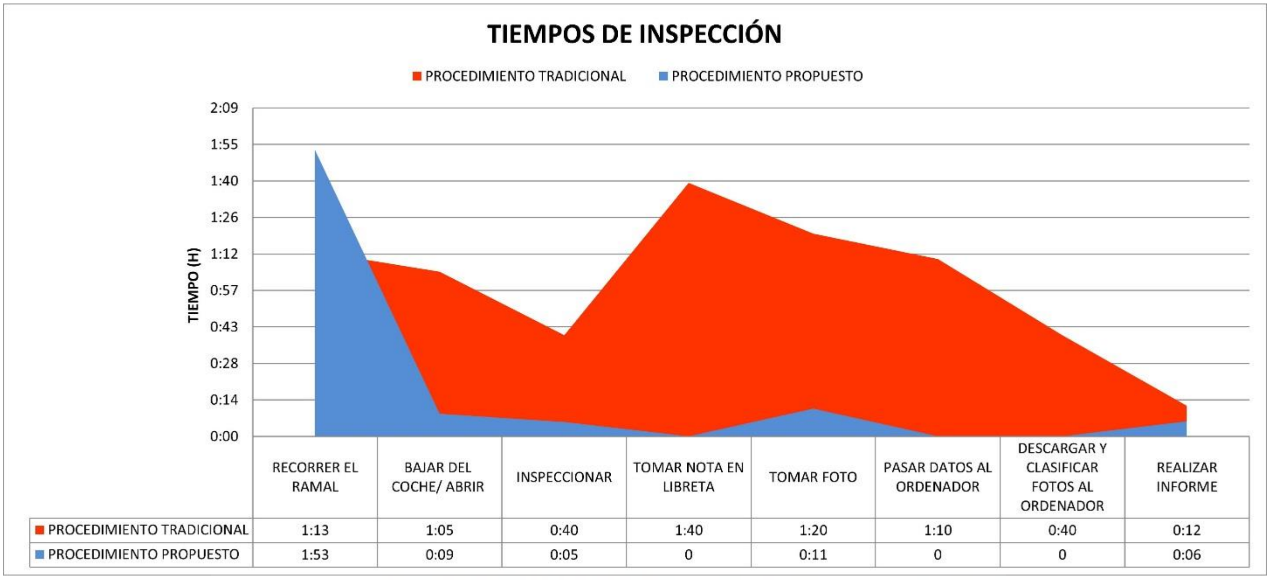
4.1. Primer RETO

En el caso del **primer Reto**, los resultados del uso de balizas BLE emparejada simultáneamente con una aplicación móvil, proporciona la ventaja de facilitar las tareas de inspección y control, permitiendo al operador recibir automáticamente en su dispositivo móvil la información relevante, para cada indicador al acercarse a él. Ello permite el telemando para la gestión y detección de averías de las redes de distribución de agua colectiva en instalaciones de riego. Todo esto sin tener que hacer inspección in situ. Eso hace que se elimine la necesidad de inspeccionar y registrar manualmente los datos de los paneles de información, o la obligación de tener que conectarse físicamente a un instrumento, minimizando los errores y acelerando la toma de datos. En algunos casos, esto evita de hecho la necesidad de entrar en los diversos espacios alrededor de la instalación. Además, el operador ha de presentar ahora un informe parcialmente complementario donde los formularios y diagramas se personalizan para la instalación en la que se encuentra, simplificando las tareas y la comprensión del sistema. En la *Tabla 8* muestra las mejoras del procedimiento propuesto, en comparación con el procedimiento tradicional.

Tabla 8. Diferencias entre los procedimientos convencionales y los propuestos.

Procedimiento	**Convencional**	**Propuesta**
Revisión de instalaciones y equipos	√ Redacción manual de datos	√ Escritura de datos asistido
	√ Posibilidad de perder información en soporte en papel	√ Soporte digital
	√ No hay confirmación automática del ID de identificación del equipo.	√ Detección automática del equipo correcto. Fotos y/o diagramas proporcionados √ Proceso de evaluación simplificado
		√ informe mejorado: comentarios, fotos.
Adquisición de datos	√ Manual	√ automatizado
	√ Formato de papel	√ formato digital
	√ difícil acceso	√ No es necesario acercarse al equipo
Preparación del informe	√ Informes semanales, dibujado manualmente	√ Informes digitales instantáneos
	√ Formato papel, tediosas y laboriosa	√ Información histórica de fácil acceso
	√ Propensos a errores o pérdidas de información	√ Datos almacenados localmente y sincronizados con la nube
		√ Sin errores ni pérdidas de información

La Figura 31, muestra el tiempo invertido en cada tarea durante una jornada laboral típica de 8 horas, mientras que inspecciona 20 instalaciones en una ruta de 25 km, para el procedimiento tradicional frente al propuesto.



	RECORRER EL RAMAL	BAJAR DEL COCHE/ ABRIR	INSPECCIONAR	TOMAR NOTA EN LIBRETA	TOMAR FOTO	PASAR DATOS AL ORDENADOR	DESCARGAR Y CLASIFICAR FOTOS AL ORDENADOR	REALIZAR INFORME
🟥 PROCEDIMIENTO TRADICIONAL	1:13	1:05	0:40	1:40	1:20	1:10	0:40	0:12
🟦 PROCEDIMIENTO PROPUESTO	1:53	0:09	0:05	0	0:11	0	0	0:06

Figura 31. Tiempos de inspección detallados por tarea individual para los procedimientos tradicionales frente a los propuestos. Se obtuvieron datos para una ruta que incluye 20 instalaciones que duraron unas 8 h.

Aunque los datos se han obtenido de nuestros primeros experimentos en un banco de pruebas controlado, y aún no abarcan una muestra estadísticamente representativa, se puede deducir que los tiempos de inspección podrían reducirse considerablemente, (a un 30% en este ejemplo, o aproximadamente dos horas y media) utilizando la plataforma y el procedimiento propuesto. El ahorro de tiempo proviene del que se dedicaba a algunas tareas, (como inspeccionar y anotar), y de la eliminación de otras, (como introducir los datos del informe y las fotos en el equipo).

4.2. Segundo RETO

En el **segundo Reto**, tras estudiar consumos energéticos de las tres fuentes principales de consumo en nuestra CCRR, y evaluar para este caso concreto el uso de distintas fuentes de energía renovables, finalmente se opta por diseñar tres plantas fotovoltaicas (Figura 32). Se observa que, entre 7 y 11 años, el precio unitario de la energía eléctrica consumida comienza a ser mayor que el precio unitario de la energía auto consumida (incluyendo el costo de instalación, mantenimiento, y rendimiento anual estimado de los paneles solares) según la instalación.

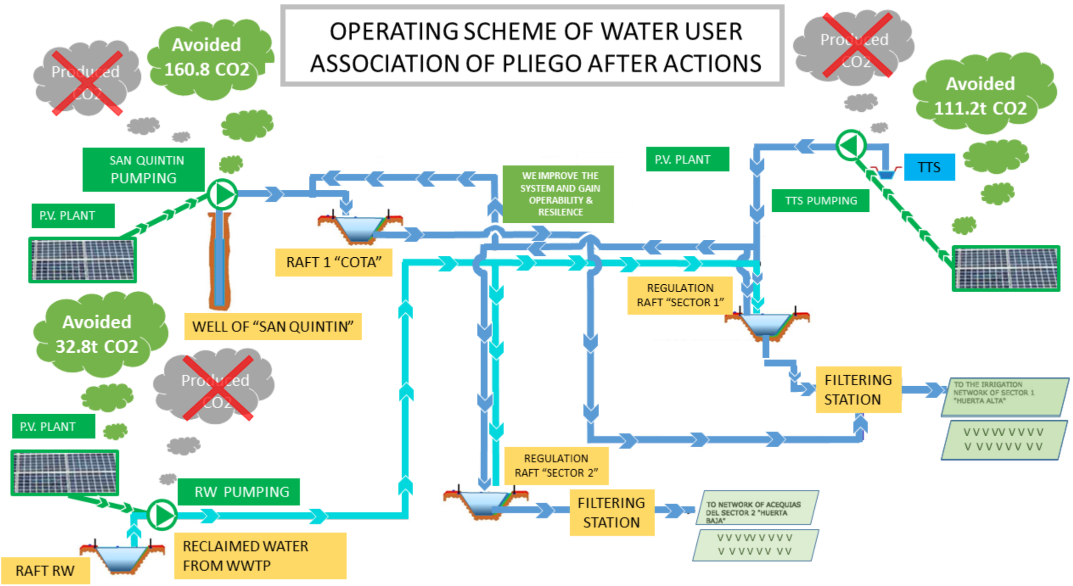


Figura 32. Nuevo esquema operativo CCRR.

Esto sirve para que se produzca una mejora en el balance de la producción de gases de efecto invernadero.

4.3. Tercer RETO

En el **tercer Reto**, han sido barajados distintos sistemas de comunicación que pudieran dar respuestas a los siguientes apartados:

- Integración de comunicaciones en banda libre de última generación.
- Concentradores mixtos GPRS / Radio.
- Facilidad de implementación y mantenimiento.
- Detección de flujo y generación de alertas (ver Figura 33).

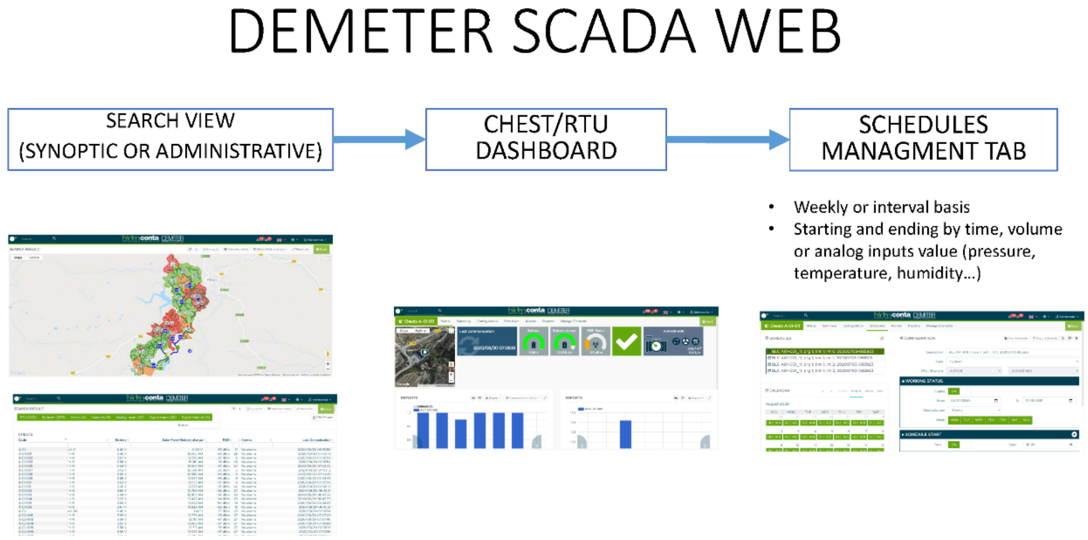


Figura 33. Flujo Demeter Scada Web.

- Eliminación de grandes infraestructuras propias.

Todo ello teniendo en consideración un estudio económico que ha dado respaldo a esta investigación.

4.4. Cuarto RETO

El **cuarto Reto**, analiza y valora las distintas acciones que se dan en un caso de estudio de una CCRR, que generan o disminuyen las emisiones de CO_2, cuantificando para cada caso concreto los valores utilizados.

- Reducción de la huella de carbono asociada a la huella hídrica. En este estudio, utilizando datos de las facturas de electricidad, se ha calculado el consumo total de energía por origen. Gracias a estos datos financieros, también se ha determinado el volumen total de agua que se ha movido dentro del sistema. Esto aclara la huella de carbono que genera la huella hídrica necesaria, para obtener una relación kWh/m^3 (IE-W). Esta relación cambiará anualmente y, si hay un seguimiento adecuado de los movimientos del agua cuando está en funcionamiento, la escala de telecontrol se puede determinar con mayor precisión y valor.

  Además, se utiliza el valor medio de las tres proporciones según el origen y se divide, por el agua total comprada. El valor final obtenido fue (IE-W) 0,62 kWh/m^3 y, teniendo en cuenta que el volumen de agua reducido por la huella hídrica es de 731.014,41 m^3. Por tanto, se obtiene una reducción de las emisiones de CO_2eq (0,382 $kgCO_2eq$/kWh), equivalente a 139 t de CO_2eq/a. (Figura 34). Cabe señalar que, para este estudio, sólo se han considerado las emisiones asociadas con el consumo de energía y la manipulación de agua para el riego. En realidad, este valor es superior porque la reducción del agua en la huella hídrica está asociada con un menor consumo de fertilizantes. Ello aumentaría este valor en aproximadamente un tercio.

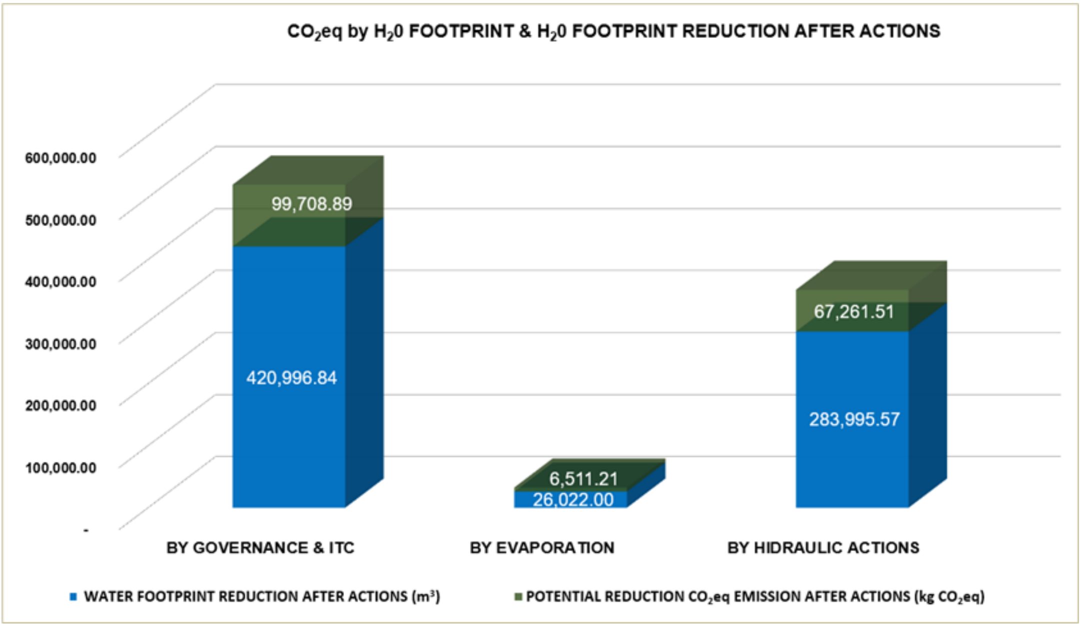


Figura 34. Reducción de CO_2eq por huella hídrica después de acciones. Fuente: Elaboración propia.

- Secuestro de CO_2eq por cultivos. Dado que el propósito de una CCRR es la producción de alimentos basados en cultivos, se buscó determinar la cantidad de CO2eq secuestrado por esta comunidad de agricultores. En consecuencia, este trabajo se ha basado en el estudio de la tipología de los cultivos y variedades de riego existentes en la zona, así como su evolución en los últimos 10 años, tanto en el municipio de Pliego, como en el municipio de Mula.

  Se ha extraído la información del Anexo 6 para el informe agronómico del "Proyecto de adaptación del Sector I "Huerta Alta" de la comunidad de regantes de Pliego (Murcia, España). Este estudio muestra la ligera regresión de las tierras de regadío cultivadas en el municipio de Pliego, así como la baja diversificación de los cultivos existentes.

  Sobre la base de estos datos, se ha estimado la distribución de las unidades de cultivo por superficie diferente de la planta, y de las tierras de cultivo. Aparte, se han aplicado los valores anuales de carbono secuestrados de acuerdo con el estudio de Carvajal *et al.* (2014), para el carbono acumulado en la planta.

  Estos valores han descontado el CO_2eq generado durante la existencia de la planta, ya que la mitad del día es dedicada a purificar CO_2eq de día, transformándolo en carbono, emitiendo un tercio aproximado de CO_2eq por la noche (Zermeño-González, A, et al. 2012). A los efectos de las tierras de cultivo se considera el carbono más que acumulado en la tierra (aprox. 6% del total de secuestrados) y toma como valor de referencia el contenido en la publicación de Visconti et al. (2017). Como se muestra en la reducción anual de CO_2eq para los cultivos de una CCRR, el valor es alto (Tabla 9), con 7.007 t de CO_2eq secuestrada de la atmósfera

Tabla 9. Resumen de la huella del secuestro de CO_2eq por cultivos.

Cultivation	**Surface (%)**	**Surface area (ha)**	Annual Estimate sequestrated kgCO_2eq/ha		Annual Estimate of emissions kgCO_2eq/ha		Captured tCO_2eq/y	Emission tCO_2eq/y	**Sequestrated t CO_2eq**
			plant	field	plant	field			
Citric trees	25	199.90							**1,696**
Lemon	19	151.93	16,040	590	4,812	520	2,527	810	1,717
Orange half session	2	15.99	9,869	565	2,961	515	167	56	111
Orange total session	4	31.98	6,220	565	1,866	515	217	76	141
Fruit trees	71	567.73	-						**4,940**
Apricot tree	16	127.94	8,450	825	2,535	740	1,187	419	768
Peach tree	37	295.86	14,463	835	4,339	740	4,526	1,503	3,023
Almond tree	18	143.93	11,356	475	3,407	445	1,703	554	1,149
Vegetables	4	31.98	-						**98**
Lettuces and similar	4	31.98	4,225	830	1,268	735	162	64	98
TOTAL	100	799.61							**7,007**

- Balance total de CO_2eq del binomio agua-energía en una CCRR

  El equilibrio total del sistema agua-energía nos proporciona muchos beneficios, como se muestra en la Figura 35.

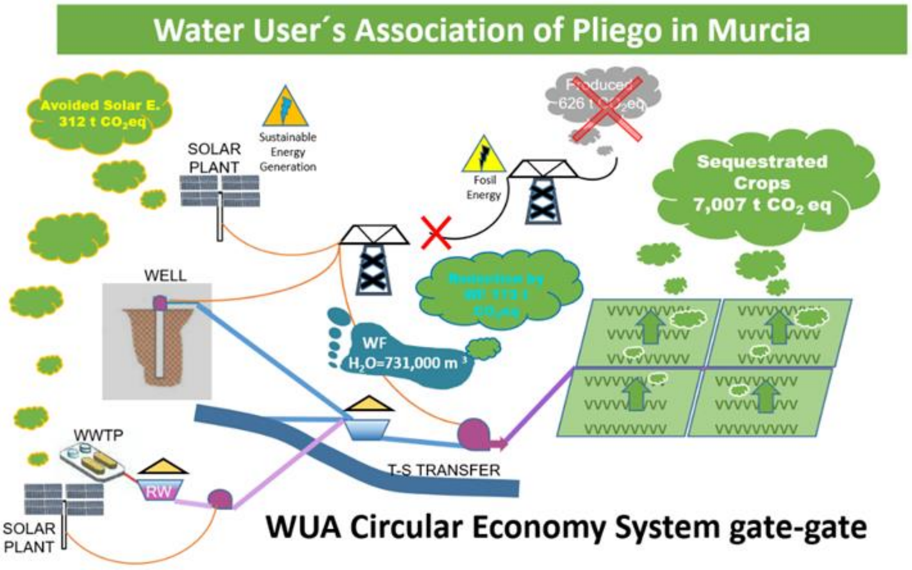


Figura 35. Resumen de los efectos ambientales generados en la CCRR.

Se han tenido en cuenta que se producen ahorros en las emisiones anuales de CO_2eq, después de la implementación de estas tres instalaciones fotovoltaicas, de la siguiente manera:

- 111,18 t CO_2eq para el bombeo TST.
- 167,31 t CO_2eq para bombear Pozo.
- 33,46 t de CO_2eq para bombear EDAR.

Estas tres acciones mejoran significativamente la capacidad energética de la CCRR, y reducirán los costes anuales de mantenimiento, una vez que se haya alcanzado el punto de equilibrio para la instalación. Además de estar totalmente desvinculados al factor de tasa eléctrica, también es importante destacar la reducción de la huella hídrica (731.014,41 m^3) que contribuye a reducir las emisiones de CO_2eq en 173 t al año. Sin embargo, la pieza clave para la agricultura en Murcia, es que el sumidero de CO_2eq debe conservarse y reducirse, en este caso, hasta 7.492,08 t de CO_2eq al año. A juicio de los autores, es una magnífica contribución al medio ambiente (Figura 36).

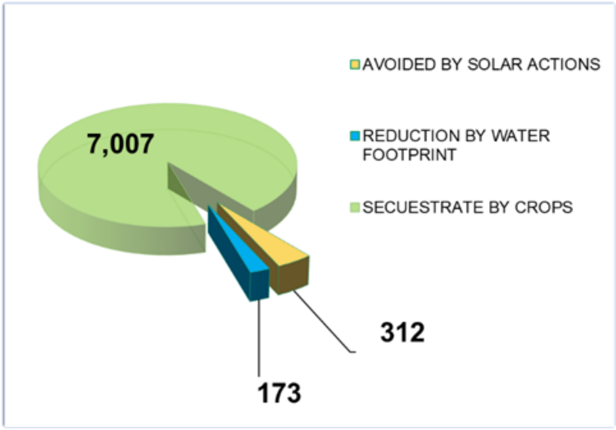


Figura 36. Resumen de la nueva reducción futura t CO_2eq/a después de las acciones. Fuente: Elaboración propia.

5. CONCLUSIONES

Los trabajos desarrollados durante la elaboración de esta Tesis Doctoral han permitido obtener las siguientes **conclusiones generales**:

La relación del binomio agua-energía en sistemas hídricos, nos ayudan a optimizar ambos sistemas dentro del marco los **Objetivos de Desarrollo Sostenible** (ODS) de la **Agenda 2030** de las Naciones Unidas, en especial del **eje prosperidad**. **Objetivos 7, 8, 9, 10, 11**. Así como los **ODS 2, 3, 5, 6, 12, 13, 15 y 17** cuya consecución provocan sinergias para dichos objetivos.

a) La agricultura que mantiene los bosques de frutales y plantaciones de hortalizas nos permite a la par alimentarnos y respirar un aire más puro (**ODS -11**). También evita el abandono de la tierra cultivable, y se traduce en una redistribución socioeconómica que, gracias a la gobernanza de las distintas administraciones, (**Reto 4**) que deben planificar la disponibilidad de recursos de forma sostenible (**ODS 12**). Siendo replicable a países en vías de desarrollo y les permita mejorar en comunidad (**ODS-10**), reduciendo la desigualdad entre los países.

b) Las asignaciones de dotaciones para cultivos y las TICs que promueven la innovación de dispositivos (**ODS-9**)**,** para mejorar la gestión del agua en la agricultura (**Reto 1 y 3**), que optimizan la gestión y el control de dichos recursos (**ODS-6**), ofrecen un nicho de mercado para las mujeres (**ODS-5**). Su papel como gestoras de explotaciones agrícolas tecnificadas están mostrando su potencial y futuro recorrido (**ODS-10**).

c) Cabe señalar que, en las zonas semiáridas del Mediterráneo, no sólo debemos considerar las explotaciones agrícolas como el principal medio de producción, sino también debemos tener en cuenta, que esta investigación orienta a las regiones agrícolas a construir y diseñar infraestructuras de riego que sean resilientes (**ODS-8**)**,** así como un método ecológico de protección contra el cambio climático (**Reto 2**) y en particular contra la desertificación **ODS-13**, (**Reto 4**).

d) Esta Tesis también, busca colaborar para cumplir los objetivos de la política europea dentro del Marco de Clima y Energía para 2030:
   - Reducción de al menos un 40% de las emisiones de gases de efecto invernadero (en relación con los niveles de 1990) (**Reto 1, 2, 3 y 4**).
   - Aumentar al menos un 32% de la participación de las energías renovables (**Reto 2**).
   - Mejorar la eficiencia energética en al menos un 32.5% (**Reto 1,2,3 y 4)**.

e) Al mismo tiempo, contribuimos al cumplimiento de los **ODS-7** Objetivos de energía limpia y asequible (**Reto 2**), **ODS-13** acción climática (**Reto 2, 3, 4**) y **ODS-15** vida y tierra (**Reto 3 y 4**).

Es mi deseo, que esta investigación contribuya a promover el crecimiento económico sostenido inclusivo y sostenible, consiguiendo reducir los GEI mediante el uso de energías renovables (**ODS-7-8**) mediante la construcción de infraestructuras resilientes, promoviendo la innovación (**ODS-9**).

También promueve la mejora de la calidad de vida de la sociedad, logrando que las ciudades y regiones del entorno rural sean más inclusivas seguras, resilientes y sostenibles **ODS-11**. Por otro lado, la publicación de los artículos en open access promueve la difusión de las lecciones aprendidas de estos casos de estudio, mejorando el traspaso de tecnología a otras regiones (**ODS-17**) y aportan, oportunidades para conseguir que en sitios con posibilidad de producción agrícola puedan aplicar energías limpias (**ODS 3**) que proporcionen agua presurizada que les permita cultivar mayor superficie de tierras laborables y reduzca el hambre en lugares con falta de recursos (**ODS 2**).

En resumen, los métodos de producción primaria, como la agricultura, deben integrarse en el desarrollo tecnológico sostenible, sirviendo de ejemplo de desarrollo a otras regiones semiáridas que necesitan soluciones accesibles. También debemos reducir la necesidad de importar energía de otros países y así poder crear nuevas oportunidades para el crecimiento sostenible mediante el uso de energías renovables. Todo eso sin olvidar que, la producción propia de alimentos, en situaciones de pandemia como la que actualmente se está viviendo (**COVID-19**), nos fortalece y nos permite mirar con mayor perspectiva la recuperación económica que con esfuerzo seremos capaces de superar.

6. ANEXO PUBLICACIONES

Seguidamente se exponen las publicaciones utilizadas como indicios de calidad, los cuales se incluyen en esta Tesis.

-Publicación 1: J. Garrigós, J.M. Molina, M. Alarcón, J. Chazarra, A. Ruiz-Canales, J.J. Martínez, Platform for the management of hydraulic chambers based on mobile devices and Bluetooth Low-Energy motes, Agricultural Water Management, Volume 183, 2017, Pages 169-176, ISSN 0378-3774.
https://doi.org/10.1016/j.agwat.2016.10.022

-Publicación 2: Chazarra-Zapata, J.; Molina-Martínez, J.M.; Cruz, F.-J.P.; Parras-Burgos, D.; Ruíz Canales, A. How to Reduce the Carbon Footprint of an Irrigation Community in the South-East of Spain by Use of Solar Energy. Energies 2020, 13, 2848.
https://doi.org/10.3390/en13112848

-Publicación 3: Chazarra-Zapata, J.; Parras-Burgos, D.; Arteaga, C.; Ruiz-Canales, A.; Molina-Martínez, J.M. Adaptation of a Traditional Irrigation System of Micro-Plots to Smart Agri Development: A Case Study in Murcia (Spain). Agronomy 2020, 10, 1365.
https://doi.org/10.3390/agronomy10091365

-Publicación 4: Chazarra-Zapata, J.; Parras-Burgos, D.; Francisco-Javier Pérez-de-la-Cruz ; Ruiz-Canales, A.; Molina-Martínez, J.M. Reducing the carbon footprint of the Water-Energy binomial through governance and ICT. A case study.Water 2020, 12, 3187.
https://doi.org/10.3390/w12113187

6.1. -Publicación 1: Platform for the management of hydraulic chambers based on mobile devices and Bluetooth Low-Energy motes.

J. Garrigós, J.M. Molina, M. Alarcón, J. Chazarra, A. Ruiz-Canales, J.J. Martínez
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Platform for the management of hydraulic chambers based on mobile devices and Bluetooth Low-Energy motes

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ABSTRACT

Agencies and institutions that are in charge of water distribution and treatment facilities devote significant resources to inspection and control of such facilities. In this paper, the procedures involved in these activities are discussed and optimized for automated treatment with mobile devices. To this purpose, a novel remote control application for the management and detection of faults and breakdowns of collective water distribution networks in irrigation systems has been developed. The developed platform makes use of BLE (Bluetooth Low-Energy) technology to provide contactless, context-and-positioning sensitive information to the user, simplifying periodic inspections and repairing tasks of the network infrastructure. Devices would be equipped with BLE-enabled motes capable of transmitting a beacon signal for equipment discovering. Operators in turn, would carry tablets or smartphones configured to detect the motes and stablish a link in case additional data must be exchanged. The tablet also allows the operator to revise and fill in a device's form customized with context sensitive information gathered from both the mote and the enterprise cloud services and finally, to update the information in the online databases.

1. Introduction

In geographical zones with limited water availability, one of the main objectives for the infrastructures that are managing water in agriculture is the improvement in the optimization of water and energy. An example of this infrastructure is the collective pipe networks for irrigation in water users associations (WUAs). Controlling the excessive water and energy consumption and achieving cost savings, it is possible to pursuit an efficient water management (Fernández-Pacheco et al., 2015; Bagirov et al., 2013; Rodríguez Díaz et al., 2011). The achievement of this objective can be obtained by means of several technologies and devices: decision support systems tools (Khan et al., 2010), software for management of pump stations (Lamaddalena and Khila, 2013), devices for energy management (Reca et al., 2014), employment of performance indicators (Córcoles et al., 2012), etc. Among the existing technologies for the adequate management of water and energy resources, irrigation systems management based upon automation and remote control tools is one of the simplest and robust methods for saving water and energy. Using a periodical control of several parameters (performance indicators of water and energy consumption, detection of faults and breakdowns, among others) at several levels (collective pipe network of a WUA, irrigation pipe network of a farmer, irrigation zone, among others) it is possible to detect, measure and manage the quantity and quality of water and the energy that is flowing in several places of the pipe network in a determined time. Based on the information provided by these devices, it is possible to suggest different scenarios of water and energy consumption. According to these scenarios, intelligent systems for opening and closing valves (Sweigard, 2003) and remote control systems for the maintenance of irrigation pipe network (Abderrahman et al., 2001) can be activated.

Moreover, water distribution and treatment facilities demand significant resources for inspection and control procedures. Therefore, efforts towards standardization, systematization and automation of these processes are currently strategic lines for many of the institutions in charge of these facilities, as they allow reducing errors, response times, rework, and ultimately, the costs associated with the facilities management (Bueno et al., 2015; Jiménez-Buendía et al., 2015).

Within this context, this paper presents a proposal for a distributed telemetry and control system, which is specifically tailored to the monitoring of distribution water infrastructures (canals, chambers, tanks, etc.) for collective pipe networks in WUA. The

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proposed platform brings as main innovations the use of mobile devices for operators and BLE (Bluetooth Low Energy) enabled sensors, or *motes*, for data acquisition.

Over the las decade, RFID (Radio Frequency IDentification) technology has been used in some cases for this kind of applications. However, RFID is limited to transmitting very little data within a short distance (centimeters). Moreover, this technology requires specialized scanners and greater effort to perform the data transmission. Both restrictions have kept its use limited to a few applications (Ruiz-Garcia and Lunadei, 2011).

Other technologies for low power wireless sensor communication, like Zigbee and ANT, lack common hardware support in consumer devices. In (Balmos Andrew et al., 2013) the authors suggest that using a more ubiquitous technology, such as BLE, that is already owned by most farmers or operators could significantly reduce cost and complexity. Their estimations for the battery life of a typical device under different duty cycles, demonstrate lifetimes of more than 2 years, which is also desirable. Other authors have studied commercial sensor nodes for wireless systems on battery supply and provided energy management approaches (Junaid Ahmed et al., 2014; Stefanos et al., 2015; Anisi et al., 2014).

In addition, the use of BLE beacons provides the advantage of facilitating the inspection and control, allowing the operator to receive automatically on his/her mobile device the relevant information for each indicator when approaching it, without having to take any kind of action. This eliminates the need for manually inspecting and recording data from information panels, or having to connect physically to the instruments, minimizing errors and accelerating the data intake.

This transparent flow of context-sensitive data is particularly useful indoors, where GPS-based systems are useless; but it is also advantageous in outdoor applications that require small sensors or a large number of devices, what would prevent the use of GPS in practice, due to the higher size-weight, power consumption and cost of this equipment (Ojha et al., 2015).

An extensive review of wireless sensor networks (WSN) with application in agriculture can be found in (Aqeel-Ur-Rehman et al., 2014), where the authors compare sensors used in agriculture domain from different points of view, including measuring principle, application purpose, communication technology and energy consumption. Bluetooth is exposed as a technology with the adequate tradeoff between cost, security, data rate, distance range and availability.

The rest of the paper is organized as follows. Section 2 describes the underlying platform developed for the inspection of water distribution and similar facilities. Then, Section 3 presents a methodology for the inspection procedures and results of the proposed method, along with a sample usage of the software. Finally, the most relevant conclusions and future research lines are drawn in Section 4.

2. Materials and methods

The advantages of WSNs in precision agriculture have been widely documented. Applications for intelligent irrigation systems (Yu et al., 2013; Navarro-Hellín et al., 2015; Coates et al., 2013) or general environmental monitoring systems (Mesas-Carrascosa et al., 2015; Shining et al., 2011; Srbinovska et al., 2015) are some of the most recent references. However, most of these applications require the interconnection of the sensors in a wide-area mesh, the use of GPRS modems or WiMAX technologies to connect to central nodes, or both. Our case study, however, differs from the architectures found in the bibliography in that there is no need of a direct link between the sensors nodes and the central host, as this link is provided by the operator‘s mobile device at the time of the regular inspection. Thus, in our case, only local (wired) connections are needed from the BLE Nano mote to its surrounding sensors. This fact simplifies and cheapens the system architecture, and does not prevent from including some special nodes with direct online connection if required for a particular setup. With these premises, the architecture of the developed platform has three principal components, as it is shown in Fig. 1. Their behavior is depicted in the following paragraphs.

2.1. Data acquisition and BLE beaconing subsystem

The mote selected for the sensor platform was the BLE Nano Kit from Red Bear Company Limited (RedBear, 2016). The Nano is one of the smallest BLE-enabled boards, only 18.5×21.0 mm, and one of the cheapest, to our best knowledge. It is based on the Nordic nRF51822 chip, which includes an ARM cortex-M0 SoC plus the BLE radio running at 16 MHz with ultra-low power consumption, less than 3 μA when it is powered from 1.8 V to 3.6 V in idle mode.

Fig. 2a shows a block diagram of the data acquisition and beaconing subsystem. It includes the Nano board and a number of dedicated signal conditioning stages or boards as needed. The PC boards are assembled and connected to the shockproof terminal blocks inside a fully insulated enclosure for standard DIN rails, as shown in Fig. 2b.

Software applications (apps) can be developed for the Nano using three different environments. For small prototypes, Arduino sketches, by means of the Arduino Library for nRF51822 developed by RedBear is the simplest option. For professional rapid development of products based on ARM microcontrollers, a better option is using the mbed Platform developed by ARM. Finally, for the most demanding applications, the nRF51822 SDK provided by Nordic gives full access to fine-tuning every chip's feature. In this case, the ARM mbed framework was selected, as it already includes standard access to advanced communication libraries for BLE, which accelerated our software development cycle. The active online community provides also a large set of modules as C++ APIs that are free and ready to use.

The app in the BLE Nano consists of two stages. The acquisition stage is able to capture data from a flow meter, valve or pressure sensor using 4–20 mA analogue inputs, digital inputs or typical industrial protocols such as Modbus, in our case. Other interfaces (I2C, SPI, RS232, etc.) have been tested on board and could be implemented if needed.

The second stage is devoted to BLE communication. Compared to Bluetooth Classic, BLE consumes less power and requires less time and effort to pair devices, but provides lower connection speeds. This stage implements the GAP and GATT profiles to a private high-level interface that is shared with the mobile device. The Generic Access Profile (GAP) stablishes the peripheral role for the Nano and sets up the advertising mode, what keeps it sending a beacon signal regularly so that it can be detected. This includes configuring the advertisement interval, which can be set from 20 ms to 10.24 s. In our case, a 2 s gap was selected, as an adequate tradeoff between speed and power consumption. It is worth noting that while in broadcasting (advertising) mode no connection is stablished, which allows considerable energy savings, which is mostly spent during the connection phase.

The GAP Beacon payload, encapsulated within the advertising data structure, has three fields: a 16 bytes identification code (UUID), a 2 bytes Mayor/Minor field, and one additional byte for the Tx Power. These fields could be used for small data broadcasting from sensors, providing enough space for most IoT applications, as in our case. However, in anticipation of future enhancements that could require larger data exchanges, we decided to include a separate GATT service for data exchange.

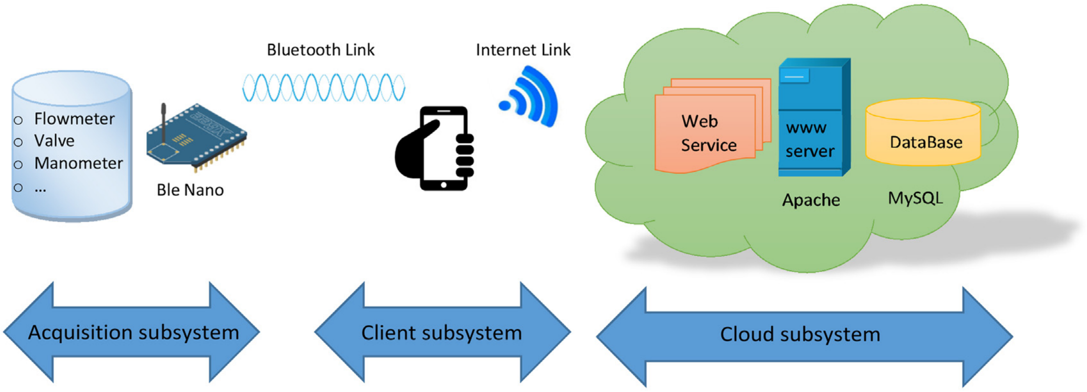


Fig. 1. An overview of the developed platform. The user can detect, analyze or control instruments and sensors attached to the BLE Nano from a mobile device through a Bluetooth Low Energy link. Acquired data is stored in the mobile local database or transferred to the online servers when an Internet connection is available.

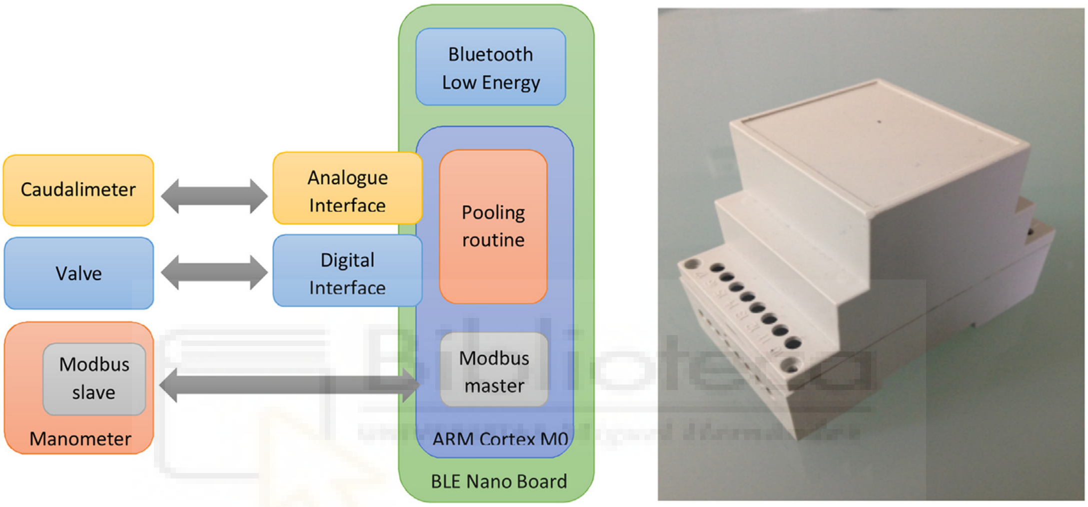


Fig. 2. Data acquisition and beaconing subsystem. Left: Block diagram of the BLE Nano Board and communication interfaces to common sensors. Right: Electronic boards are assembled inside a ruggedized enclosure for industrial applications before deployment.

The Generic Attribute Profile (GATT) enables interacting devices to adopt a client-server relationship. These roles must explicitly connect and handshake to transfer data, defining a protocol and some attributes. As most of the energy consumption takes place during the device linking process and, to a lesser extent, during the data transfer once connected, the motes' autonomy would not be greatly influenced. For our purpose, the GATT profile was defined with just one service providing three read-only attributes that were used to hold and transmit the values read from the two digital sensors and the analogue one. However, this structure could be easily expanded as required for complex facilities.

Once the GAP and GATT profiles are configured, the ARM microcontroller enters sleep mode, interrupted just to send the BLE beacon with the specified interval. If a mobile device tries to connect, the microcontroller exits the sleep mode, negotiates the connection and enters a pooling cycle where it reads data from the sensors and sends them to the mobile device. Once the client device is disconnected, the microcontroller enters again in sleep mode and the advertising role is enabled. Fig. 3 shows a high-level flow chart for the proposed behavior.

2.2. Operator interface and data management subsystem

The operator front end and data management subsystem has been developed as an Android app. This allows using any of the vast amount of Android-based tablet and smartphone devices as the operator's interactive tool. The relevance of the mobile communications and the ubiquity of the Android platform has drawn attention from researchers and many applications are under development in several fields that adopt this technology (Montoya et al., 2013; Rafoss et al., 2010), because of additional advantages: low cost, great community of developers, free developing tools, and huge online repositories with ready to use libraries for almost any application.

The app has been developed using a layered methodology, where every layer provides certain services to the upper layer, resulting in a modular and sustainable software. Fig. 4 shows the main modules that compose the application. The data layer is located at the lowest level. This layer is in charge of the data management within the app. It consists of a Bluetooth module developed under the singleton design pattern (that restricts the instantiation of a class to one object) and a SQLite handler to provide communication with the internal database of the Android device. The business logic layer composes the intermediate level. In this layer, the Android service module runs a background process that is used to constantly scanning BLE devices. It also sends notifications to the operator that let him/her access the discovered devices. Also located in this layer, the Cloud module manages the communication with external cloud services and the exchange of information with the enterprise database, using the JSON open-standard for-

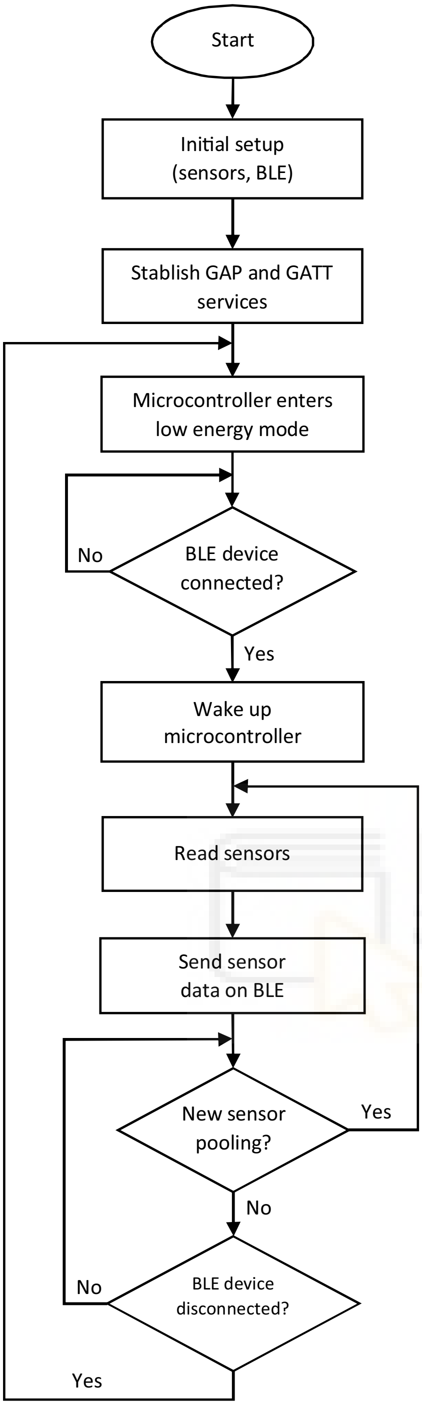


Fig. 3. Flowchart of the software application running on the BLE Nano.

mat for data object codification. The presentation tier forms the upper level of the modular application. This layer holds mainly the graphic user interface (GUI) and serves as a tool for structuring information. The GUI's functionality allows manually scanning for BLE motes, generating internal and externals reports for a given facility, taking photographs that can be added to the reports, and sending all that information to the cloud servers. Of course, in case of no Internet connection, data will be stored in an internal database on the mobile device, and it will be transmitted latter on when the connection is reestablished.

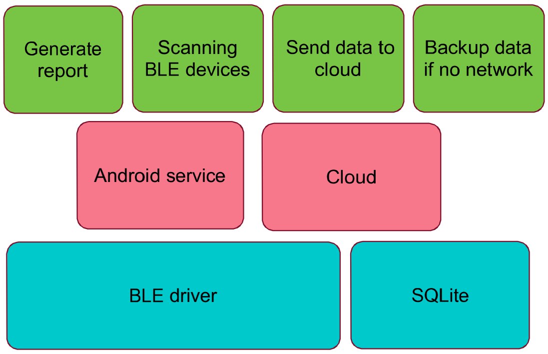


Fig. 4. Modules and layered structure of the Android application developed for the mobile device.

Table 1
List of general items that must be checked by default. The app screen would be customized with the specific gadgets on each facility, read from the database for a given beacon, so that the operator would see an individualized form.

External parameters	Internal parameters
Location Access	Connection joints
Perimeter of the chest	Vacuum suckers
Access gate	Valves
Covering deck	Manometers
Walls' surfaces	Water meters
Lateral and top ventilation	
Staircase	

2.3. *Online cloud subsystem*

Cloud services provide a convenient way of making an application scalable and distributed as needed. For our pilot plant, the cloud subsystem is composed of a MySQL database and an Apache server. The database is managed with the standard CPanel tool. Once the database is implemented and online, a web service is defined for data transferring. As it was mentioned previously, the messages that are sent and received by the online platform use the JSON data format. Nowadays JSON is the most common data format used for asynchronous browser/server communication, due in part to its open standard nature and the use of a human-readable text format. This has favored the fact that practically every modern software language supports JSON. In our case, a set of background services on the Apache 2 server was developed on PHP. This service layer can be broaden as needed. Some of these services are responsible for talking to the database driver to perform a query, or encapsulating the recovered data in a JSON object before sending it back to the device that performed the query.

3. Experimental results and discussion

A typical collective water distribution network for irrigation is composed of pumping stations, several levels of pipelines, intermediate storage tanks, valves to operate the network, etc. Access to network elements is done through underground or booth manholes, where the above devices are grouped together to facilitate handling (Fig. 5).

The manual inspection process consists of three main procedures:

1 Review of the state of the plant. The operator will check external and internal elements and the facility's structure itself. Table 1 depicts some of the parameters that are reviewed. The state of each item is evaluated and cataloged as one between three different options, and a paper checklist is complimented. If during this preventive maintenance a deficiency is discovered, or a spares

Fig. 5. Two examples of typical underground (left) or booth (right) water management facilities.

Fig. 6. Detailed view of the inside of a representative manhole.

replacement task should be issued, a note will be included in the final report. The forms to be complimented are generic and not particularized for each plant.

2 Data collection. The operator checks the set of instruments in the facility and writes down the values shown in each case. This task can be hampered by the arrangement of the instruments and difficult access to some areas. As an example, Fig. 6 shows the inside of a manhole. Reading the flowmeter placed in the bottom pipeline would require significant time and effort, considering the pressure to inspect a large number of facilities as fast as possible.

3 End of day report preparation. After the working path, the operator uses his/her notes to compose a final digital report on a computer.

As it can be appreciated, in general, these manual procedures are slow and prone to errors. The proposed procedure, however, would make use of the developed platform, described in Section 2. Using this platform, inspection and management operations are greatly facilitated. The new automated procedure would consist of the following steps.

The operator would carry an Android device, tablet or smartphone, equipped with the developed application and with direct connection to the Internet, if available. These devices are preferred over laptops, because they are more portable, smaller and have greater autonomy. Moreover, there are many brands on the market, which lets users find the screen size, memory, cost and communication interfaces (3G, Bluetooth, Wi-Fi...) that best fits their requirements. The software application uses a background service that continuously and automatically scans compatible BLE devices. If a BLE beacon is detected, a notification is raised on the screen (Fig. 7a) and the operator can access the start activity, which shows the discovered motes (Fig. 7b). Of course, it is also possible to access this screen voluntarily and perform a manual scan cycle at any time.

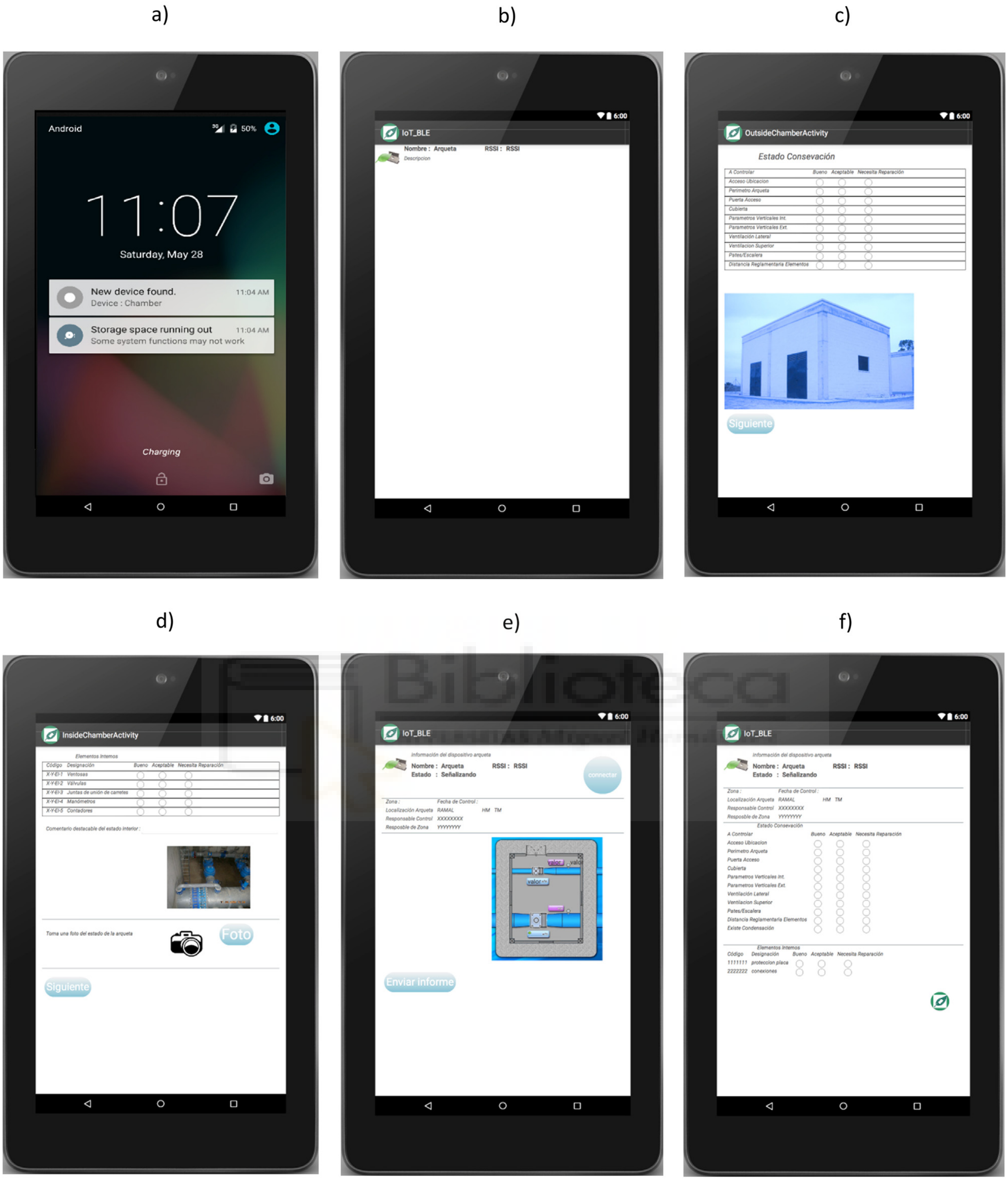
Selecting a BLE mote opens a new screen with the device's relevant information. As the beacon's identification tag (or UUID) is unique, this screen can recover customized parameters for this device and associated sensors or instruments, from the local (mobile device) or online databases. Thereby, the operator receives customized forms and checklists for the equipment he/she is just looking at, instead of a generic document. The activity ExternalManholeStatus (Fig. 7c) allows evaluating the external parameters of the plant. The next activity, InternalManholeStatus (Fig. 7d) would serve to evaluate the internal elements, including the options of inserting a comment, or a photo of a deteriorated equipment that must be replaced, for example.

The screen DataAdquisition (Fig. 7e), provides the option of stablishing a bidirectional connection with the selected mote through a GATT profile. In this mode, the mote enters an infinite loop where it pools the sensors it has connected. The data acquired from the instruments is printed in real time on the screen over a schematic connection graph that helps the operator to interpret the layout. This screen could also be used to send data to the equipment, providing new set points, configuration data, etc. For our initial tests, however, this functionality was not required and has not been implemented yet.

The operator can interrupt the acquisition stage by pressing the button that enters the last activity SendFinalReport (Fig. 7f). At this moment, the last values read from the sensors are stored. This final screen shows the full report, obtained by merging the information extracted from the database, entered by the operator for the facility status and received from sensors. The operator can then review the report and validate it pressing a button. At this moment, the report is sent to the online database or, if there is no network coverage, it is stored locally to be uploaded later.

In summary, the use of BLE beacons in the plant paired with a mobile app, provides the advantage of facilitating the inspection and control tasks, allowing the operator to receive automatically on his/her mobile device the relevant information for each indicator when approaching it, without having to take any kind of action. This eliminates the need for manually inspecting and recording data from information panels, or having to connect physically to an instrument, minimizing errors and accelerating the data intake. In some cases, this avoids in fact the need to enter the various spaces around the plant. Moreover, the operator is presented now a partially complimented report where the forms and diagrams are customized for the facility he/she is actually into, simplifying his task and understanding of the plant. Table 2 shows the improvements of the proposed procedure compared with the traditional one.

Fig. 8 shows time spent in each task for a typical 8 h workday, while inspecting 20 facilities in a 25 km route, for the traditional versus proposed procedure. Data were taken by a researcher who accompanied an operator during a standard route, using traditional



New device found. 11:04 AM
Device : Chamber

Storage space running out 11:04 AM
Some system functions may not work

Fig. 7. Android application screens. (a) Notification of new BLE Nano beacon detected. (b) Scanning screen, showing discovered motes. (c) An example of a form report for the external status diagnosis. (d) Another sample report for internal status evaluation, including comments and photo. (e) Data logging from sensors connected to the BLE Nano. (f) Last screen for reviewing and storing the Final Report.

and proposed procedures in successive days. Although data has been obtained from our first experiments in a controlled test-bench and do not yet cover a statistically representative sample, it can be inferred that inspection times could be considerably reduced (to a 30% in this example, or roughly two and a half hours) using the proposed platform and procedure. Time savings come from the reduced time spent in some tasks, such as inspecting and annotating, and from the elimination of others, like entering the report data and photos to the computer.

4. Conclusions

This paper proposes a novel distributed telemetry platform specifically tailored for collective water distribution networks in

Table 2
Differences between conventional and proposed procedures.

Procedure	Conventional	Proposed
Revision of facilities and equipment	√ Manual data writing √ Possibility of losing information on paper support √ No automatic confirmation of the equipment identification ID.	√ Assisted data writing √ Digital support √ Automatic detection of the correct equipment. Photos and/or diagrams provided √ Simplified assessment process √ Enhanced report: comments, photos.
Data acquisition	√ Manual √ Paper format √ Difficult access	√ Automated √ Digital format √ No need to approach the equipment
Preparation of the report	√ Weekly reports, manually drawn √ Paper format, querying tedious and laborious √ Prone to errors or information losses	√ Instant digital reports √ Historical info easily accessible √ Data stored locally and synced to the cloud √ No errors or information loss

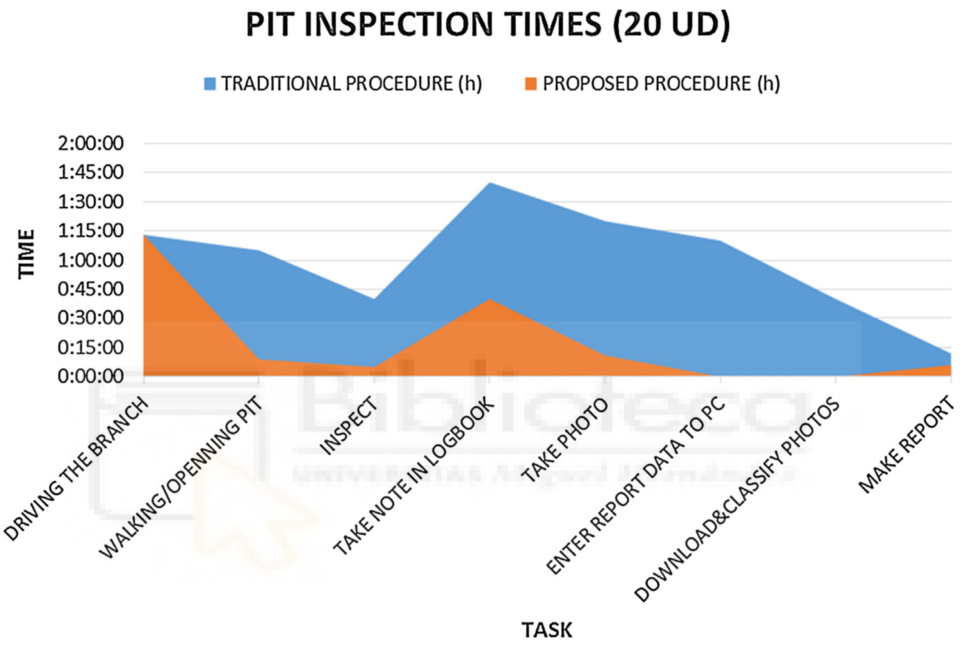


Fig. 8. Inspection times detailed by individual task for the traditional vs proposed procedures. Data were obtained for a route including 20 facilities that lasted about 8 h.

WUA that facilitates and accelerates the inspection and control tasks to be performed periodically on this type of facilities. The use of BLE-enabled motes reduces the friction of the procedures from the operator point of view and the possibility of errors in the data collection process. Our sensor platform is complemented with Android-based mobile devices that merge together three data sources: context-sensitive information received from the local or Internet databases for a given instrument, real time data received on BLE from the instrument's sensors, and operator's observations related to the physical condition of the facility. The obtained report can be locally stored or transmitted to the enterprise cloud servers when Internet connectivity is available. By using standard web services and formats, such as JSON, our platform is versatile enough to adapt to most of the information technology services and databases that were already in use by the company. Our first experiments on a limited environment show substantial improvements in inspection times and greater reliability in data collection. With the employment of this novel device it is possible to improve the efficiency of water and energy in the infrastructures for collective pipe networks in WUA. The real time detection of faults, breakdowns and additional information about the maintenance of the pipe network allows a quick, easy and cheap tool for controlling water and energy.

Next steps will be to expand the set of communication interfaces to other widely adopted sensor buses such as I2C, SPI or USB, to increase the number of devices the system is able to interact with. Likewise, for a final deployment over a given company infrastructure several enhancements on the cloud subsystem might be necessary, such as shifting from SQLite-MySQL schema to document-oriented databases (Couchbase Lite-CouchDB) or similar frameworks already in use.

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6.2. -Publicación 2:, A. How to Reduce the Carbon Footprint of an Irrigation Community in the South-East of Spain by Use of Solar Energy.

Chazarra-Zapata, J.; Molina-Martínez, J.M.; Cruz, F.-J.P.; Parras-Burgos, D.; Ruíz Canales
Energies 2020, 13, 2848.

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How to Reduce the Carbon Footprint of an Irrigation Community in the South-East of Spain by Use of Solar Energy

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Abstract: The climate change that plagues the world is causing extended periods of water shortage. This situation is forcing farmers in the region of Murcia in Spain to modernize their irrigation systems to optimize use of the scarce water they have and seek a circular water economy using the recovered water. Moreover, an associated problem is the need for energy that these facilities require in order to pressurize the required water. The use of photovoltaic generation contributes to the reduction of greenhouse gas (GHG) emissions. Food produced in this region tends to have guaranteed markets in Europe and, geographically, due to the high quality of phytosanitary controls and traceability during their marketing, their optimal cultivation, and selection and labelling is verified, specifying valuable information such as: collection date, origin, the use of organic fertilizers among others. To maintain market access, it is important to continue implementing other environmental improvements, i.e., reductions in either hydro or carbon footprints. Previous studies have failed to include the prospect of environmental use of isolated facilities to replace existing consumption, seeking the monetarization of the facility as well as prioritizing the reduction of GHG. Previous studies have failed to include the perspective of environmental use of isolated photovoltaic installations, based on existing consumption, thus, going beyond the monetarization of the facility, to prioritize the reduction of GHG applied in practice by environmentally sensitized farmers. This study was conducted in an existing facility with great technical complexity and three different sources of water supply, over 1500 plots and an altitude range in plots and reservoirs of more than 400 m.

Keywords: irrigation modernization; sustainable agriculture; water reuse; CO_2 reduction; circular economy

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1. Introduction

The new irrigation modernization projects in the Spanish Levante are characterized by replacing traditional irrigation systems (in which free-sheet pipes are used), (25% citric trees, 71% fruit trees, 4% vegetables) with new pressurized irrigation systems [1]. The main requirement of these systems is to employ sustainable energy sources [2], to obtain a minimal working pressure that enables their use with irrigation located in their different modalities, producing improved water efficiency and performance [3]. Currently, these energy sources come from the network mainly originating in fossil fuel and generating a carbon footprint that we must strive to reduce [4]. This study is an effort to meet the three objectives of European policy within the Framework on Climate and Energy by 2030 [5]:

- A reduction of greenhouse gas emissions of at least 40% (relative to 1990 levels).
- An increase of at least 27% of the share of renewable energy.
- An improvement of energy efficiency by at least 27%.

Concurrently, we aim to contribute to meeting the SDGs number 7 (affordable and clean energy), and 13 (climate action). This study focuses on a water user's association (WUA) with three different sources of water supply: water transferred between basins, water obtained from wells and water recovered from a wastewater treatment plant, with tertiary treatment. In the latter case, pumping is required to supply the highest-level tanks, which guarantee sufficient pressure to irrigate the plots [6]. To this end, the energy consumption of each of the pumping stations has been studied, according to their origin, as well as their associated emissions and after analyzing the different possible solutions using clean energies [7]. Subsequently, the amount of emissions avoided by the use of dimensioned photovoltaic plants has been determined and the reduction of greenhouse gases (SDG) has been quantified [8].

2. Material and Methods

For a comprehensive analysis of the situation, the agroclimatic characteristics and the needs of the crops were studied, which in turn are adapted to the endowments granted by the basin organization (Riber Basin). Data were collected from the different electrical invoices of each consumption point, selecting large consumption (main pumps). This data was processed by separating the different costs from the invoice until the actual pumping consumption was isolated. Once these actual consumptions were calculated, this provided us with information regarding the starting point of the maximum monthly energy needs and the corresponding CO_2 emissions, generated over one year, month to month. Several "clean" solutions were considered, such as the generation of energy by turbine-transported water taking advantage of section changes in pipes [9] or wind at points with air current records. However, the use of these methods does not guarantee a sufficient supply of energy for the different monthly demands. Only photovoltaic energy is able to guarantee the necessary energy during any time of the year. The possibility of implementing other energies in a complementary manner was, therefore, ruled out. Moreover, the high cost of the installation was considered, in addition to the loss of energy during transport to the point of use. Furthermore, the lack of a guarantee of continuous wind existence, able to provide sufficient energy for the proper functioning of the pressurized irrigation system and the insufficient production of energy by turbine, considering the low points of possible production, were insufficient in terms of the consumption, and the energy losses due to transportation did not make it viable. Once the days of maximum required energy were known, the photovoltaic plant was sized and potentially avoided emissions were obtained. The adoption of these measures will help to achieve the Sustainable Development Goals [10] and encourage other user communities to employ this energy source.

2.1. Precedents

The WUA of the zone of the study is located in the Region of Murcia (Spain). The irrigable area is 373.59 ha (Figure 1). This WUA has been constituted from the union of different groups and irrigation associations.

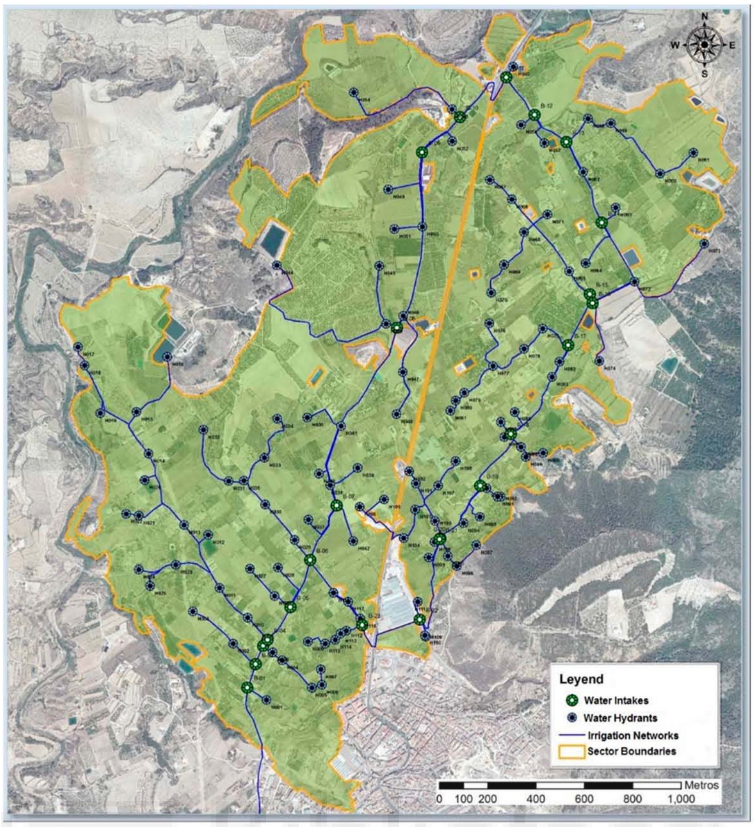

Figure 1. Irrigated area of the study zone of the water user's association (WUA). (Source: Segura's Hydrographic Confederation).

This WUA includes two natural exploitations: a well and the Tajo-Segura transfer (TST). Additionally, a third exploitation comes from the wastewater treatment plant (WWTP) in the village of the case study [11].

2.2. Climatology, Thermal Regime, Agroclimatic Traits, and Precipitation Regime

The following will detail the climatic and thermal factors of the study area:

- **Climate:** The climatic analysis of the irrigation zone is conditioned by the following factors:
    - Latitudinal position, which determines the intensity of solar radiation. The area is between the 37°57′ and 37°01′ parallel, being responsible for the high temperatures in summer.
    - Altitude position, which determines the intensity of the precipitations and the prevailing winds of the area.
    - Specific conditions of the irrigation area regarding plant roughness and sufficient water supply capacity during the driest months.
    - General atmospheric circulation that crosses the region. The presentation of the anticyclone will condition the atmospheric circulation, although it will be tempered by the existing relief structure, which in turn conditions the distribution of precipitation throughout the year.
- The atmospheric conditions of the study area are determinants of the region's typical climate, characterized by a decrease in the moisture content of the air masses that, together with the Béticas mountain system, produce the RainShadow effect and result in dry, temperate and clear weather types, both in winter and in summer.
- **Thermal regime and agroclimatic traits**:

- ◦ The average monthly temperature is colder between 8 and 11 °C; the average minimal temperature is between 4 and 7 °C. The risk of frost is, therefore, low.
- ◦ The average warmest temperatures are between 26 and 28 °C, with maximum averages between 32 and 34 °C.
- ◦ The average annual rainfall is 200–300 mm. The dry period lasts between 7–11 months, according to the seasons.
- ◦ The thermal conditions enable the cultivation of cereals and cotton.
- ◦ The climate of the Mediterranean subtropical area is warm or semi-warm.
- ◦ The vegetation of the area, due to its aridity, hygrocontinentality and physiognomic formation is transitional between Durilignosa and Siccideserta.

- **Precipitation regime**: In the precipitation analysis, we have already anticipated that, due to its arid thermo-Mediterranean thermal regime indicated in the previous section, and other climatic factors, very weak rainfall records are obtained, which, only in years of flooding rarely exceed 350 mm throughout the region.

2.3. Water Needs and Available Resources

Currently, with a provision for 10 years, the WUA has three uses with an annual allocation of 3,629,361 m^3 (Table 1).

Table 1. Total volume supply of the available resources.

Explotation	Capital Flows		Annual Appropriation (m^3)	Regulating Rafts (m^3)
	Daily Flow (L/s)	Flow (m^3/h)		
Well	95	342	2,326,158	45,000
Tajo-Segura Transfer	300	1080	1,140,000	230,000
Wastewater treatment plant	40	144	163,203	39,464
TOTAL			3,629,361	

Wastewater treatment plant 40 144 163,203 39,464
TOTAL 3,629,361

The manner in which irrigation waters are used consist of pumping from the different sources to their own regulation ponds (Table 1), which are owned by the WUA. From there, through conduits, the water is channelled to the points of consumption according to the crop water needs. The extraction by means of pumping takes place in the most economical periods of the hired electricity tariff. Figure 2 displays the water needs which must been covered:

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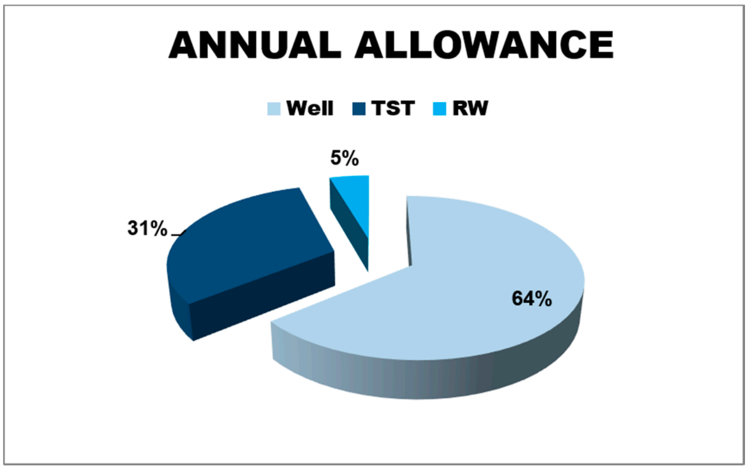

Figure 2. Percentage of water volume needed to cover the demand, according to the water supply source.

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2.4. Financial Expenses of the Electric Consumption by Different Sources

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The electric consumptions during 2016 depend on the source of extraction of the irrigation water. The financial expenses will be analysed, according to the billed power and consumed energy. See current operating scheme (Figure 3).

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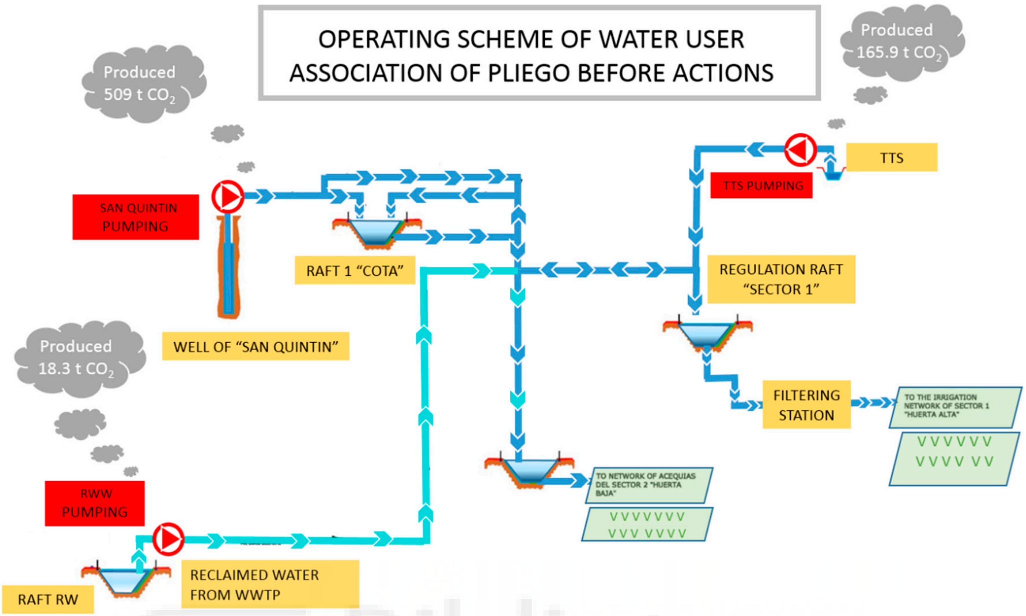

Figure 3. Current operating scheme of WUA.

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2.5. Financial Expense of Extraction by Means of the Well

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For the extraction by means of subsurface water pumping from the well of the system the commercial tariff T6.1 (Spanish normative) was used. This tariff includes high voltage and a power over 15 kW in three periods: P1 = 10 kW; P2 = 10 kW; P3 = 10 kW; P4 = 10 kW; P5 = 10 kW; P6 = 451 kW. The monthly expense is shown in Figure 4. It is clear that the WUA is mainly using the well pump during the less expensive hourly period, based on the P6 tariff.

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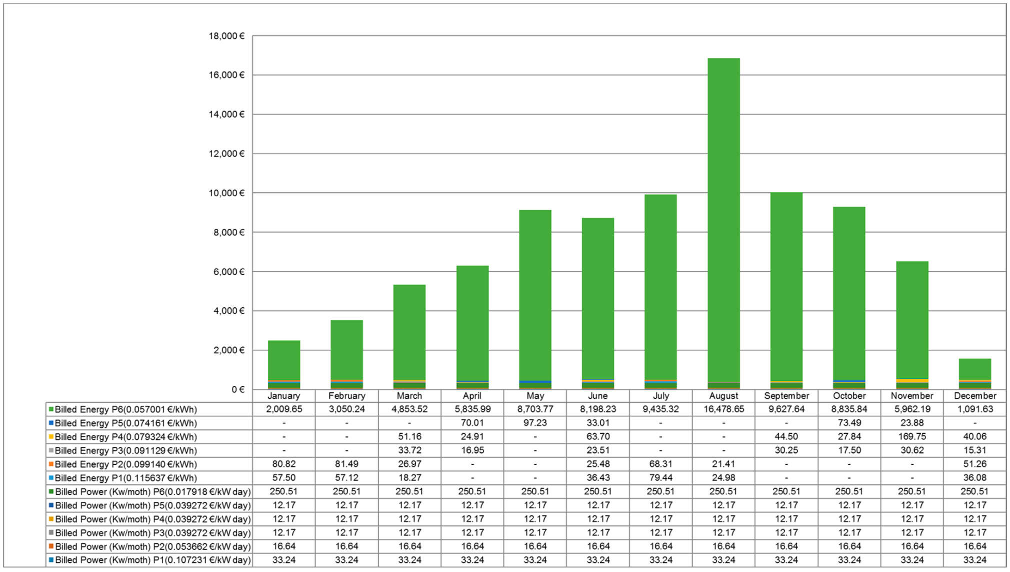

	January	February	March	April	May	June	July	August	September	October	November	December
🟩 Billed Energy P6(0.057001 €/kWh)	2,009.65	3,050.24	4,853.52	5,835.99	8,703.77	8,198.23	9,435.32	16,478.65	9,627.64	8,835.84	5,962.19	1,091.63
🟦 Billed Energy P5(0.074161 €/kWh)	-	-	-	70.01	97.23	33.01	-	-	-	73.49	23.88	-
🟨 Billed Energy P4(0.079324 €/kWh)	-	-	51.16	24.91	-	63.70	-	-	44.50	27.84	169.75	40.06
⬜ Billed Energy P3(0.091129 €/kWh)	-	-	33.72	16.95	-	23.51	-	-	30.25	17.50	30.62	15.31
🟧 Billed Energy P2(0.099140 €/kWh)	80.82	81.49	26.97	-	-	25.48	68.31	21.41	-	-	-	51.26
🟦 Billed Energy P1(0.115637 €/kWh)	57.50	57.12	18.27	-	-	36.43	79.44	24.98	-	-	-	36.08
🟩 Billed Power (Kw/moth) P6(0.017918 €/kW day)	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51	250.51
🟦 Billed Power (Kw/moth) P5(0.039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
🟨 Billed Power (Kw/moth) P4(0.039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
⬜ Billed Power (Kw/moth) P3(0.039272 €/kW day)	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17	12.17
🟧 Billed Power (Kw/moth) P2(0.053662 €/kW day)	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64	16.64
🟦 Billed Power (Kw/moth) P1(0.107231 €/kW day)	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24	33.24

Figure 4. Financial expenses of the well. 2016.

Figure 4. Financial expenses of the well. 2016.

Energies **2020**, *13*, x FOR PEER REVIEW 8 of 28

2.6. *Financial Expense of Extraction by Means Tajo-Segura Transfer (TST)*

2.6. Financial Expense of Extraction by Means Tajo-Segura Transfer (TST)

For the water pumping extraction from TST water, the commercial T6.1 tariff was hired. This tariff is detailed in Section 2.1. The monthly expense is displayed in Figure 5.

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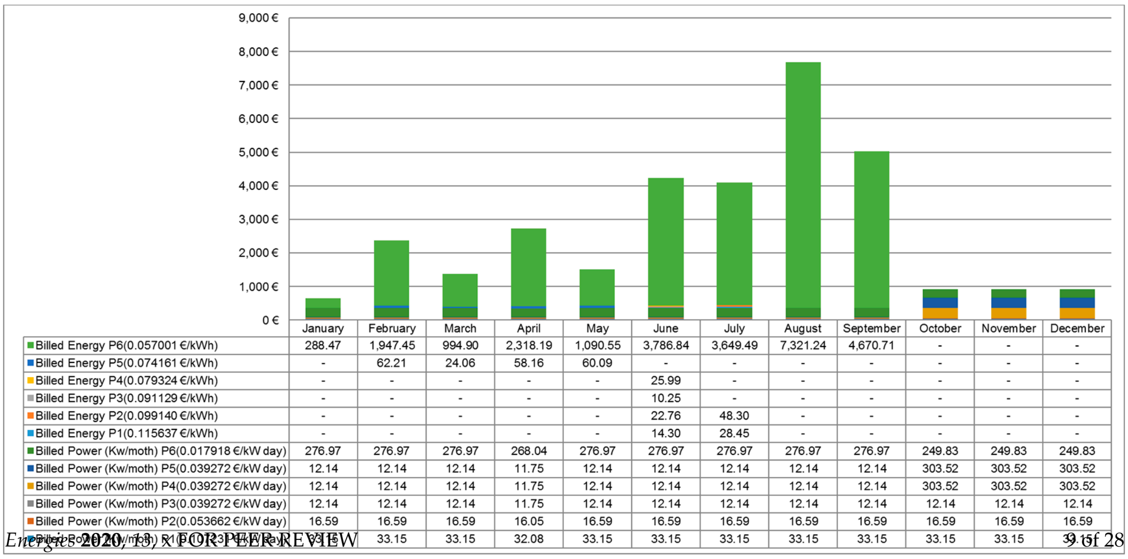


	January	February	March	April	May	June	July	August	September	October	November	December
🟩 Billed Energy P6(0.057001 €/kWh)	288.47	1,947.45	994.90	2,318.19	1,090.55	3,786.84	3,649.49	7,321.24	4,670.71	-	-	-
🟦 Billed Energy P5(0.074161 €/kWh)	-	62.21	24.06	58.16	60.09	-	-	-	-	-	-	-
🟨 Billed Energy P4(0.079324 €/kWh)	-	-	-	-	-	25.99	-	-	-	-	-	-
⬜ Billed Energy P3(0.091129 €/kWh)	-	-	-	-	-	10.25	-	-	-	-	-	-
🟧 Billed Energy P2(0.099140 €/kWh)	-	-	-	-	-	22.76	48.30	-	-	-	-	-
🟦 Billed Energy P1(0.115637 €/kWh)	-	-	-	-	-	14.30	28.45	-	-	-	-	-
🟩 Billed Power (Kw/moth) P6(0.017918 €/kW day)	276.97	276.97	276.97	268.04	276.97	276.97	276.97	276.97	276.97	249.83	249.83	249.83
🟦 Billed Power (Kw/moth) P5(0.039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	303.52	303.52	303.52
🟨 Billed Power (Kw/moth) P4(0.039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	303.52	303.52	303.52
⬜ Billed Power (Kw/moth) P3(0.039272 €/kW day)	12.14	12.14	12.14	11.75	12.14	12.14	12.14	12.14	12.14	12.14	12.14	12.14
🟧 Billed Power (Kw/moth) P2(0.053662 €/kW day)	16.59	16.59	16.59	16.05	16.59	16.59	16.59	16.59	16.59	16.59	16.59	16.59
🟦 Billed Power (Kw/moth) P1(0.107231 €/kW day)	33.15	33.15	33.15	32.08	33.15	33.15	33.15	33.15	33.15	33.15	33.15	33.15

Energies **2020**, *13*, x FOR PEER REVIEW 9 of 28

Figure 5. TST Financial expense 2016.

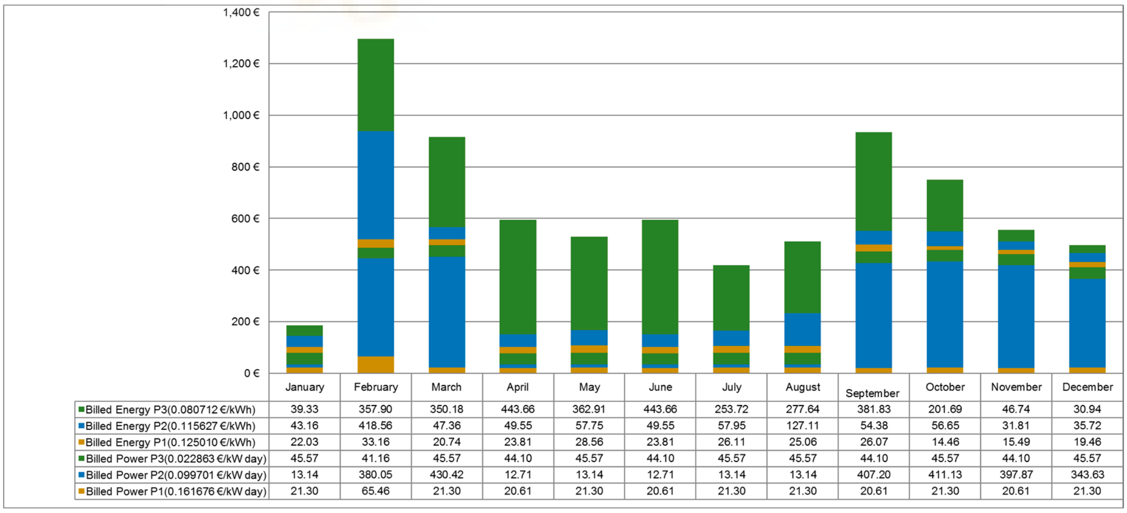
Figure 5. TST Financial expense. 2016.

2.7. *Extracting the Financial Expense of Water from the Wastewater Treatment Plant (WWTP)*

2.7. Extracting the Financial Expense of Water from the Wastewater Treatment Plant (WWTP)

For the water pumping extraction of water from the WWTP the commercial T3.1 tariff (Spanish normative) was hired. This consists of high voltage and the power over 15 kW in three periods: P1 = 5 kW; P2 = 5 kW; P3 = 75.636 kW. The monthly expense can be observed in Figure 6.

For the water pumping extraction of water from the WWTP the commercial T3.1 tariff (Spanish normative) was hired. This consists of high voltage and the power over 15 kW in three periods: P1 = 5 kW; P2 = 5 kW; P3 = 75.636 kW. The monthly expense can be observed in Figure 6.



	January	February	March	April	May	June	July	August	September	October	November	December
🟩 Billed Energy P3(0.080712 €/kWh)	39.33	357.90	350.18	443.66	362.91	443.66	253.72	277.64	381.83	201.69	46.74	30.94
🟦 Billed Energy P2(0.115627 €/kWh)	43.16	418.56	47.36	49.55	57.75	49.55	57.95	127.11	54.38	56.65	31.81	35.72
🟧 Billed Energy P1(0.125010 €/kWh)	22.03	33.16	20.74	23.81	28.56	23.81	26.11	25.06	26.07	14.46	15.49	19.46
🟩 Billed Power P3(0.022863 €/kW day)	45.57	41.16	45.57	44.10	45.57	44.10	45.57	45.57	44.10	45.57	44.10	45.57
🟦 Billed Power P2(0.099701 €/kW day)	13.14	380.05	430.42	12.71	13.14	12.71	13.14	13.14	407.20	411.13	397.87	343.63
🟧 Billed Power P1(0.161676 €/kW day)	21.30	65.46	21.30	20.61	21.30	20.61	21.30	21.30	20.61	21.30	20.61	21.30

Figure 6. WWTP financial expense. 2016.

Figure 6. WWTP financial expense. 2016.

In the case of the WWTP, the WUA is mainly using the extracting pump in the less-expensive periods. This is in line with tariffs P1 and P2. The WUA is using this water source in order to satisfy the water needs of the crop according to the type of hectare, during February and March and from the end of the summer to the end of the year.

The WUA of the studied area faced a bill of 81,949.1 € (taxes included) in 2016, as shown in Figure 7. As previously cited, because of the location of the WUA in a semi-arid zone, the maximal financial expenses occur during the period of maximal water demand, over the summer months.

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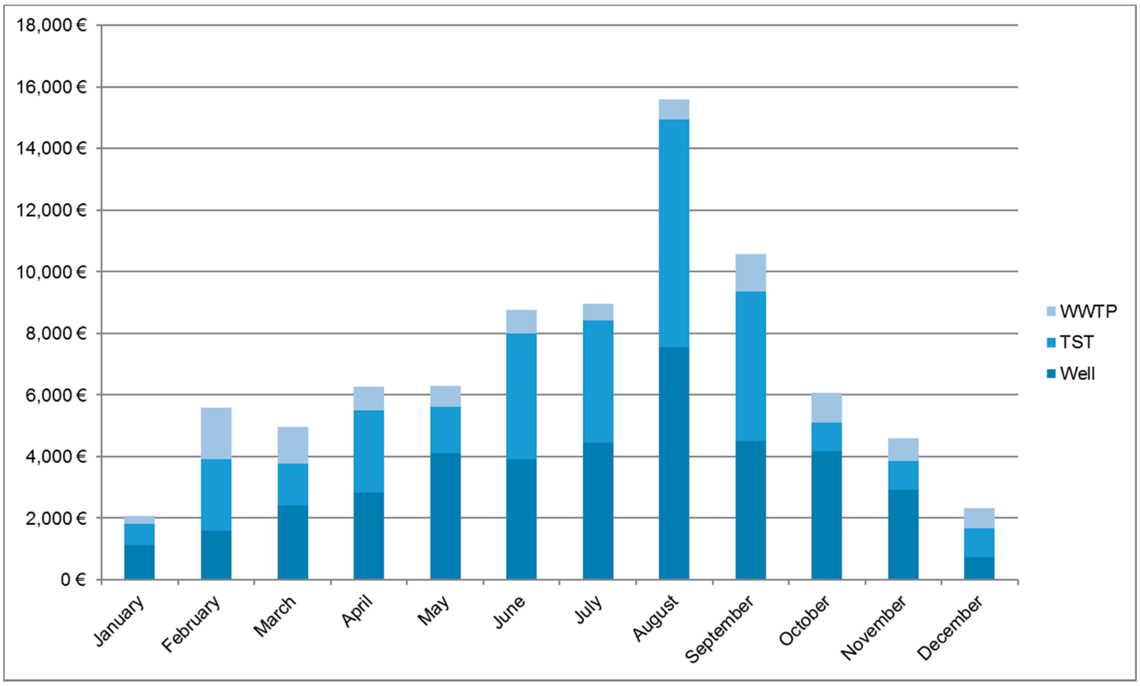

Figure 7. Total financial expense. 2016.

3. Adopted Measures for Reduction of the Carbon Footprint

3.1. Minimization of the Energy

The entire energy consumed by the WUA is for water elevation. For this reason, a study of the working state of the pumps compared with the optimal equipment requirements for real conditions was developed.

Subsequently, the energy consumption was minimized by replacing all the pumps (Table 2). The European Commission (reference) includes a decalogue of energy efficiency which indicates that, firstly, it is necessary to save the maximum of the possible energy. After this consumption, the conventional energy must be substituted by renewal energy. This depends on the degree of efficiency of its implementation in the system.

Table 2. Details of the elevation pumps and adopted improvements.

	Manometric Eight (m.c.a)	Q (L/s)	Current Pump		Future Pump	
			Power (kW)	Performance (%)	Power (kW)	Performance (%)
WWTP	115	40	74	56	63.64	70
TST	105	126.7	315	56	237.28	70
Well	250	90	295	48.47	232.9	70.52

The new elevation pumps include a greater efficiency with less power. Consequently, this equals less consumption. The efficiency of the old pumps was 50%.

3.2. Analysis of the Available Technologies

After a detailed analysis of the different technologies available, the photovoltaic generation was chosen as the optimal option. This is because of the maturity of the technology, the availability of areas, the elevated irradiation in the zone and the proximity between generation and consumption zones. Other options considered and rejected were as follows:

- Wind energy: only two turbines could be considered considering the wind map published by CENER (National Renewable Energy Centre) [12] two generators with an estimated generation power of 6 kW could be considered with which a generated power of about 20 kWh/day and 6761 kWh/Year versus 2,032,471 kWh could be obtained is negligible production with considerable investment with considerable investment. It would be necessary to complement this with another alternative and safe energy source in order to avoid periods without energy.
- Water energy: the irrigation network design enables the possibility to take advantage of the existing overpressures in several points of the system in order to generate electric energy. After a technical study, the incorporation of this technology was evaluated. The solution was the incorporation of two micro turbines linked to the existing pressure-reducing valves.

Moreover, the installed powers were 10 and 7.5 kW. This option was discarded because of the low power available. Additionally, the excessive distance between the generation and the nearest consumption (nearly 3 km to the filtering system) can generate great losses during the energy transportation.

3.3. Legislative Alternatives of Photovoltaic Installations

During the execution of the project, the Spanish regulations RD 244/2019 of April 2019 [13] were in force, which is why the solution to the problem was resolved in compliance with the regulations presented in this paper.

- **Alternative 1.** Electricity supply with self-consumption.

To obtain the supply of electricity by means of self-consumption, type 2 is included, according to Spanish regulations (art. 5 of RD 244/2019), this standard includes the administrative, technical and economic conditions of the modes of supply of electricity with self-consumption and production with self-consumption. This is due to the fact that the hired power is more than 100 kW at this point. In the self-consumption mode, the electricity system is required to be registered as a consumer and producer (art. 4.1.b RD 244/2019). This electrical system must be registered in the RIPRE register (Registration of Electrical Energy Production Facilities in Special Regime), in the Ministry of Industry, Energy and Tourism of Spain. This mode enables the possibility of selling the overproduction, however, it is necessary to consider the expenses and taxes that must be applied for this option:
—Generation toll (0.50 o/MWh)
—Generation tax for electrical producers (7% of turnover).
In the case of the sale of the overproduction, some tax expenses for the system owner must be declared in the generation of tolls and taxes. In conclusion, this alternative does not fully improve the reduction of the carbon footprint as it is powered by the conventional production network.

- **Alternative 2.** Supply of electrical energy by means of an isolated photovoltaic generation system.

This alternative eliminates the complexity of system legalization because RD 244/2019 does not apply. As a curriculum, the main objectives to meet due to the improvement of the energy efficiency of the WUA irrigation system are:
1. Suppression of electricity power generation costs.
2. Electrical energy is produced by conventional sources of renewable energy. This allows for an environmental improvement by reducing CO_2 emissions into the atmosphere. Based on the above reason, this alternative was selected for this project.

Currently, the legal conditions for the installation of photovoltaic plants have been improved even if further fed into the grid and generating excess energy [11]. However, all the plants described here are perfectly valid.

3.4. Solar Photovoltaic System

In order to calculate the generated energy in each of the photovoltaic systems, the PVGIS (Photovoltaic Geographical Information System) [14] and PVWATTS [15] tools provide web-based solar radiation databases for the calculation of PV potential in several countries and with the Satellite Application Facility on Climate Monitoring (CM SAF) database belonging to the European Organization for the Exploitation of Meteorological Satellites. This software was created by the Joint Research Center of the European Commission. This software uses all the climate (irradiation, temperature, among others) and geographical values of the area. The generated energy in a photovoltaic system with a determined inclination, and orientation is then obtained.

For the design of the system the recommendations of the Spanish Energy Diversification and Saving Institute (IDEA in Spanish) were taken into account, particularly for the calculation of the separation between rows and modules and the optimal inclination of the panels depending on the latitude.

If necessary, plans have been made to provide a generator owned by the community of irrigators, although the photovoltaic infrastructures are sized in order to avoid their start-up, given the high cost per kWh generated in a group (above 20 euro cts./kWh).

Another important aspect is that since we have accumulation rafts and we do not depend on an instant demand, we will not install batteries of accumulators, with the consequent economic saving. Consequently, the inverter will be programmed so that depending on the levels in existing rafts and the level of production that exists, the pumping will be fed from the photovoltaic field.

3.5. Calculation of the Photovoltaic Solar Installation for the Pumping of the Well

We chose to develop a procedure to calculate the photovoltaic pumping installation of the well, as an example of the calculation since it is the main source of water supply for irrigation. As already mentioned, PVGIS software is used by the CM SAF database to obtain, among other values, the daily average electricity production of the given system (kWh) as well as the average global irradiation per square meter received by the modules of the given system (kWh/m^2) (Table 3).

Table 3. Optimization details of the solar panels according to their position, inclination and orientation.

Fixed System (Optimized): Inclination = 34°, Orientation = 0°				
Month	**E_d**	**E_m**	**H_d**	**H_m**
January	1170.00	36,300	4.27	132
February	1360.00	38,200	5.01	140
March	1610.00	50,000	6.10	189
April	1590.00	47,600	6.10	183
May	1660.00	51,500	6.49	201
June	1770.00	53,000	7.00	210
July	1810.00	56,100	7.28	226
August	1720.00	53,300	6.91	214
September	1520.00	45,500	5.96	179
October	1380.00	42,700	5.31	165
November	1200.00	36,000	4.45	133
December	1060.00	33,000	3.89	120
Yearly average	**1490**	**45,300**	**5.74**	**174**
Total for year	**543,000**		**2090**	

E_d: Average daily electricity production from the given system (kWh); E_m: Average monthly electricity production from the given system (kWh); H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2); H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2).

With this data, the maximum power of the photovoltaic system is obtained as well as the total budget of the installation and its components (Table 4).

production from the given system (kWh); Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m²); Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m²).

With this data, the maximum power of the photovoltaic system is obtained as well as the total budget of the installation and its components (Table 4).

Table 4. Summary of the main data of the photovoltaic installation for the well.

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Solar Radiation Database Used: PVGIS - CM SAF	
Location	38°2′22″ North, 1°29′31″ West
Elevation	310 m a.s.l.
Peak power of the photovoltaic (PV) system	350 kWp
Estimated losses due to temperature and low irradiance	11.2% (using local ambient temperature)
Estimated loss due to angular reflectance effects	2.6%
Other losses (cables, inverter, etc.)	14.0%
Combined PV system losses	25.6%
Budget	**630,000 €**

PVGIS (Photovoltaic Geographical Information System), CM SAF (Satellite Application Facility on Climate Monitoring).

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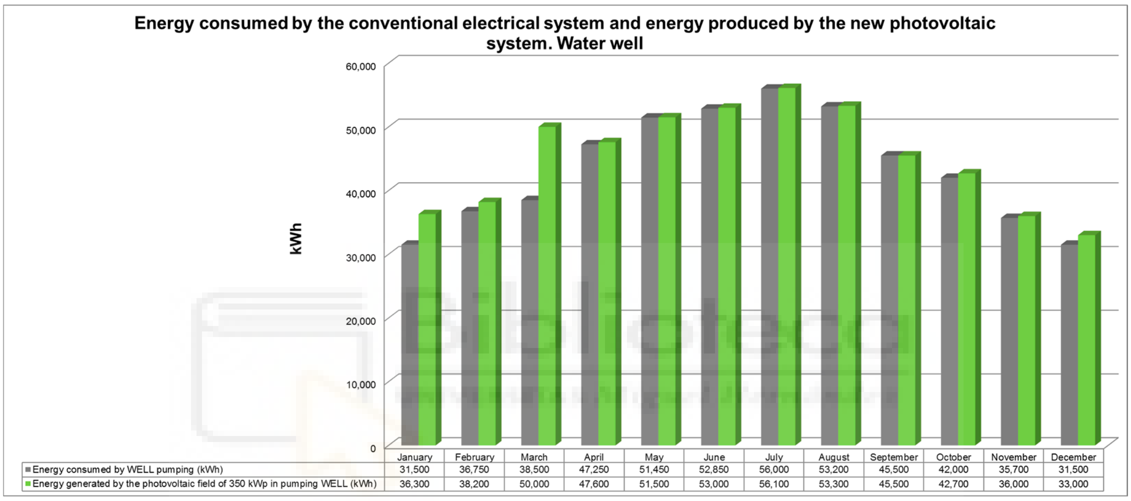


	January	February	March	April	May	June	July	August	September	October	November	December
■ Energy consumed by WELL pumping (kWh)	31,500	36,750	38,500	47,250	51,450	52,850	56,000	53,200	45,500	42,000	35,700	31,500
🟩 Energy generated by the photovoltaic field of 350 kWp in pumping WELL (kWh)	36,300	38,200	50,000	47,600	51,500	53,000	56,100	53,300	45,500	42,700	36,000	33,000

Figure 8. Energy consumed by the conventional electrical system and energy produced by the new photovoltaic system (water well).

Figure 8. Energy consumed by the conventional electrical system and energy produced by the new photovoltaic system (water well).

As displayed in the figure above, the energy needs are fully covered by our proposed photovoltaic system. Below, we analyze the profitability of the new system by calculating the internal rate of return (IRR), to 31 years as the useful life of our facility, used as an indicator of the viability of any project (Table 5).

Table 5. Summary procedure for calculating the 31-year internal rate of return (IRR).

Well Photovoltaic Solar Economic Framework										
Year	**Electrical Consumption without Photovoltaic Energy (Kwh)**	**Production with Photovoltaic Energy (Kwh)**	**Cumulated Photovoltaic Production (Kwh)**	**Spending on Electricity in Pumping Well without Photovoltaic Installation without VAT (€)**	**Expenditure Fuel Oil (Generator) with Photovoltaic Installation without VAT (€)**	**Cost of Accumulated Kwh without Photovoltaic (€/Kwh)**	**Maintenance Expenses (€)**	**Total Expenses (€)**	**Accumulated Total Expenses (€)**	**Cost of Accumulated Kwh with Photovoltaic (€/Kwh)**
1	522,200.00	543,200.00	543,200.00	31,793.46	0.00	0.061	600.0	630.600,0	630,600.00	1.161
2	522,200.00	538,854.40	1,082,054.40	34,019.00	0.00	0.065	630.0	630.0	631,230.00	0.583
3	522,200.00	534,543.56	1,616,597.96	36,400.33	0.00	0.070	661.5	661.5	631,891.50	0.391
4	522,200.00	530,267.21	2,146,865.17	38,948.35	0.00	0.075	694.6	694.6	632,586.10	0.295
5	522,200.00	526,025.07	2,672,890.24	41,674.73	0.00	0.080	729.3	729.3	633,315.40	0.237
6	522,200.00	521,816.87	3,194,707.11	44,591.96	0.00	0.085	765.8	765.8	634,081.20	0.198
7	522,200.00	517,642.34	3,712,349.45	47,713.40	0.00	0.091	804.1	804.1	634,885.30	0.171
8	522,200.00	513,501.20	4,225,850.65	51,053.34	0.00	0.098	844.3	844.3	635,729.60	0.150
9	522,200.00	509,393.19	4,735,243.84	54,627.07	0.00	0.105	8886.5	8886.5	644,616.10	0.136
10	522,200.00	505,318.04	5,240,561.88	58,450.96	0.00	0.112	1330.8	1330.8	645,946.90	0.123
11	522,200.00	501,275.50	5,741,837.38	62,542.53	0.00	0.120	1397.3	1397.3	647,344.20	0.113
12	522,200.00	497,265.30	6,239,102.68	66,920.51	0.00	0.128	1467.2	1467.2	648,811.40	0.104
13	522,200.00	493,287.18	6,732,389.86	71,604.95	0.00	0.137	1540.6	1540.6	650,352.00	0.097
14	522,200.00	489,340.88	7,221,730.74	76,617.30	0.00	0.147	1617.6	1617.6	651,969.60	0.090
15	522,200.00	485,426.15	7,707,156.89	81,980.51	0.00	0.157	1698.5	1698.5	653,668.10	0.085
16	522,200.00	481,542.74	8,188,699.63	87,719.15	0.00	0.168	1783.4	1783.4	655,451.50	0.080
17	522,200.00	477,690.40	8,666,390.03	93,859.49	0.00	0.180	1872.6	1872.6	657,324.10	0.076
18	522,200.00	473,868.88	9,140,258.91	100,429.65	0.00	0.192	1966.2	1966.2	659,290.30	0.072
19	522,200.00	470,077.93	9,610,336.84	107,459.73	0.00	0.206	2064.5	2064.5	661,354.80	0.069
20	522,200.00	466,317.31	10,076,654.15	114,981.91	0.00	0,220	2167.7	2167.7	663,522.50	0.066
21	522,200.00	462,586.77	10,539,240.92	123,030.64	0.00	0.236	2276.1	2276.1	665,798.60	0.063
22	522,200.00	458,886.08	10,998,127.00	131,642.78	0.00	0.252	2389.9	2389.9	668,188.50	0.061
23	522,200.00	455,214.99	11,453,341.99	140,857.77	0.00	0.270	2509.4	2509.4	670,697.90	0.059
24	522,200.00	451,573.27	11,904,915.26	150,717.81	0.00	0.289	2634.9	2634.9	673,332.80	0.057
25	522,200.00	447,960.68	12,352,875.94	161,268.06	0.00	0.309	2766.6	2766.6	676,099.40	0.055
26	522,200.00	444,376.99	12,797,252.93	172,556.82	0.00	0.330	2904.9	2904.9	679,004.30	0.053
27	522,200.00	440,821.97	13,238,074.90	184,635.80	0.00	0.354	3050.1	3050.1	682,054.40	0.052
28	522,200.00	437,295.39	13,675,370.29	197,560.31	0.00	0.378	3202.6	3202.6	685,257.00	0.050
29	522,200.00	433,797.03	14,109,167.32	211,389.53	0.00	0.405	3362.7	3362.7	688,619.70	0.049
30	522,200.00	430,326.65	14,539,493.97	226,186.80	0.00	0.433	3530.8	3530.8	692,150.50	0.048
31	522,200.00	426,884.04	14,966,378.01	242,019.88	0.00	0.463	3707.3	3707.3	695,857.80	0.046
	16,188,200.00	**14,966,37.01**		**3,245,254.53**	0.00		**65,857.80**	**695,857.80**		
							IRR (to 31 years)		**10.34%**	

We obtained an IRR (31 years) of 10.34%, a more than acceptable percentage that indicates the viability of our project. The graph below displays the cumulative price curve for grid electricity and the accumulated price of electricity generated by photovoltaic panels (Figure 9).

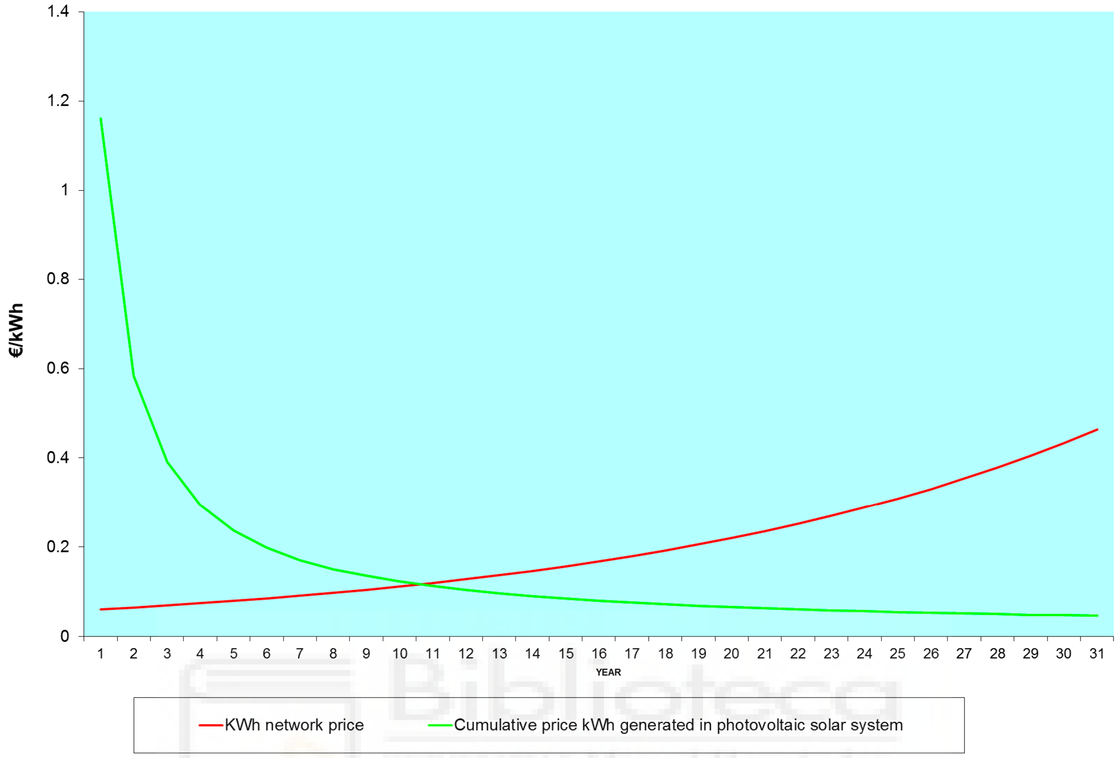


Figure 9. Comparative kWh cost of network versus cost of kWh generated by photovoltaic solar installation. Water well.

If we observe the cutoff point between both curves, this indicates the year when the unit price of the electric energy consumed starts to be greater than the unit price of the self-consumed energy (including the cost of the installation, maintenance, and the estimated annual decrease in the performance of solar panels).

3.6. Summary of Calculation of Photovoltaic Solar Installations

Following the calculations in the previous section, the data of the photovoltaic installations of the three sources of water supply for irrigation are obtained (Tables 6–8).

Table 6. Summary of the photovoltaic solar installation of the pumping in the well.

Pumping Well—Photovoltaic Installation	
Projected power	232.9 kW
Annual generated energy	543,200 kWh
Budget	**630,000 €**
Total number of p 1.400 unities of 250 Wp, c/u	
Regulators-Inverters	350 kW
IRR (31 years)	10.34%
Nº of years for profitability	11

Table 7. Summary of the photovoltaic solar installation of the Tajo-Segura transfer pumping.

Pumping TST—Photovoltaic Installation	
Projected power	237.3 kW
Annual generated energy	360,971 kWh
Budget	**630,000 €**
Total number of p 1.400 unities of 250 Wp, c/u	
Regulators-Inverters	350 kW
IRR (31 years)	8.31%
Nº of years for profitability	10

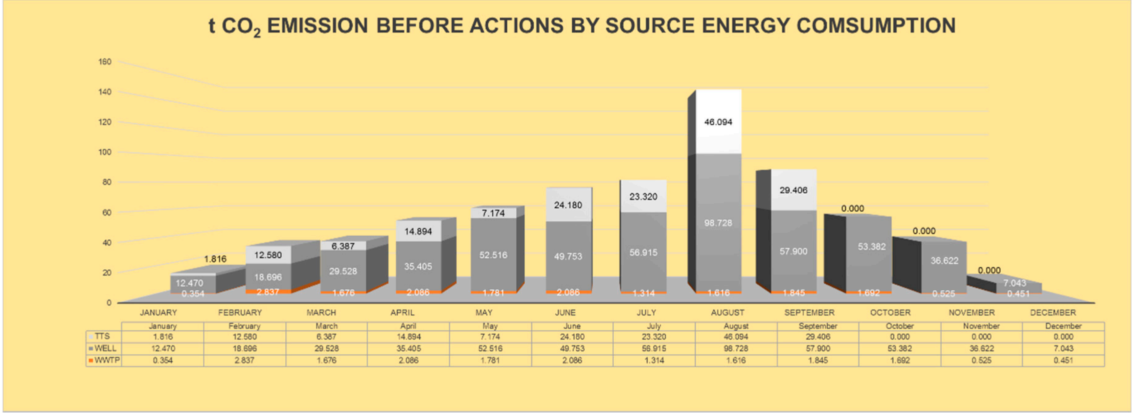
Table 8. Summary of the photovoltaic solar installation of the pumping at wastewater treatment plant.

Pumping WWTP—Photovoltaic Installation	
Projected power	63.64 kW
Annual generated energy	108,640 kWh
Budget	**126,000 €**
Total number of p 280 unities of 250 Wp, c/u	
Regulators-Inverters	60 kW
IRR (31 years)	11.99%
Nº of years for profitability	7

4. Results and Discussion

4.1. Results

This study examined each of the pumping stations, obtaining the 31-year IRR of a network disconnected from the photovoltaic system (supplied in time by a portable generator); interesting values have been obtained from the point of view of profitability, equaling 8.31% for TST pumping, 10.34% for the pumping well and 11.99% for the pumping WWTP. The equivalent quantity in kg for the CO_2 emissions released into the atmosphere were calculated (considering that the 1 kWh ratio corresponds to 0.341 kg of CO_2) [16], thus the total amount of CO_2 produced was 693.07 t (Figure 10).



	January	February	March	April	May	June	July	August	September	October	November	December
▫ TTS	1.816	12.580	6.387	14.894	7.174	24.180	23.320	46.094	29.406	0.000	0.000	0.000
■ WELL	12.470	18.696	29.528	35.405	52.516	49.753	56.915	98.728	57.900	53.382	36.622	7.043
🟧 WWTP	0.354	2.837	1.676	2.086	1.781	2.086	1.314	1.616	1.845	1.692	0.525	0.451

Figure 10. CO_2 emissions released into the atmosphere. 2016.

Figure 10. CO_2 emissions released into the atmosphere. 2016

It is important to note that the pumping operating periods for the different months should be adapted to the monthly generation curve of a photovoltaic facility [17], redistributing this consumption into adjacent months by leveraging energy storage through water elevation to reservoirs at high altitudes, rather than batteries, which equals significant savings in the cost of water. Likewise, this represents significant savings in the cost of installations (Figure 11).

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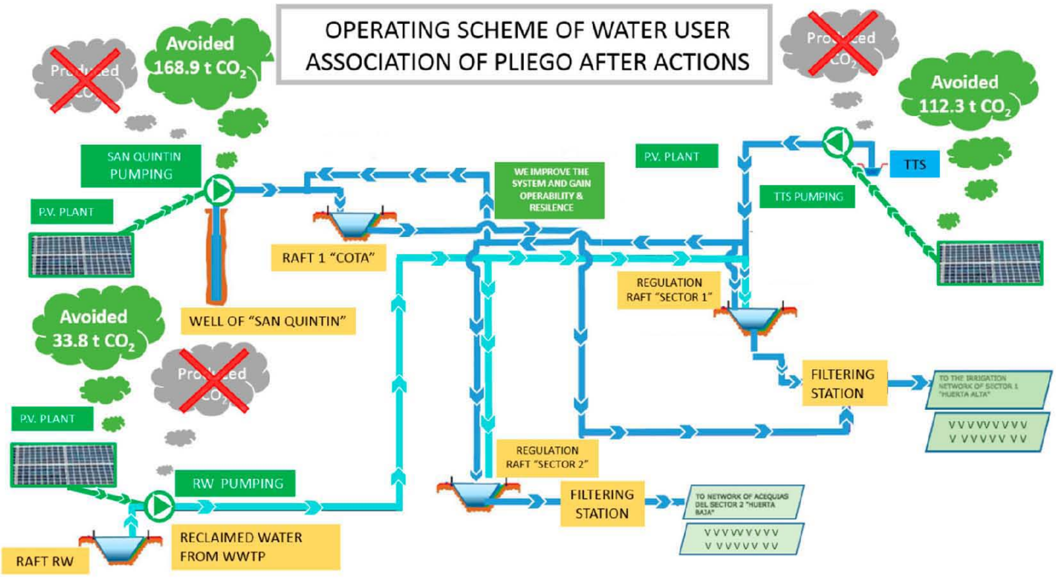
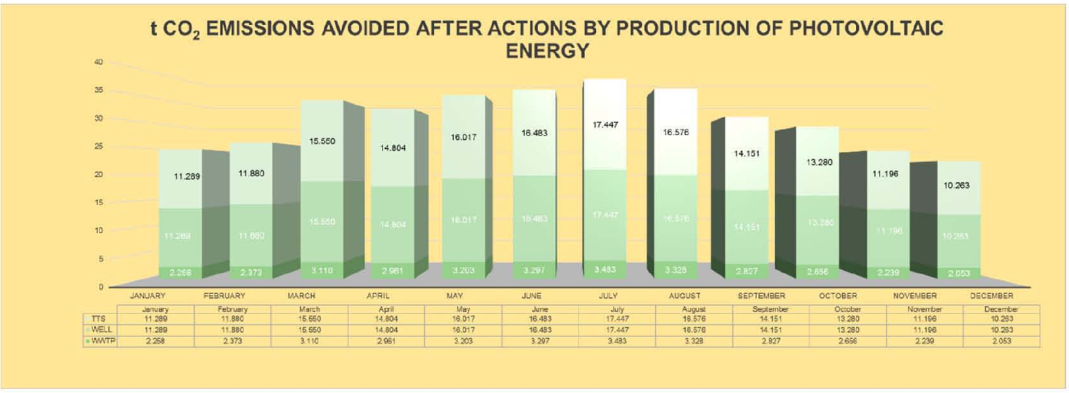


Figure 11. New WUA operating scheme.

Figure 11. New WUA operating scheme.

In the graph included, it is important to note the example provided for the calculation of the photovoltaic installation for pumping wells, the meeting point between the two curves (cumulative price curve of the grid electricity and the accumulated electricity price generated by photovoltaic panels); this cut-off point indicates the year after which the unit price of the electricity consumed begins to be higher than the unit price of self-consumed energy (including installation cost, maintenance, estimated annual performance of solar panels). This moment is before year 10 for TST pumping, before year 11 for the pumping well, and before year 7 for WWTP pumping. Moreover, we must not only weigh economic studies [18,19] when carrying out such actions. It is necessary to understand the reality of our global framework and to be aware that we must reduce CO_2 emissions. This study has evaluated the total CO_2 emissions avoided by the production of our photovoltaic plant, considering that the government is currently developing regulations to allow the grid to pour the surplus of energy produced, which is not used in the plant. Thus, the monthly amount of CO_2 emissions avoided is shown in the graph below (Figure 12), in which the values are the result of applying the grams of CO_2/kWh avoided by the generation of photovoltaic power (341 g CO_2/kWh) [20], less CO_2 generated for the implementation of the photovoltaic plant (30 g CO_2/kWh) [21]. This value has been adopted for the use of polycrystalline modules and supported by simple concrete supports on the draining ground as shown in the photo (Figure 13).

In the graph included, it is important to note the example provided for the calculation of the photovoltaic installation for pumping wells, the meeting point between the two curves (cumulative price curve of the grid electricity and the accumulated electricity price generated by photovoltaic panels); this cut-off point indicates the year after which the unit price of the electricity consumed begins to be higher than the unit price of self-consumed energy (including installation cost, maintenance, estimated annual performance of solar panels). This moment is before year 10 for TST pumping, before year 11 for the pumping well, and before year 7 for WWTP pumping. Moreover, we must not only weigh economic studies [18,19] when carrying out such actions. It is necessary to understand the reality of our global framework and to be aware that we must reduce CO_2 emissions. This study has evaluated the total CO_2 emissions avoided by the production of our photovoltaic plant, considering that the government is currently developing regulations to allow the grid to pour the surplus of energy produced, which is not used in the plant. Thus, the monthly amount of CO_2 emissions avoided is shown in the graph below (Figure 12), in which the values are the result of applying the grams of CO_2/kWh avoided by the generation of photovoltaic power (341 g CO_2/kWh) [20], less CO_2 generated for the implementation of the photovoltaic plant (30 g CO_2/kWh) [21]. This value has been adopted for the use of polycrystalline modules and supported by simple concrete supports on the draining ground as shown in the photo (Figure 13).



	January	February	March	April	May	June	July	August	September	October	November	December
TTS	11.289	11.880	15.550	14.804	16.017	16.483	17.447	16.576	14.151	13.280	11.196	10.263
WELL	11.289	11.880	15.550	14.804	16.017	16.483	17.447	16.576	14.151	13.280	11.196	10.263
WWTP	2.258	2.373	3.110	2.961	3.203	3.297	3.483	3.328	2.827	2.656	2.239	2.053

Figure 12. CO_2 emission in tons avoided by the production of photovoltaic energy.

Figure 12. CO_2 emission in tons avoided by the production of photovoltaic energy.

Figure 13. Photovoltaic installation.

Figure 13. Photovoltaic installation.

4.2. Discussion

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This research is part of an International European Project on the Effects of Climate Change, Sustainable Energy and Wastewater and Regenerated Management, within the European ALICE project (AcceLerate Innovation in urban wastewater management for Climate changE, https://www.alice-wastewater-project.eu/). In relation to the objectives established in the project, this study highlights the experience provided by the Region of Murcia, located in the southeast region of Spain, where more than 20 assault tanks and over 90 wastewater treatment plants have been built to reuse 97% of wastewater for agricultural use, avoiding an effect on valuable water bodies and sensitive areas of the coast with an exceptional quality of recovered water, which can be used for agricultural use without any health risks, in addition to reusing digested and treated sludge for use as nutrients for fertilization and improving productive capacities in crops. This project highlights the need for an interaction between the different developed countries that produce CO_2, as well as examining the consequences this has for them and third parties. To this end, there is a need to reduce energy consumption and exchange these for ecological sources capable of reducing the carbon footprint, as is the case of the Region of Murcia, a pioneer in alternative energy uses. Similarly, knowledge and experiences are exchanged on the uses of new technologies, such as the application of solar energy for disinfection, detection and remote control of emerging contaminants for disposal, the use of nanomaterials for wastewater treatment and others. All this training and information is being applied in the modernization of purification systems to continue the safe use of regenerated water in agriculture, combining it with the use of renewable energies that contribute to reducing the carbon footprint and improving the water footprint. The novelty is the implementation of solar energy to manage the energy demands of a community of irrigators of more than 600 years [22] which is characterized by having micro plots in a very abrupt environment, where the existing geographical and climatic conditions, make it necessary to manage scarce available water resources by pressurizing irrigation networks to improve water efficiency. To this end, on the basis of the available water sources, including the regenerated WWTP

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of the population of Pliego (Murcia), the demand for water has been estimated, as well as the production capacity for solar energy that will enable the management of agricultural spaces seeking sustainable production and the reduction of CO_2 emissions, thus preserving the environment. Herbaceous and forage cereals are produced in central and northern Spain, along with large expanses of vineyards, while the Mediterranean regions stand out for their production of vegetables, as well as for the cultivation of oil and cotton thanks to their geomorphological and climatic characteristics, among which the elevated hours of sunshine stand out, producing products of the highest quality [23]. The problem of these coastal regions is the low rain intensity, therefore, they must make the most of the small amount of water available. This is only possible by pressurizing irrigation networks, with the consequent energy expenditure making it economically and environmentally unviable. Were it not for the use of renewable energy that, in addition to reducing CO_2 emissions, contributes to generating a sustainable system that will keep plants en masse, the progress of desertification [24] that threatens southern Europe would be increasing.

5. Conclusions

The result of these actions produces an improvement in the avoidance of emissions thanks to the implementation of photovoltaic plants. However, these measures must also be accompanied by management improvements regarding the schedules of irrigation shifts, and starter systems [18] for pumping via the use of inverters, together with the implementation of new pumps with better performance and lower consumption.

In our case, the system vulnerabilities have been studied based on critical infrastructure risk analysis methods, which have been developed, and have been shown to be effective for pipes, as well as for achieving greater safety and reliability [25]. After evaluating the initial hydraulic system, we detected that during daytime pumping-taking advantage of photovoltaic energy, there was a conflict or threat to the irrigation of crop areas located at low dimensions, as shown in Figure 14 from the raft dimension. The single reversible conduit, which pumped water from the raft of regenerated water to the rafts at a higher height, while lowering it and making changes in the direction of water, mobilizing large flows by using important section pipes, caused numerous problems in valves, and special parts, causing a greater likelihood of breakage [26]. Consequently, this entailed damage, by having to empty the pipes, considering the cost of repairing the conduits, in addition to the water wasted during the discharge and filling the conduits in order to carry out the repairs. Furthermore, this comes with a risk, according to the importance of the breakage, of a lack of supply capacity which, in turn, in certain horticultural crops can entail a loss of production.

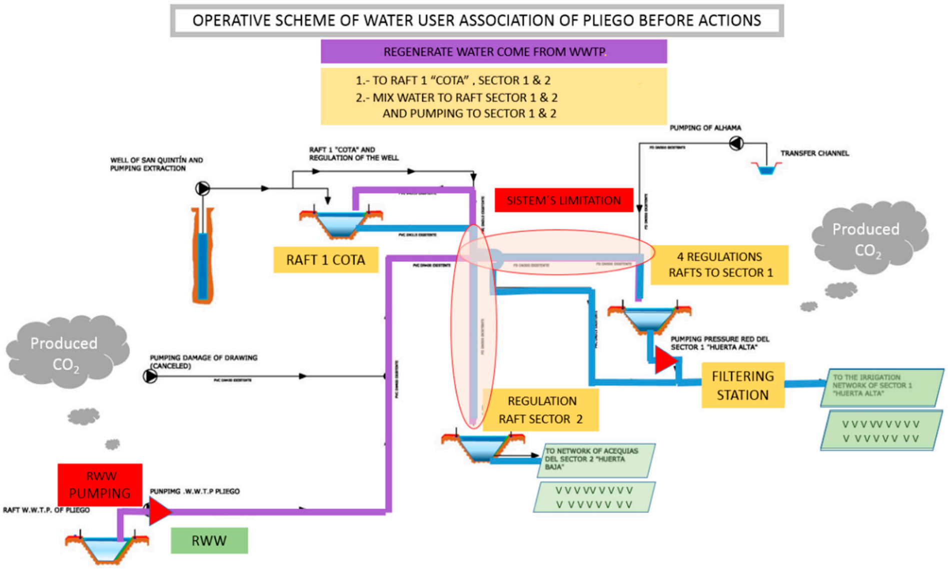

Figure 14. Operative scheme of WUA of Pliego before actions.

Figure 14. Operative scheme of WUA of Pliego before actions.

To this end, we decided to duplicate the main conflictive conduits to render the system more robust, and to guarantee the maximal use of the photovoltaic energy generated, as shown in Figure 15, obtaining a new operating scheme.

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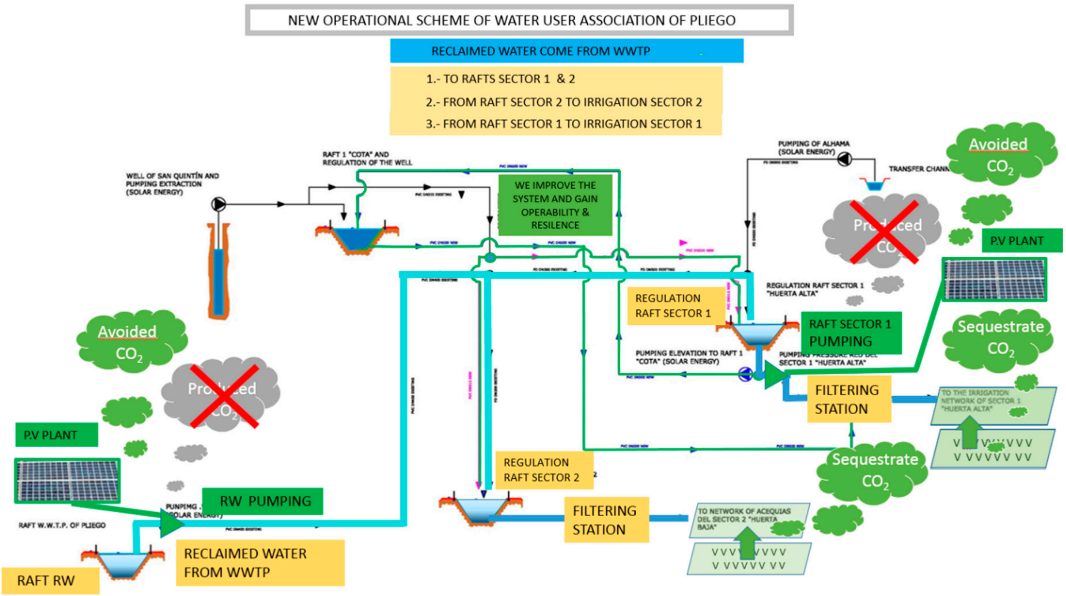

Figure 15. New operational scheme of WUA of Pliego.

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In addition, considering the initial carbon emissions shown on the grid, these can be higher than those that are actually avoided and this is not only due to the improvement of sustainable energy sources, but also to the addition of other actions related to selecting the best system, or water governance and the use of ITCs (Information and Communications Technologies) that also cause reduced emissions. Finally, it should be noted that the implementation of these three photovoltaic installations have led to savings in annual CO_2 emissions, amounting to 314.99 t CO_2 (Table 9).

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Table 9. Summary of avoided carbon footprint by solar actions (t CO_2).

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Avoided Carbon Footprint by Solar Actions (t CO_2)	PV kWh/year	g CO_2/kWh	t CO_2
Photovoltaic installation pumping WWTP	108,640	311	33.79
Photovoltaic installation pumping Well	543,200	311	168.94
Photovoltaic installation pumping TST	360,971	311	112.26
			314.99 t CO_2/year

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Photovoltaic installation pumping TST	360,971	311	112.26
		314.99 t CO_2/year	

Consequently, these three actions significantly improve the energy capacity of the irrigator community, and not only reduce annual maintenance costs, once the installation is amortized, but are not affected by the electricity tariff factor. It should be noted that in semi-arid areas of the Mediterranean we must not only think of fruit/agricultural plantations as the main means of production, but also as an ecological method of protection against climate change, to combat desertification. Based on these findings, a number of recommendations can be made to future installations with photovoltaic energies regarding the necessary steps that should be made in an attempt to implement these improvements:

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1. Determine the type of crop, as well as its associated area to obtain its water demands.

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2. Identify the water resources and balance the needs of water resources.
3. Determine the energy needs, at critical points (calculating the CO_2 emitted).

4. Select the points of greatest energy demand and calculate the area necessary to implement the solar field.
5. Determine the graph for its implementation and calculate the avoided CO_2.
6. Implementation of an irrigation management system in the plots to adapt the production of photovoltaic energy to its consumption.
7. In extreme cases, some farmland must be conditioned, leaving land fallow, in order to achieve a sustainable energy system.

This process can be applied to any association of farmers or users from any country in the Mediterranean area, in regions with climatic characteristics similar to the study area, with a shortage of rains and great heatstroke. Thus, primary production methods, such as agriculture, must be integrated into technological development, serving as an example of development for other semi-arid regions that require accessible solutions. Furthermore, this may reduce the need to import energy from other countries, providing new opportunities for sustainable growth through the use of renewable energies such as photovoltaic energy (total reduction of 371.67 t CO_2 avoided, once the entire photovoltaic energy produced has been harnessed).

This is one of the many steps taken by this community of irrigators in the region of Murcia, Southeast of Spain, in order to manage the natural resources available [27]. Thus, by evaluating the supply chain from its origins considering this as a fundamental aspect of the life-cycle assessment (LCA), aided by Smart-Agri technologies applied, along with the sensorization and inclusion of these databases generated with telemeasures and uploaded to the cloud, this information can be integrated into the Ecoinvent LCA database [28], helping to support farmers applying for environmental certificates for their products.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

WUA	Water user's association
WWTP	Wastewater treatment plant
TST	Tajo-Segura transfer
E_d	Average daily electricity production from the given system (kWh)
E_m	Average monthly electricity production from the given system (kWh)
SDGs	Sustainable Development Goals
LCA	Life-cycle assessment
GHG	Greenhouse gas emissions
H_m	Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
PVGIS	Photovoltaic Geographical Information System
CM SAF	Satellite Application Facility on Climate Monitoring
IRR	Internal rate of return

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6.3. -Publicación 3: Adaptation of a Traditional Irrigation System of Micro-Plots to Smart Agri Development: A Case Study in Murcia (Spain).

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Article

Adaptation of a Traditional Irrigation System of Micro-Plots to Smart Agri Development: A Case Study in Murcia (Spain)

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Abstract: Currently, water users associations (WUAs) in semi-arid areas of southeastern Spain (Murcia region) send a multitude of data supplied by sensors in the field to the cloud. The constant technological revolution offers opportunities for small farms not to be abandoned, thanks to the Internet of Things (IoT). This technology allows them to continue to manage remotely using smartphones/tablets/laptops. This new system contributes to the mitigation of climate change from several aspects: reduction of water footprint and energy consumption (in the pumps that pressurize the grid, such as in the optimization of the proposed solution, by using batteries that communicate in low radiation of electric and magnetic alternating fields (LoRad), General Packet Radio Service (GPRS), or narrowband IoT (NB-IoT), or clean energy). The analysis of these data and the incorporation of new IoT technologies facilitate the maintenance of green roofs and ensure the continuity of these farms. The direct benefit obtained is remarkable CO_2 removal that prevents desertification by the abandonment of arable land. This communication shows the implementation of a Smart Agri system in areas with micro-plots (surface less than 0.5 ha) with low-cost technology based on long-range (LoRa) systems, easily maintainable by personnel with basic knowledge of automation, which transforms into a very interesting solution for regions with development roads. In addition, complex orography and difficult access are added in both physical and technological environments. The main technical limitations found in such plots are poor coverage for mobile phones and unworkable and expensive implementation by wiring or WiFi/radio systems. Currently, thanks to the Smart Agri system implemented in this WUA in Murcia, farmers can manage and control the irrigation systems in their plots from home. Then, they cannot lose their crops and respect the isolation conditions imposed by the Spanish government as a result of the alarm caused by COVID-19.

Keywords: carbon footprint; water footprint; LoRa; IoT; desertification; COVID-19

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1. Introduction

The use of the Internet of Things (IoT) by water users associations (WUAs) contributes to the mitigation of climate change from several aspects, including the reduction of the water footprint [1–3] and energy consumption. Several wireless communication systems have been employed in these systems, such as long-range (LoRa) [4], among others. Maintaining green roofs and the continuity of these farms can be done by incorporating new IoT technologies [5–7]. One of the direct benefits obtained is remarkable CO_2 removal [8], which prevents desertification by the abandonment of arable land. This paper shows the implementation of a Smart Agri system in areas with micro-plots (surface less than 0.5 ha) with low-cost technology based on LoRa systems [9]. In addition to the advantages mentioned above, these systems allow the remote management of fields with isolation conditions because of the restrictions caused by COVID-19 all over the world [10].

A case study located in Pliego (Spain) will be described. Pliego is a municipality in the central area of the region of Murcia. The Pliego water users association (WUA), due to the current drought that is hitting the east of Spain, increased energy consumption and its price, and the scarce availability of water resources for the irrigation of land, needs to act so that the traditional crops of farming families that are managed by descendants with new technologies do not become a desert. Forced to move to cities with new job prospects in order to survive the low yield produced by inherited smallholdings, these families have little time to pay attention to their farmland and represent the last link to the land of their parents. It is necessary for them to reduce and optimize the water demand for the irrigation of crops compatible with the terrain and to use new technologies to allow the management of their crops, dedicating a few minutes a day without having to travel to their farms. This is combined with elderly farmers who still manage the land in situ, looking skeptically at smartphones. The new technologies are applied in rural areas of mainly agricultural regions with a great history of technological development, as is the case in Murcia. They are the hope for certain types of micro-farms, which are not economically profitable, in order to avoid desertification (Sustainable Development Goal (SDG) 15.3: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world") [11–13]. These new technologies are capable of reducing some areas of water scarcity by abandonment. At the same time, they promote the sequestration of CO_2 by means of agricultural plantations in order to reduce the water footprint (SDG 12.4: "By 2020, achieve environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment") [14,15]. Specifically, thanks to the evolution of IoT, there are combined solutions for these purposes. For example, narrowband IoT (NB-IoT) provides a technical solution, which, combined with the use and dissemination of smartphones, allows the rural population to fix problems. Moreover, this technology allows access by people located outside of the rural plots. Most of them are successors of farmers who have been forced to emigrate to cities in search of better job opportunities. This situation is forcing the abandonment of micro-plots. The remote control, automation, and management of irrigation systems of these crops (Figure 1) represent an opportunity to change this situation. Computer applications and energy-efficient software will give the opportunity to modernize and manage plots with minimum investment.

Annually, thousands of engineers from all over the world visit this region to learn about these systems, from high distribution networks (pumps, reservoirs, filters, among others) to irrigation systems close to crops (drip irrigation [16–19] collection and reuse of filtered water to the subsurface [20–22] and spraying [23], among others [24–26]).

In this scenario, more than 20 years ago [27], the first attempts to automate WUAs emerged. The intention was to obtain meter readings and remote control of the opening and closing of valves. Initially, the most sophisticated devices were used with Fieldbus technologies with two-wire power and communications. Separate communication power was included in other facilities (four wires). These early attempts failed due to the high cost of installation and wire network maintenance. In this case, it was the precise installation of miles of buried wire along hectares of farmed land. An alternative to wire networks was radio modem-based systems [4]. They consisted of integrated technologies from industry, adapted for use in rural environments because of their high consumption and sensitivity to weather factors. Deployment was easier due to wireless communication, but there was still a high maintenance cost. This involves, on the one hand, the use of licensed communication bands, and, on the other hand, huge energy consumption.

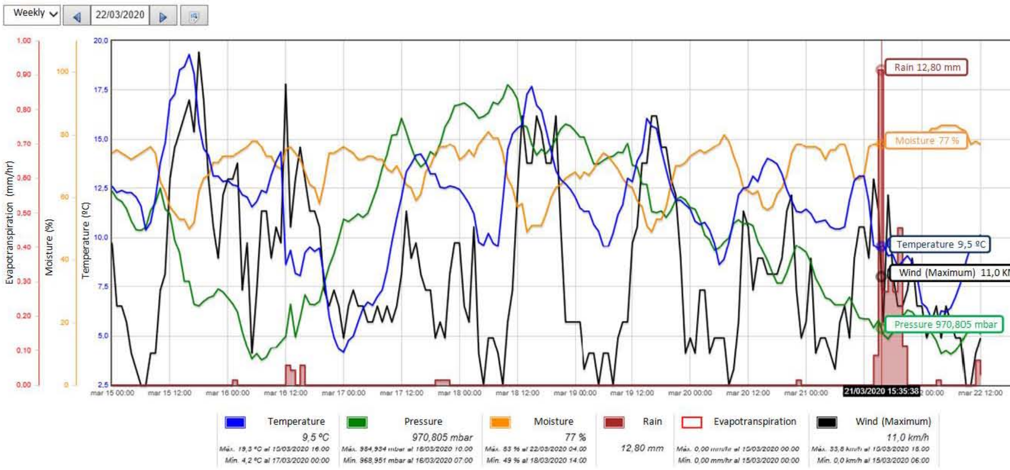

Figure 1. Graph of data available to users via the Internet of Things (IoT).

Energy consumption requires the installation of large solar panels. In addition, high power dissipation caused numerous breakdowns because of the overheating of equipment. With the improvement of wireless technologies (WiFi, Zigbee, etc.), communication modules based on free-band 433 MHz and then 868 MHz appeared [28,29]. They were quickly adapted to replace the old radio modems. With much lower acquisition and deployment cost, the biggest problem was the short communication distance. This situation forced the use of numerous hubs and repeaters in the network. This ultimately led to the development of less robust topologies due to the abundance of nodes. For hubs, however, radio modems were still used with the same problems described above. With the development of mobile telephony, the first equipment based on Global System for Mobile Communication (GSM) and later General Packet Radio Service (GPRS) began to appear [30]. This equipment, already designed specifically as solutions to be applied to irrigation, were much more adaptable and their deployment, with exclusive dependence on the coverage of the area, was very simple. As fully independent equipment transmitting directly to the Internet, they form extremely robust topologies. The aim is to design a system that allows the management and control of micro-plots operated through IoT technologies, helped by friendly apps that are manageable, even for people with basic knowledge about these technologies. All the technical problems of this specific case would be solved. At the same time, it would allow carrying out the procedures at any time of the day and anywhere in the world where there is an Internet connection [31–34].

2. Materials and Methods

The case study of the application of information and communication technology (ICT) in the Pliego WUA irrigation system includes several levels of devices and sensors. The main objective of this research was to integrate two types of systems: a new one in Sector 2 with larger plots, whose new implementation allowed the use of commercial hardware but required a minimum amount of control for 16 plots to be economically viable, compared to another for Sector 1 of smaller size and abrupt orography, capable of serving micro-plots with independent remote transmission units.

The main scheme of the system is described in Figure 2. The data provided by the different sensors are recorded according to their degree of importance (the greater the importance, the greater the frequency of reading), and are turned over to the remote transmission units (RTUs) for storage up to 6 months. When the communication ports are opened, they launch a LoRa signal that is picked up by the nearest concentrator, and this identifies the communication station and labels the date, compares whether the received data are more recent than what is stored and whether this is how it records them

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(otherwise it does not store them), and this process is repeated to at least 2 concentrators to guarantee communication. In turn, if these concentrators have new instructions that have been sent from the app by users or administrators, they return them during the temporary communication window (repeating the verification process) and can thus reprogram the RTUs to modify the programming (such as opening and closing valves, increasing the frequency of meter reading, determining if an anomaly has been detected). Finally, after closing the communication cycle, which in our case was limited every 2 h to extend the battery life (it can be modified if there are problems), the data are uploaded to the network and recorded on a physical hard disk and optionally in the cloud, to later be viewed on the users' app and the supervisory control and data acquisition (SCADA) system. This does not mean that there is no update of the scale in 2 h, but all data provided by the sensors of all WUAs of the system are completed every 2 h. At the same time, critical points (primary network and some in the secondary) are read in real time and updated instantly in the app and the SCADA.

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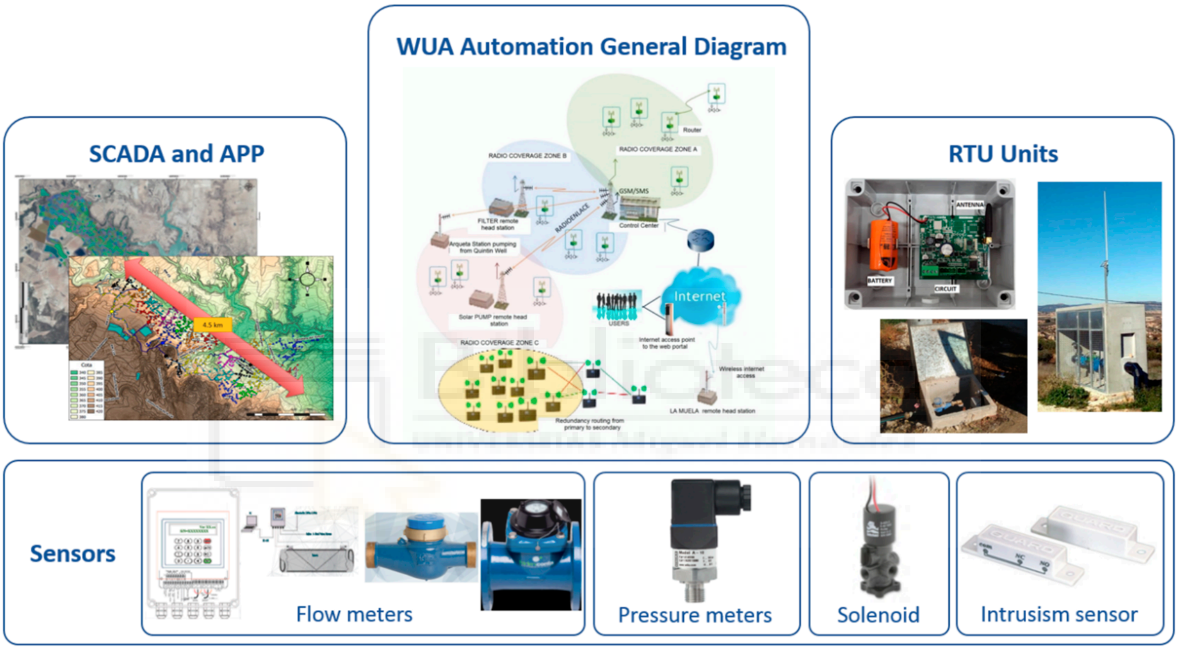

Figure 2. Scheme of automation system in Pliego water users association (WUA).

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We focused on the development of new hardware and software expressly designed to solve communication problems and facilitate the management of irrigation schedules by users and make it easier for administrators to control the entire system with sufficient information to make decisions that are most beneficial, and for this it was necessary to satisfy three main functions:

1. System consultation: serves the managers to be able to control the operation of the system in real time (not open hydrants flow consumed, pressure at control points, etc.).
2. Acquisition of historical data: allows administrators and users to know and consult the data already recorded (consumption, pressure, valve opening/closing states, etc.).
3. Reading or on-demand action: provides the last recorded data and allows interactions with connected elements.

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Taking into account these requirements, our system was designed, and here we describe the main integrated devices in this automation system, as indicated in Figure 3. There are two automation levels apart from the screen system for consulting and management (SCADA, apps, others). The first level consists of remote transmission units (RTUs). First, in the RTUs, the concentrators can be distinguished. This device is a concentrator of communication and RTUs with inputs and outputs.

level consists of remote transmission units (RTUs). First, in the RTUs, the concentrators can be distinguished. This device is a concentrator of communication and RTUs with inputs and outputs. Moreover, it can communicate with a central server using GPRS technology or free-band radio, and can operate continuously for 6 months in the absence of communication without a loss of information. This is a totally autonomous device. The concentrators are powered by batteries and, as additional support, can manage their charge through small solar panels. Additionally, these devices include the possibility of wireless firmware reprogramming. The most basic equipment can control up to 4 hydrants, 1 digital input and 1 output, and 2 analog inputs, although this number can be expanded by using input/output (I/O) expansions. They can work as a GPRS or radio endpoint and as a GPRS/radio mixed communications hub. These devices collect and concentrate the communications from a radio subnet and retransmit them via GPRS.

The other RTU type is the slave. These devices can communicate with a central server using GPRS technology or free-band radio, and can work continuously for 6 months in the absence of communications without a loss of information. These devices are fully autonomous. They are powered by a single lithium battery that gives them autonomy greater than 3 years in the GPRS version and 10 years in the radio version (24 daily communications). They can control hydrants and digital input, and can work as GPRS endpoints or radio. In this case, there is also the possibility of wireless firmware reprogramming. The consumption is 35 uA in the absence of communications, while consumption increases depending on the number of communications per hour and their duration (Table 1) [35,36].

Table 1. Annual battery consumption depending on number of communications.

		Number of Daily Communications							**Always Connected (1 Hourly Communication)**
		1	**2**	**4**	**6**	**8**	**12**	**24**	
Analog input reading interval 4–20 mA (min)	60	7.85	7.64	7.44	7.25	7.44	7.25	6.73	0.11
	30	4.37	4.31	4.24	4.18	4.24	4.18	4.00	0.11
	15	2.32	2.30	2.28	2.26	2.28	2.26	2.21	0.10
	10	1.58	1.57	1.56	1.55	1.56	1.55	1.53	0.10
	5	1.21	1.21	1.20	1.20	1.20	1.20	1.18	0.10

The RTUs include antennas to avoid the lack of coverage because of the topology. Hubs have antennas on 4 m masts. Concentrators simultaneously control the sector outlets.

The sensors included in this system are described as follows. Initially, 1300 units of variable caliber multiple jet counters with pulse emitters were installed. Additionally, 20 units of Woltmann meters, with a diameter of 150 mm with pulse emitters, were included. Finally, the project included 6 units of noninvasive ultrasonic flow meters. They were connected to a Siemens power line communication (PLC) in a solar pump and can also be connected to the remote units described above. The PLC is integrated in the system. The valves of the entire irrigation system are controlled by approximately 1320 units of 3-latch solenoid valves. Finally, the pressure is controlled by 28 units of 0–10 bar pressure transductors.

First, to prepare this study, data from Pliego, a village located in Murcia (Spain), and the census of farmers of Sector 1 of the WUA's Pliego network were offered in the crop inventory of the region of Murcia 2016–2017 [37]. These were analyzed in order to guide the sectors according to the type of predicted crop. The intention was to take advantage of different hydraulic needs according to the months of the year when the crop grows.

Second, it should be noted that the installation of a remote control system in the WUA of Pliego was a challenge, both technically and economically. The main characteristics that were taken into account will be described here. To prepare this study, data on water consumption of different hydrants were analyzed. This analysis was developed in order to know the current demand depending on the type of crop on the ground, based on the census of the Sector 1 network. For this purpose, invoices of each micro-plot for the last 5 years were studied. Moreover, the existing main networks that

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can factorize and telecommand from the network and the different water resources were studied (wells, reservoirs, regenerated water from wastewater treatment plants [38], pumping station systems). The data they supply to the system (flows, water quality parameters, and network pressure) every hour for mono-hydrant flow meters and in real time at critical control points of the primary network and some of the secondary network are analyzed to keep pressure levels at a value around 25 m of the water column.

The RTUs include antennas to avoid the lack of coverage because of the topology. Hubs have antennas on 4 m masts. Concentrators simultaneously control the sector outlets.

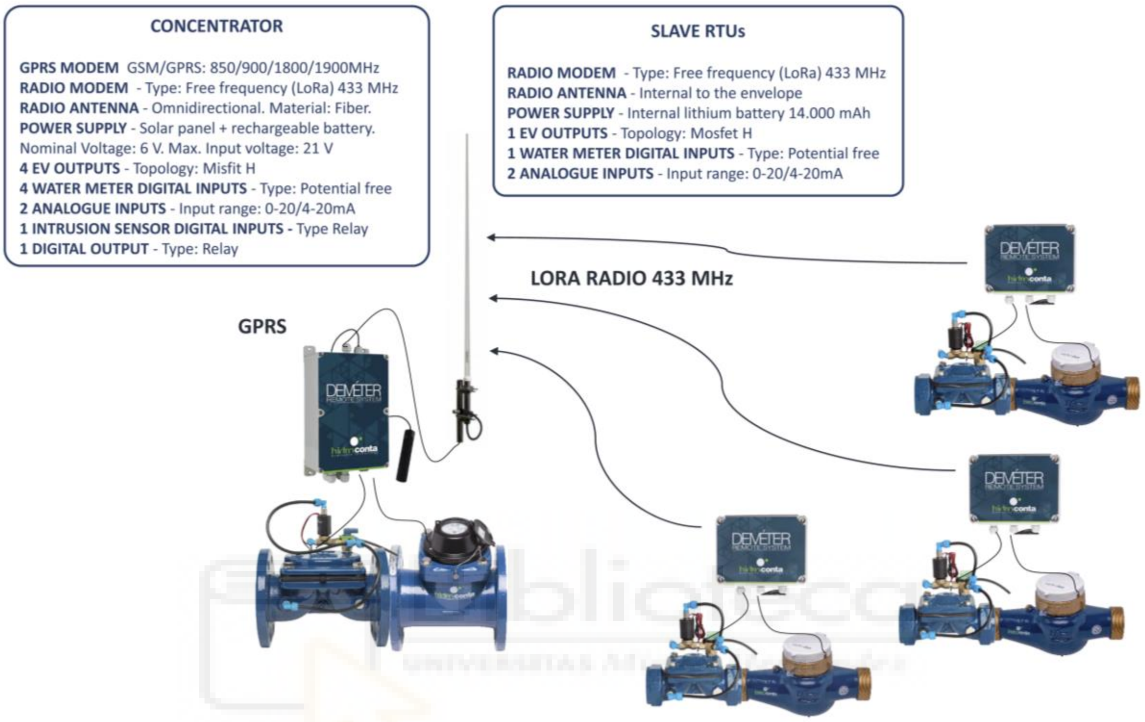

Figure 3. Descriptions of sensors in Pliego WUA.

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Several challenges had to be solved, mainly automating an existing network and offering users the ability to select irrigation scheduling for their micro-plots. Additionally, the location in a steep terrain involves great communication difficulties. All of this has to be managed in a way that is economically and environmentally sustainable [39]. For this purpose, the different technologies available to date [40–42] and their possible uses were evaluated, analyzing the pros and cons of each.

The challenge of this research was to design a cheap, scalable, easy-to-implement and maintain remote control system with the ability to fill the gap of existing hydraulic network topologies. For this purpose, providing solutions to any WUA regardless of its extension, topography, hydrant concentration, or coverage was intended. This system would provide a solution not only for WUAs with good conditions (extension, topography, hydrant concentration, and coverage), but other WUAs that, because of their special characteristics, have had difficulty automating with existing technologies until now. In this case, the price of each device for each user socket is EUR 298 compared to EUR 1300 that the alternative of installing a remote would cost. Regarding ease of maintenance, the biggest advantage is that they use standard batteries that are easy to replace. Finally, remote control is achieved thanks to the functionality of the device to connect over the Internet.

2.1. Analysis of Smart Agri System

Pliego's WUA includes three characteristics that are a technical challenge for the installation of a remote control system that is economically acceptable [43]: the average size of plots, the distribution of hydrants, and the geophysical space in which it is located.

2.1.1. Average Parcel Size

The area of the sector under investigation, Huerta Alta (Sector I), reaches 373.59 ha. Taking into account that 1949 users are registered (Figure 4), they have an average parcel size of less than 0.2 ha per plot. This implies extreme atomization of the irrigation that makes this WUA an exceptional case, making it difficult to maintain and amortize equipment, whether hydraulic or electronic, to serve the area. The parcel used to draft the same was obtained from three fundamental sources:

- Census of the WUA of spread registers;
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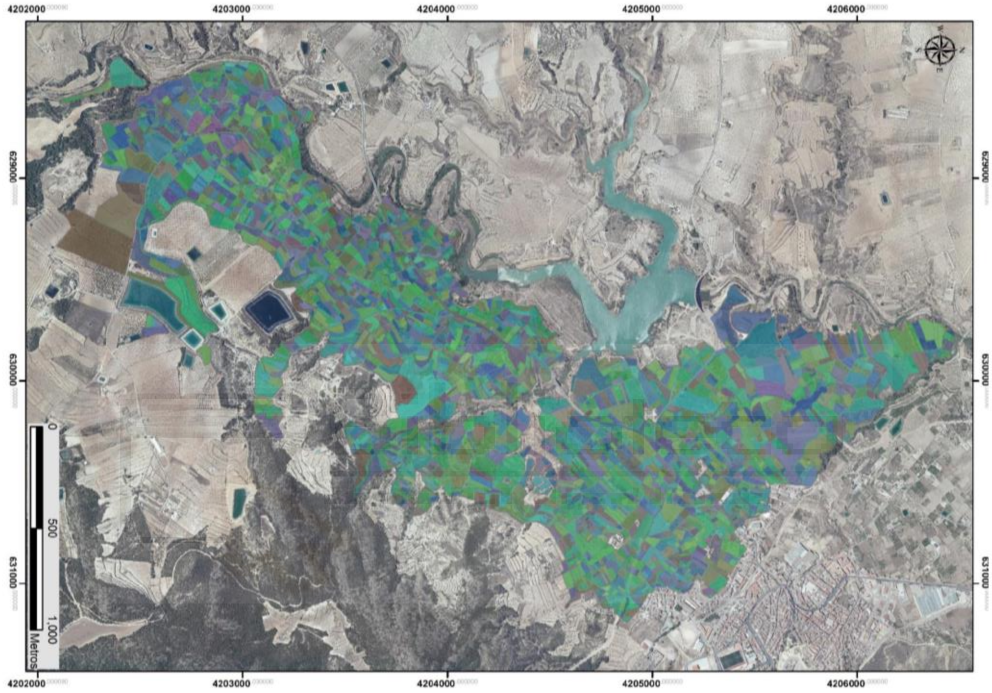

Figure 4. Distribution of micro-plots for remote control in Pliego WUA.

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2.1.2. Distribution of Hydrants

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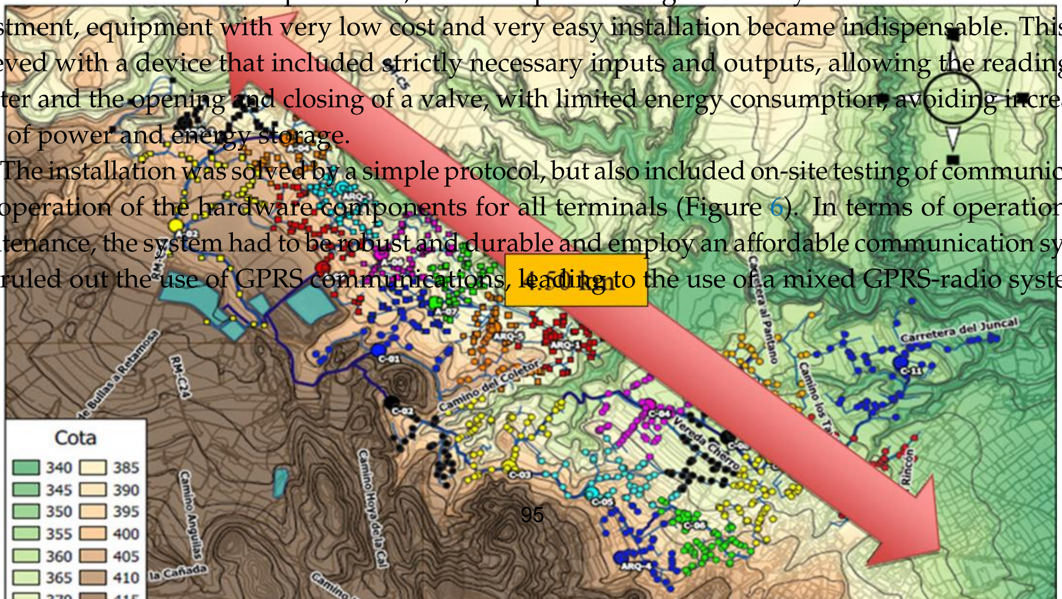
This means one device per 0.2 ha, which requires a large economy at various levels. For the investment, equipment with very low cost and very easy installation became indispensable. This was achieved with a device that included strictly necessary inputs and outputs, allowing the reading of a counter and the opening and closing of a valve, with limited energy consumption, avoiding increasing costs of power and energy storage.

The installation was solved by a simple protocol, but also included on-site testing of communication and operation of the hardware components for all terminals (Figure 6). In terms of operation and maintenance, the system had to be robust and durable and employ an affordable communication system. This ruled out the use of GPRS communications, leading to the use of a mixed GPRS-radio system.



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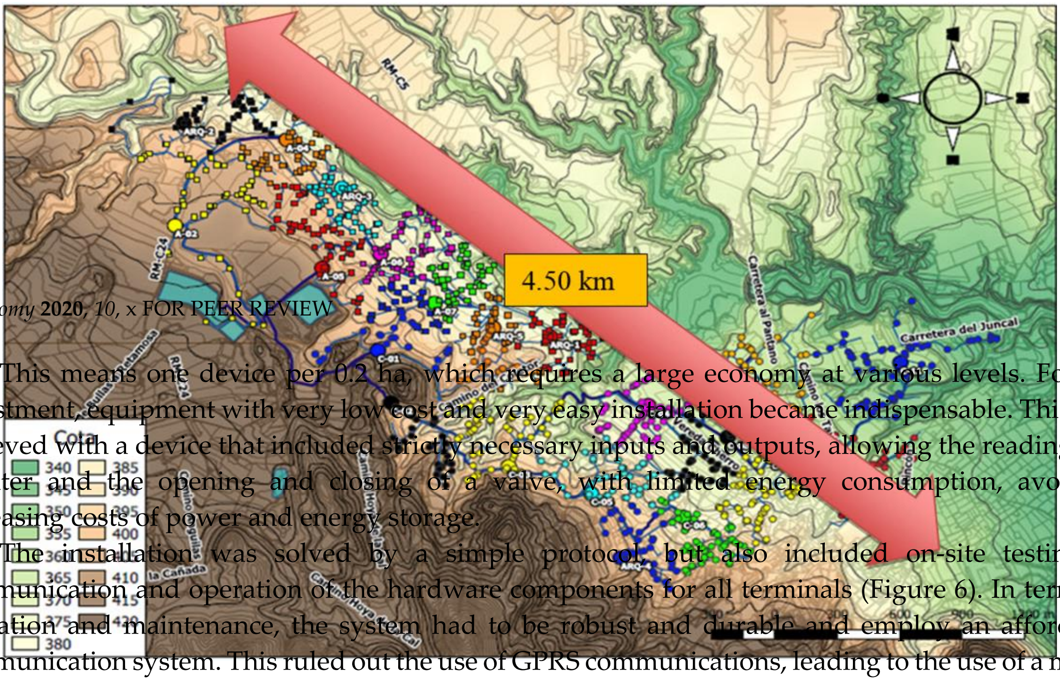

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Figure 5. Distribution of hydrants for remote control in Pliego WUA.

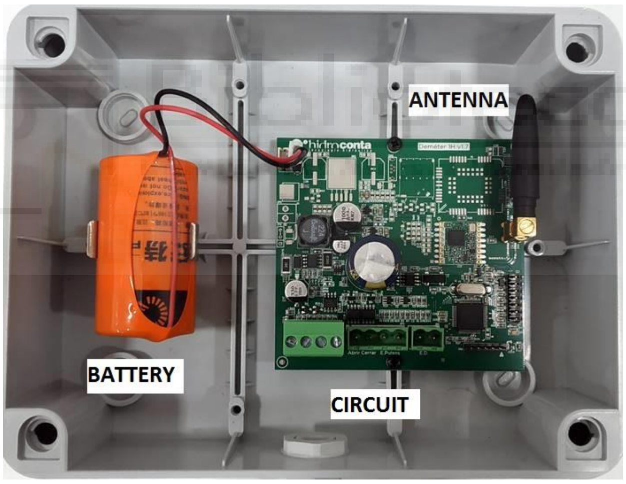

Figure 6. Smart Agri equipment and components (single user in a micro-plot).

For this purpose, the concentrators described above, which incorporate high-gain radio antennas that ensure the reception of communication in the ideal case of direct vision between them at distances reaching 5 km, were used (Figure 7). This distance should not be assessed in absolute terms but in relation to the size of the antennas in both the emitting and receiving equipment, in this case 270 cm in the hub and 5 cm in the slave RTU. In certain extremely difficult locations, correct communication was achieved by installing a 40 cm external antenna on the slave equipment. This was necessary in eight arches, which, considering a total of 1205 installed radio terminals (Figure 8), represent less than 0.7%. Figure 8 includes a hydrant, which consists of a flow meter with pressure regulation in order to connect the farmer's drip irrigation system.

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In order to reduce equipment maintenance costs, lithium batteries with an estimated duration of 10 years were used (Figure 9). In addition, the simple installation excluded fixed anchors and unnecessary screws, allowing the possibility of moving the equipment for quick and efficient inspection and operation. The lifetime of the battery depends on different factors (accuracy of float voltage, frequency of discharges, number of discharges, maximum discharge rate, depth of discharges,

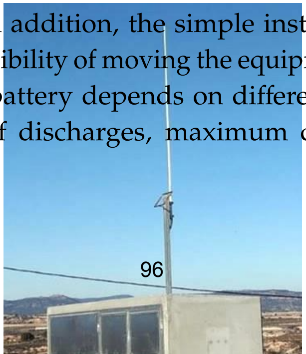

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Figure 7. Gener ctorization arch).

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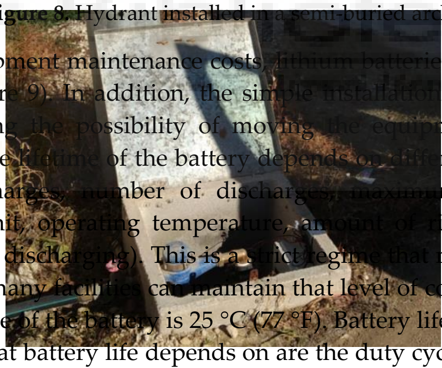
Figure 8. Hydrant installed in a semi-buried arch.



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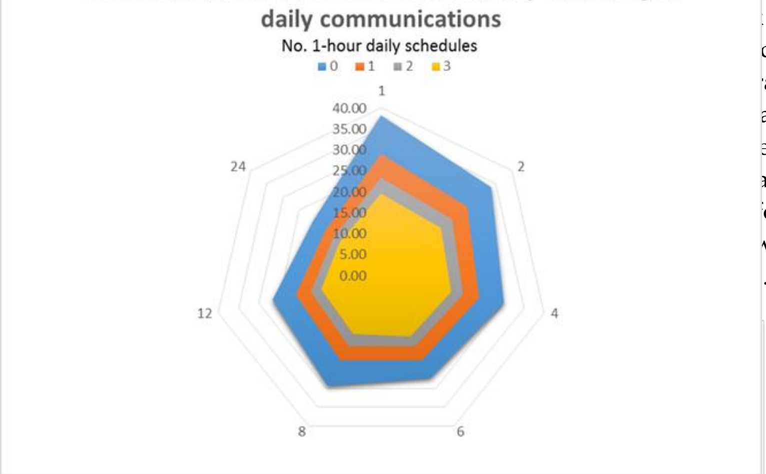

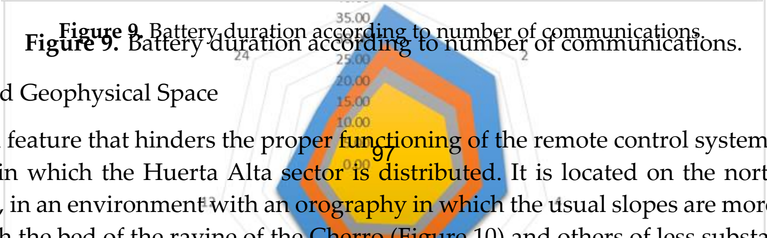

Figure 9. Battery duration according to number of communications.

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2.1.3. Occupied Geophysical Space

The third feature that hinders the proper functioning of the remote control system is the natural environment in which the Huerta Alta sector is distributed. It is located on the northern slope of Sierra Espuña, in an environment with an orography in which the usual slopes are more than 1/2 and the crops reach the bed of the ravine of the Cherro (Figure 10) and others of less substance.

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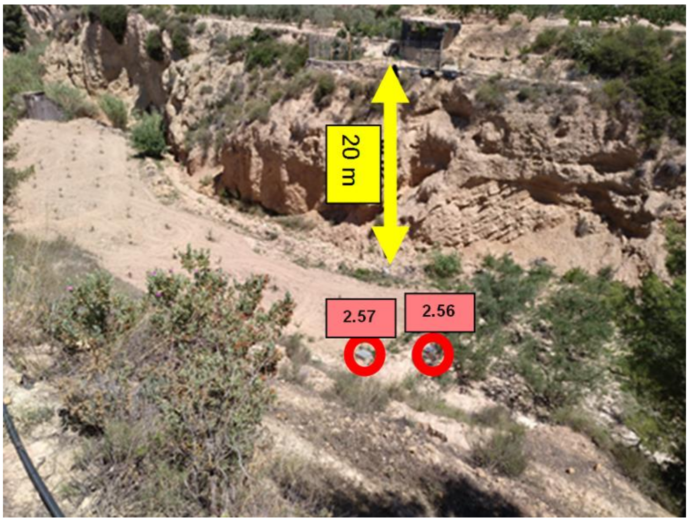

Figure 10. Crops in the ravine of Cherro and shots.

On the other hand, it is a highly anthropized environment, which reaches the population of Pliego and includes urbanized plots and seasonal residences. Both the orography and the existence tall buildings represent complications for the use of radio communications required by the conditions described above. To achieve the desired communication robustness, it was necessary to carry out a coverage study prior to the distribution of GPRS-radio hubs. These difficulties were enhanced by the characteristics of the arches contained in the equipment, which have very small dimensions as a result of the mono-hydrant distribution and the small caliber of the necessary hydraulic elements. This involves the emission of radio communications with the equipment installed a few centimeters from the ground, making constructions and low-rise elements possible obstacles. Another benefit of the redundancy system is the possibility to keep communications active even when there are specific obstacles such as vehicles and temporary installations.

It should be noted that given the band spectrum used and the amount of communication required per device, another aspect to consider to ensure the robustness of communication is the amount of equipment associated with each hub, which has a unique channel owner. To satisfy the amount of information to be transmitted without sacrificing the economics of operation and maintenance of the facility, a compromise solution was reached in which the number of slave radio terminals per GPRS-radio hub was limited to a maximum of 80.

3. Results and Discussion

As a result of the research carried out, it is worth highlighting the progress developed in the following aspects:

3.1. Integration of Communications in Latest Generation Free-Band

LoRa modulation is a low-power, long-range radio specification designed specifically for low-power consumption devices. Its operation, broadly speaking, is based on repeating the same message several times across its bandwidth, so that it manages, due to this sending redundancy, to overcome noise levels that would make communication with standard modulation impossible, thus achieving sensitivity greater than −145 dBm. This characteristic translates, as mentioned above, as a significant increase in transmission distance of equal power with other more traditional modulations and a high tolerance for installation in areas that by their orography do not have direct lines of antenna vision that are necessary for the proper functioning of such systems.

3.2. GPRS-Radio Mixed Hubs

A Smart Agri four-counter terminal can be configured to act as a hub for other terminals of one or four radio counters that route communications through it, all without losing the original ability to control the valves and counters connected to the hardware. The device, thanks to the energy support of its solar panel, can remain permanently connected to both radio and GPRS to be able to route the packets it receives from one end or the other, no matter when they are generated. This system, like other hub-based systems, has a weak point: if the hub fails, all remotes that hierarchically depend on

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3.3. Ease of Deployment and Maintenance

For all elements of the Smart Agri system, specific firmware has been incorporated that allows the operator who is responsible for its installation to check and debug all functions of the equipment (valves, counters, analog inputs, communication, etc.). This allows people to be 100% sure that the computer is properly installed and communicating, significantly limiting installation errors. This feature is very important for deployments in hard-to-reach areas (most cases), as it avoids having to move more than once to the same location during commissioning. The hardware is designed to facilitate the maximum possible maintenance. The equipment is usually installed in places with difficult access and conditions of extreme temperature and humidity, where maintenance is not easy for long periods of time. All system elements (connectors, splice strips, etc.) have been selected so that replacement of components due to faults, firmware updates, or any other reason can be done easily and quickly and with a minimum number of tools. Batteries, for example, are standard. The installation manager can easily get them from any Internet store and they can be easily replaced with just a screwdriver.

3.4. Flow Detection and Alert Generation

In our specific case, the server using the Demeter system is deployed with a local server exclusive to the installation and with the location required by the client. However, it is fully compatible with a cloud server, for which it contracts commercial services from third parties, and in which different installations coexist. Privacy is secured by login and a permissions system.

The system scheme once the information reaches the server is shown in Figure 11. In this case, unlike the long-range wide-area network (LoRaWAN), there is no network server, since with GPRS hubs and terminals, the information arrives by GPRS to the application server or back end. The application server interprets the GPRS communications and payload using representational state transfer (REST) APIs. The same REST API is used by the different interfaces for access to the system or fronts (Demeter SCADA Web through any Internet browser and Hydroconta metering app through any smartphone) and by applications at the highest level of third parties with which we have integrated.

The firmware of the remote units performs an extrapolated reading of the flow passing through the counter. The equipment measures the time between detecting two pulses so that it can accurately calculate the flow where it is being watered. This information allows communities to have a deeper understanding of their networks without having to install expensive flow measurement equipment, which also needs an external power supply in most cases. The system generates a multitude of alerts, all of them configurable by the user.

First of all, it is possible to have alerts related to the hardware, such as a communication failure, low battery, and a dirty solar panel, among others. Then, there are those related to the valves, such as closed valve flow detection and no flow detection with an open valve, and those related to the meter, such as excess flow and flow defects. Activation thresholds can be configured by the user based on their permissions. The same is true for analog-related inputs. For example, for pressure, an alarm will be generated for excess pressure or pressure defects. Thresholds are similarly configured by the user. The system also allows for configuring several phone numbers so that critical alerts can be sent via SMS and brought to the attention of responsible staff at the time they occur.

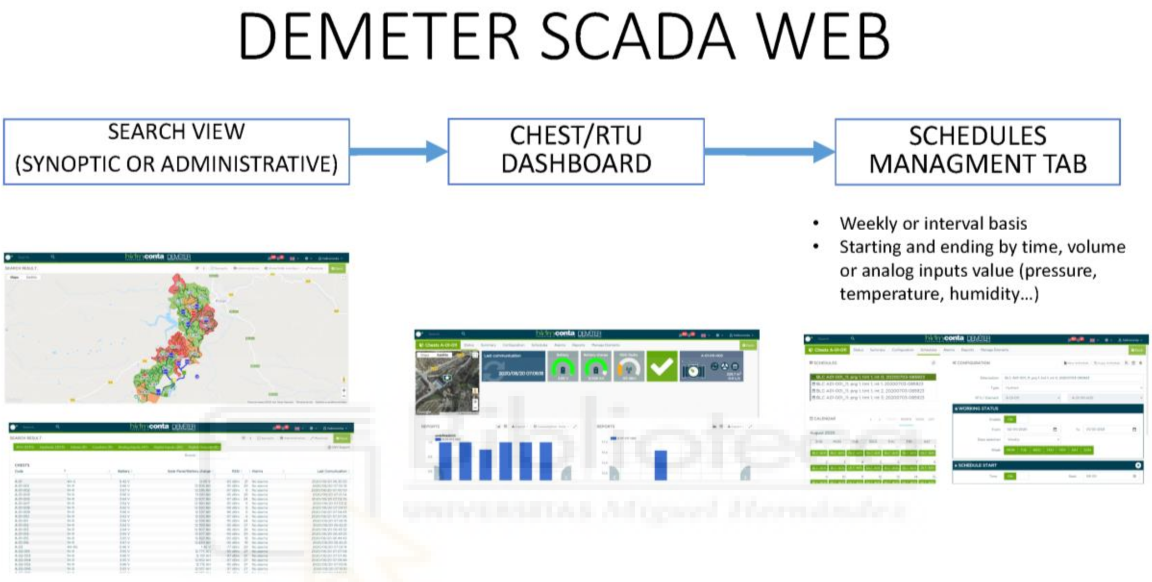

Figure 11. System scheme once information reaches the server.

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3.5. Elimination of Its Own Large Infrastructure

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Currently, it is very difficult to find a geographical area, especially in Spain, that lacks mobile phone coverage, which makes the situation of having to deploy a radio-only network extremely rare. In all other cases where we have equipment transmitting, either directly via GPRS or through its assigned hub to the Internet, it becomes unnecessary to install at the headquarters of the watering community any equipment related to the remote system (Figure 12).

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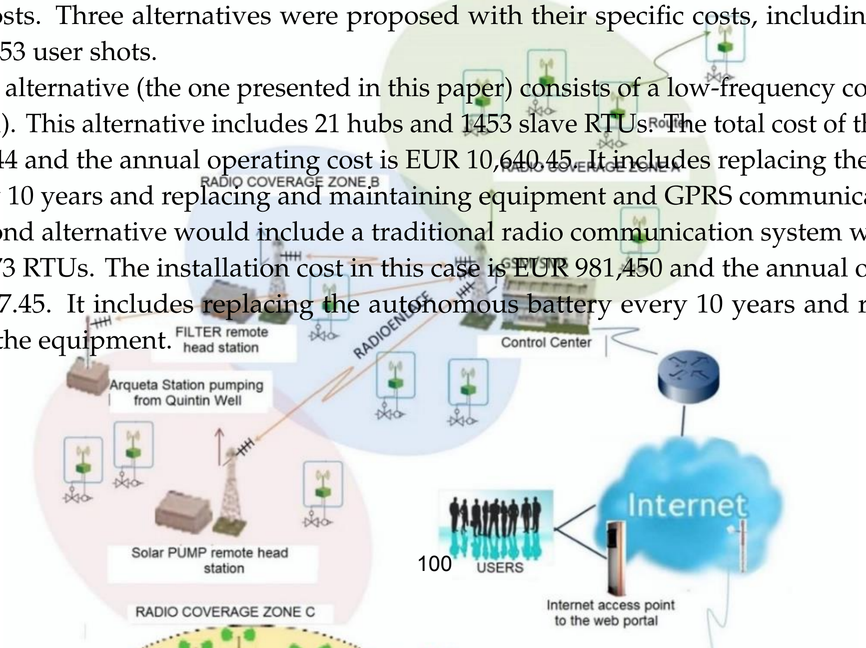
The option is given to install the system server in the cloud, which prevents the client from maintaining the server (cooling, replicating databases, power consumption, etc.) and avoids all associated costs. Three alternatives were proposed with their specific costs, including 20 shots by sector and 1453 user shots.

The first alternative (the one presented in this paper) consists of a low-frequency communication system (LoRa). This alternative includes 21 hubs and 1453 slave RTUs. The total cost of the installation is EUR 446,644 and the annual operating cost is EUR 10,640.45. It includes replacing the autonomous battery every 10 years and replacing and maintaining equipment and GPRS communications.

The second alternative would include a traditional radio communication system with two radio links and 1473 RTUs. The installation cost in this case is EUR 981,450 and the annual operating cost is EUR 49,057.45. It includes replacing the autonomous battery every 10 years and replacing and maintaining the equipment.



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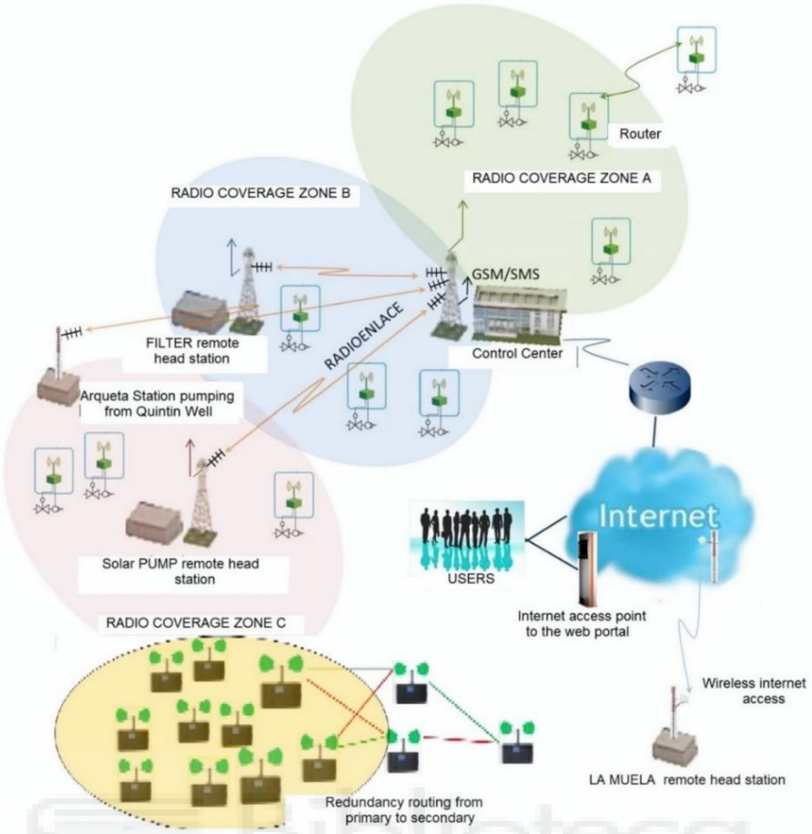

Figure 12. Integration scheme of different systems.

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The third alternative is a complete GPRS system with 1473 RTUs, at a total installation cost of EUR 438,954 and total annual operating cost of EUR 62,925.45. It includes battery replacement every 10 years, and replacement and maintenance of GPRS equipment and communications. The details of obtaining these costs are listed in Table 2.

Table 2. Details of the different systems.

Systems	Description	Amount
Radio long-range (LoRa)	Battery replacement (autonomous, 10 years)	145.3
	Equipment replenishment and maintenance (2%) **	30
	GPRS communications	21
Traditional radio	Battery replacement (autonomous, 10 years)	147.3
	Equipment replenishment and maintenance (5%) **	74
GPRS	Battery replacement (autonomous, 10 years)	147.3
	Equipment replenishment and maintenance (5%) **	30
	GPRS communications	1473

** A lower annual equipment replenishment rate (2% vs. 5%) is expected for the LoRa radio system because it is low-power radio with far fewer high-temperature conditions in field installation versus traditional high-power radio and GPRS.

To determine the viability of the system, areas planted according to crop were studied (Figure 12), and peach trees, with a higher percentage of implantation and average annual benefit estimated at EUR 3722/ha [44], were selected as a representative crop, with this value analyzed and compared. The cost–benefit graph shows the investment according to the communication system and is easily appreciated for small plots with surface values of less than 0.05 ha, as in our case (Figure 13). The other solutions require a higher rate of return and can make investment in automation unfeasible.

Despite having a similar implementation cost, the expenses and maintenance costs are higher, and this is compounded by a lack of guaranteed communication coverage, which makes them unfeasible.

Agronomy **2020**, *10*, x FOR PEER REVIEW 14 of 18

Agronomy **2020**, *10*, x FOR PEER REVIEW 14 of 18

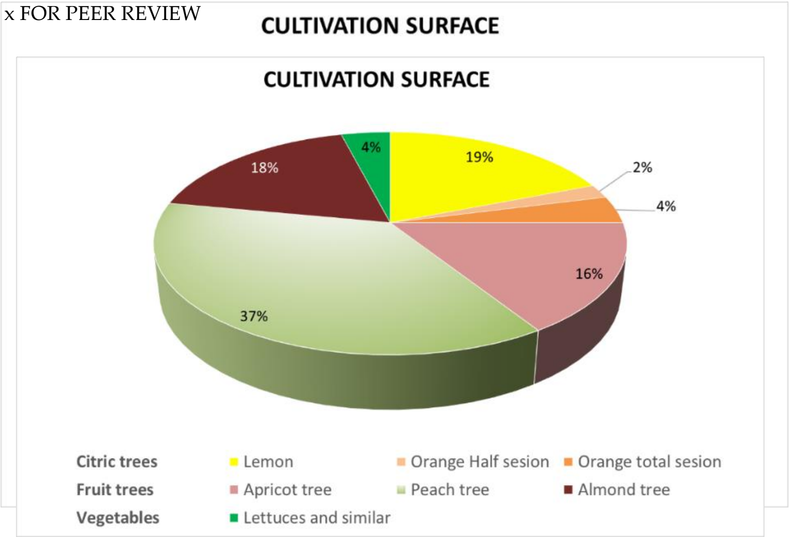

Figure 13. Crop type according to surface.

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On the other side of the scale, the use of LoRa is evaluated, because despite being a well-known technology, it has not been satisfactory due to limitations in the communication band, which have been corrected by software that establishes communication motives every hour, with a redundancy system to guarantee the robustness of the system without depending on the weather and coverage of the area. The proposed alternative is clearly the most appropriate from the cost–benefit analysis point of view (Figure 14).

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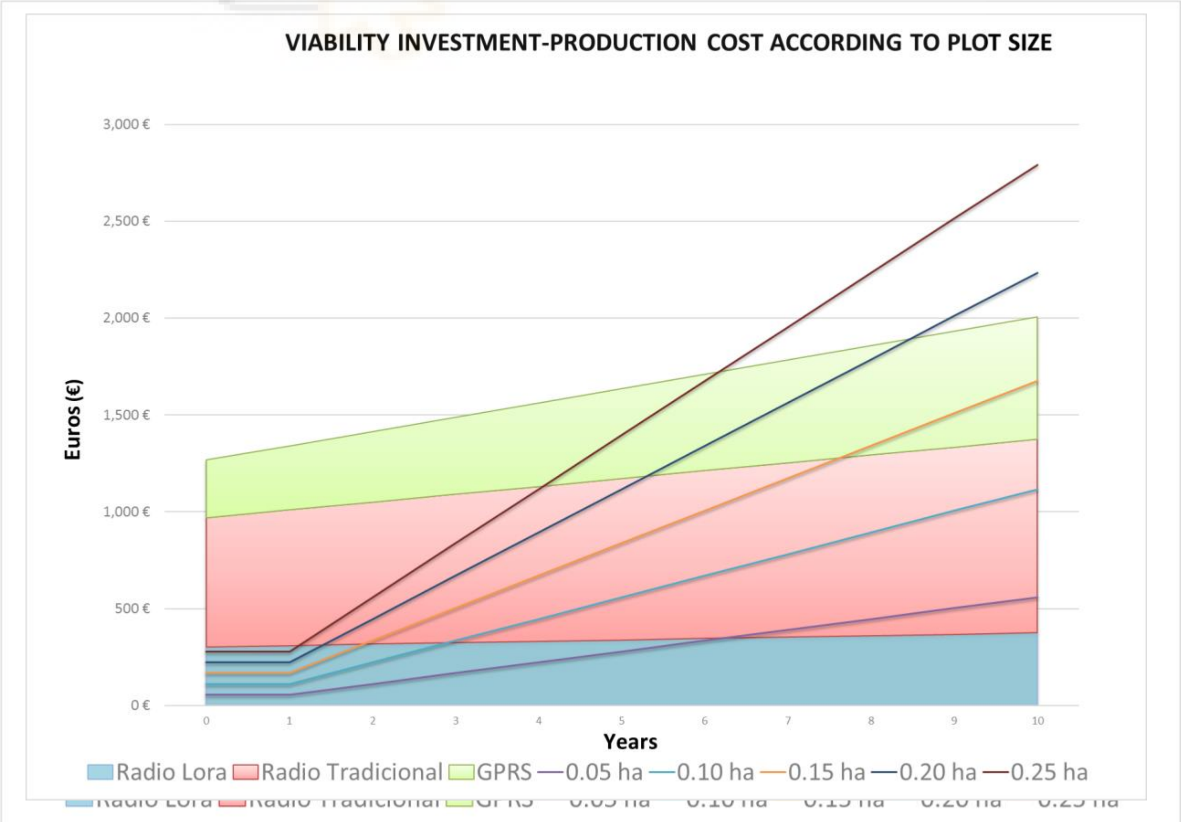

Figure 14. Feasibility of investment as a function of the type of architecture versus plot surface.

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The new technology developed by Smart Agri offers the ability to control the irrigation status of crops from any point. Thanks to the modernization of irrigation in the southeast of Spain, software is being developed that improves the way farmers work. New IoT applications are preventing the abandonment of fields that have survived since time immemorial in the Segura River Basin. With these new tools, it is possible to improve the gaps; Internet agriculture, which continues to evolve, also collaborates to counter climate change, reducing the water footprint and carbon footprint. On the other hand, it is notable that situations such as the one we are currently experiencing (COVID-19 pandemic) [45] enable safer management and subsistence of vital agricultural products for the population, reducing the exposure of farmers who use these IoT technologies, even in extreme situations such as isolation.

Some of the advantages of this device are as follows:

- The telemetry solution is open and allows connection to various sensors with standardized outputs on the market.
- It is possible to monitor the state of other devices, relay outputs, and analog or digital outputs.
- The included I/O device is a data server that responds to requests from a data cloud platform or other devices such as mobile phones and tablets, among others.
- The monitoring devices are connected to the Internet. Machine-to-machine (M2M) protocols determine whether they operate independently or as part of the SCADA system. This allows communication with other devices or machines.
- Communication between devices and people is a strong point. It is possible to connect with a single click from anywhere. Additionally, it is possible to configure alerts.
- The stored data (historical and real time) are exposed on dashboards accessible by the web on any browser and are very intuitive to interpret.
- The precision agriculture telemetry platform enables graphics to be customized to the needs of the user.
- The charts are helpful to interpret what is happening and allow the user to establish better criteria for managing the farm as a whole.
- The data make agriculture smarter by improving management from the agronomic, environmental, and economic points of view.

Author Contributions: Conceptualization, J.C.-Z.; validation, A.R.-C. and J.M.M.-M.; supervision: A.R.-C. and J.M.M.-M.; investigation, writing—original draft preparation, writing—review and editing, conceptualization, software, formal analysis, resources, data creation, visualization, project administration: J.C.-Z., D.P.-B., and C.A. All authors read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

API	Application programming interface
BBDD	Databases
FSK	Frequency shift keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
ICT	Information and communication technology
LoRad	Low radiation of electric and magnetic alternating fields
NBIoT	Narrowband IoT
RTU	Remote terminal unit
SASW	Smart Agri SCADA web
SCADA	Supervisory Control and Data Acquisition
SDGs	Sustainable Development Goals
SMS	Short message service
TST	Tajo-Segura transfer
WUA	Water user's association
WWTP	Wastewater treatment plant

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6.4. -Publicación 4: Reducing the carbon footprint of the Water-Energy binomial through governance and ICT. A case study.

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Reducing the Carbon Footprint of the Water-Energy Binomial through Governance and ICT. A Case Study

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Abstract: This paper reveals reductions of up to 485 t CO_2 eq (CO_2 equivalent) of greenhouse gas (GHG) emissions of energy origin associated with the water-energy binomial which can be achieved after modernizing and automating a Water User Association (WUA) of over 1780 users with microplots in a total area of 775 ha in southeastern Spain. This case study aims to show how the latest advances in information and communication technologies (ICTs) for precision agriculture are being applied efficiently with the implementation of a Smart Agri system, capable of making improvements through the use of renewable energies (64.49% of the total CO_2e- avoided), automation in irrigation water management, by applying adequate governance, use of ICTs (731,014 m^3 per water footprint reduction with 20.41% of total CO_2 eq of associated electrical origin), hydraulic improvements (283,995 m^3 per water footprint reduction, 13.77% of the total CO_2 eq of associated electrical origin) and reduction of evaporation in reservoirs (26,022 m^3 of water by water footprint reduction with 1.33% of the total CO_2 eq electrical origin avoided) that act as batteries to accumulate the daily solar energy and enable watering at night, when irrigation is most efficient. It is important to consider the valuable contribution of these artificial green lungs, not only in terms of food for the European Union, but also as a CO_2 eq sink that supports the planet's GHGs. As shown in this study, this is made possible by the joint governance led by the Water Users Association (WUA) and co-led by different management organizations with the support of ICT.

Keywords: water footprint; photovoltaic; reclaimed water; irrigation modernization; reservoirs

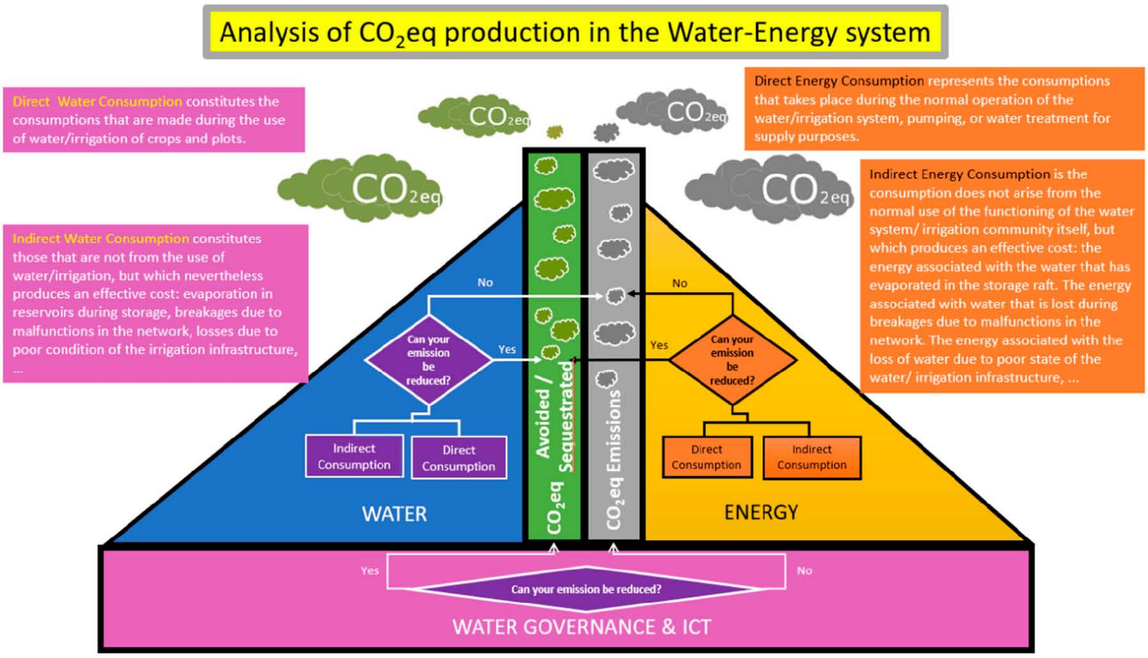
1. Introduction

The first reports of water governance in Murcia date back to the time of Alfonso X 'El Sabio', in the thirteenth century [1]. The rules for the use of water for agricultural use came from Muslim settlements. The Muslim people passed on the knowledge learned from the East [2], using the energy of the moving water to elevate it to lands above river level, adding value to the land dedicated to dry crops thanks to others with irrigation. In doing so, they understood the need to seek renewable energy sources. Farmers in the Region of Murcia (Spain), in the Segura basin, have maintained, improved and preserved the hydraulic facilities they inherited, while striving to produce the best fruits and vegetables in Europe.

The water and energy binomial applied to farms, using pressurized water systems, is a consequence of the water stress to which temperate areas of the Mediterranean area are subjected. The decrease in water availability, due to climate change, is forcing Murcian farmers to develop sustainable water energy systems to make their farms viable and reduce the water footprint by reducing their water consumption, taking advantage of the torrential rains captured by storm/environment tanks [3], using recovered water [4] and increasing the efficiency of its distribution systems. In addition, alternative energies are required to reduce emissions costs and production [5–7], together with the carbon footprint associated with the required energy consumption (based on real-time ICT governance and management [8–10]).

This study is based on the different energy audit systems used in Eastern Spain [11–13]. To this end, a scheme has been established that may be applicable to other water systems, which analyses the emissions generated, both avoidable and non-avoidable. Figure 1 shows a diagram that evaluates different actions based on their relevance and effectiveness. In a first phase, the total water unit system (irrigation system) should be examined and localized energy component consumption evaluated [14], considering both water reduction and carbon footprint. To achieve a global result, energy turnover has been studied in recent years along with water consumption by existing sectors. The diagram shows the role of water governance (Figure 1, purple zone), which is similar to a remote control management system. A maximum demand per hectare should be established because new crops should not be planted in certain sectors so as not to collapse the system. As for water problems (Figure 1, blue zone), this study examined how to sectorize the irrigator community by grouping sectors by similar manometric height levels, because excess pressure can cause leaks at irrigation points [15]. In addition, different scenarios are studied that are able to supply water according to demand by combining various sources (i.e., wells, transfers, regenerated water), without compromising viability. It is also necessary to locate any leakage to repair them or determine the abnormal operation of the hydraulic elements, complementing this with the use of regenerated water [16], just as astronauts do [17–19]. These processes are achieved through an energy balance where water intakes and CO_2 eq emissions are well established. Once these steps are completed, it is necessary to study the parts of the system that consume energy (Figure 1, orange zone) and generate emissions [20]. The energy consumption needed to replace them with renewable energies should be analyzed [21] or reduce consumption by applying smart measures and systems. In addition, water losses due to evaporation should be examined because, in this case, the losses caused are significant and lead to energy waste and avoidable emissions. Additionally, this study sought to visualize the sequestration of CO_2 eq by agricultural plantations (the artificial lungs of southern Europe), [22]. Several publications have been revised and used as a method of calculation, CO_2 eq sequestration by green mass has been differentiated from cultivation and soil depending on crop type and area, as well as its emissions during breathing in the night phase and emissions produced by fertilization. With these values, a balance of the CO_2 eq sequestered a WUA has been calculated.

Water **2020**, *12*, x FOR PEER REVIEW 3 of 18



Analysis of CO_2eq production in the Water-Energy system

Direct Water Consumption constitutes the consumptions that are made during the use of water/irrigation of crops and plots.

Indirect Water Consumption constitutes those that are not from the use of water/irrigation, but which nevertheless produces an effective cost: evaporation in reservoirs during storage, breakages due to malfunctions in the network, losses due to poor condition of the irrigation infrastructure, …

Direct Energy Consumption represents the consumptions that takes place during the normal operation of the water/irrigation system, pumping, or water treatment for supply purposes.

Indirect Energy Consumption is the consumption does not arise from the normal use of the functioning of the water system/ irrigation community itself, but which produces an effective cost: the energy associated with the water that has evaporated in the storage raft. The energy associated with water that is lost during breakages due to malfunctions in the network. The energy associated with the loss of water due to poor state of the water/ irrigation infrastructure, …

Figure 1. CO_2 eq analysis production in a Water-Energy system. Source: Own elaboration.

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2. Materials and Methods

2. Materials and Methods

This study analyzed the monthly consumption of all consumption points in the Water Users Association (WUA) over the last 10 years (about 216,360 records). This data was processed in Excel to determine energy turnover for the year 2016 (considered the baseline year). In addition, all inputs and water consumption during 2016 were collected to determine a real kWh value of the energy associated with each m^3 of water consumed. With the kWh/m^3 obtained annually, the CO_2eq t values associated with energy consumption were calculated to determine the carbon footprint generated by an WUA. Later (with this kWh/m^3 value, and after applying ICTs, governance measures and consumption reductions), it is possible to calculate how much energy is being wasted, also avoided CO_2eq emissions are calculated. Subsequently, to show the benefits of crop management, a study was carried out on the evolution of crops over 10 years in the two municipal terms associated with this WUA, based on this work on the studies by CEDEX (Center for Studies and Experimentation in Public Works in Spain) on sequestered CO_2 eq by these crops, according to their species, the sequestered CO_2 eq was determined.

The applied methodology has been included in several publications. A general aspect about the evaluation of the nexus food, energy and water is cited by Sadeghi et al. in 2020 [23]. This was located in USA. Another publication is about the determination of water footprint and primary demand for rice systems in China [24]. This paper includes the calculation of carbon footprint (CF), nitrogen footprint (NF), and primary energy demand (PED) of different rice production systems. Another case study was located in Spain [25]. The study was developing the reduction of water footprint and energy consumption (in the pumps that pressurize the grid, such as in the optimization of the proposed solution, by using batteries that communicate in low radiation of electric and magnetic alternating fields (LoRad), General Packet Radio Service (GPRS), or narrowband IoT (NB-IoT), or clean energy). The case study was about irrigation systems. Some aspects about energy balances and greenhouse gas emissions in agricultural zone in China [26] is cited in other paper. In this study, the objective was to evaluate the difference of crop and livestock products regarding energy balances, greenhouse gas (GHG) emissions, carbon economic efficiency and water use efficiency using a life cycle assessment (LCA) methodology on farms in three sub-oases within the Shihezi Oasis of China. Moreover, some authors of this article included an additional study about the reduction of carbon footprint in a water user's association in Spain [27]. In this case, the use of photovoltaic generation for the contribution in the reduction of

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greenhouse gas (GHG) emissions is analyzed. Additionally, the water and energy footprint for this system is presented. These methodologies have been included in the present paper.

2.1. Field Data

The Water Users Association (WUA) of the area under study is located in the Region of Murcia (Spain). The irrigable area is 799.71 ha: SECTOR I "HUERTA ALTA" (373.58 ha) and SECTOR II "HUERTA BAJA" (426.03 ha). This WUA is a combination of different irrigation groups and associations with over 1400 farmers. This WUA is fortunate to be able to choose three sources of water from different sources (regenerated water from the wastewater treatment plant (WWTP) in the village of the case study, water from the Tajo–Segura Transfer (TST), and a well on the property). The associated costs are proportional to the energy needed to pump the water and transport it to the plots that require the water and to lift it to the height applicable to the crops. Water governance and planning plays a fundamental role in achieving long-term life cycle analysis (LCA) objectives (our case study LCA gate to gate). Actions in agriculture are not instantaneous; they require a medium term to be effective and achieve significant objectives. The use of energy is associated with a carbon footprint which must be reduced to achieve the sustainable development goals (SDGs) and reduce the impact on the environment. Furthermore, the water footprint is associated with water governance, either by reducing its losses by improving distribution pipelines, improving management through automated systems that identify leaks and ultimately optimizing irrigation systems.

2.1.1. Agroclimatic Characteristics

It is important to consider the key agroclimatic characteristics of this WUA in relation to our study: a characteristic warm or semi-warm Mediterranean subtropical climate, with high temperatures during the summer determined by its latitude, reaching values of 32–34 °C, scarce rainfall (200–300 mm per year), although intense in years of flooding (e.g., torrential rains may occur, surpassing 350 mm). For these reasons water supply capacity must be guaranteed during the driest months, in the years of most rainfall.

2.1.2. Available Resources and Water Demand

To determine the true needs of the WUA, the operating regimes of the different sources available were analyzed and a reference year was used, which was most suited to the average consumption over the last 10 years. These data (Figure 2) provided a snapshot of the needs per month. As these needs are seasonal (that is, supply varies with the months of the year, depending on the weather and the state of storage of the transferring Tagus basin), this requires the collaboration of the reservoirs that are in service and the different available resources. The annual amount of available water is 3,629,361 m^3 which guarantees the survival of the crops. Using these values as a starting point, it is important to analyze and propose actions to compare and quantify the potential associated improvements. To do so, an initial scenario must be established, with specific data that can later be evaluated. This study considered 2016 as the baseline year.

2.2. Equivalent CO_2 eq Flow to the Atmosphere

If the quantity of consumed kWh for irrigation water supply is analyzed, the total amount for 2016 was 2,032,471 kWh. To calculate the carbon footprint generated it is important to know the transformation rate of this value. The fork values of the studies investigated range from 0.0413 $kgCO_2eq/kWh$ in a study conducted in Brazil according to Cardozo et al. [28], up to 0.947 $kgCO_2eq/kWh$ recorded by China in the two studies investigated by Li Cheng et al. [29] and Wan et al. [30] reached a value of 0.780, 0.608 and 0.166 $kgCO_2eq/kWh$ in Iran [31,32] and in Spain [33], respectively.

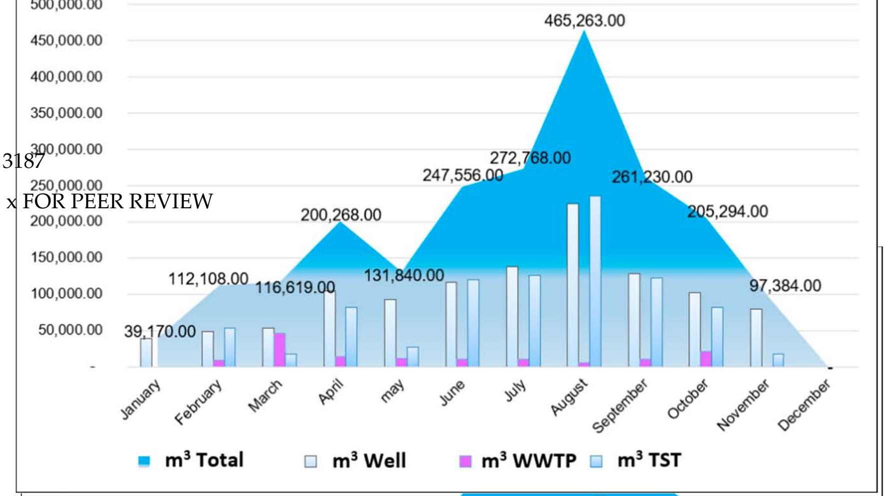

Figure 2. Monthly water purchased, according to the water supply source. Source: Own elaboration.

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The values used in this study were based on the annual transformation rates called "electric mix factor ($kgCO_2eq/kWh$)", determined by the National Commission on Markets and Competition (CNMC, www.gdo.cnmc.es). The last 5 years were considered in order to calculate the average value (Figure 3).

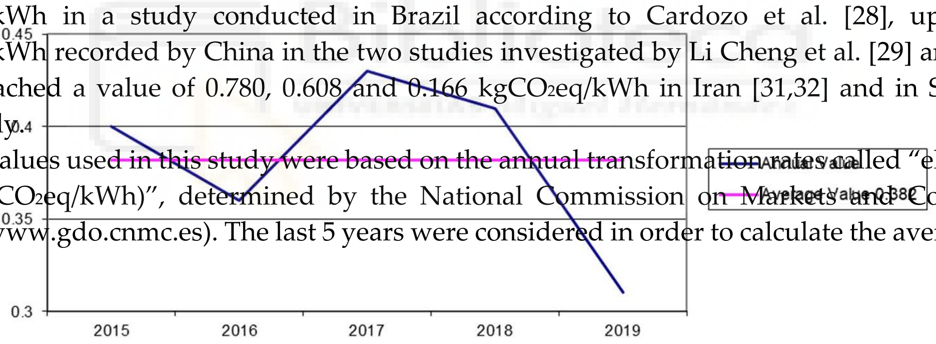

Figure 3. Evolution of the transformation index for electric energy in Spain ($kgCO_2eq/kWh$) 2015–2019. Source: Own elaboration, based in official CNMC data (Spain) (www.gdo.cnmc.es).

In the case of electrical energy, the rate of transformation varied between 0.041 and 0.947 $kgCO_2eq/kWh$, due to the generation mix used in each study area. This has been a key factor in calculating GHG emissions from water management in irrigation, and consequently it is important to deepen this aspect, analyzing and considering variations in the rate of transformation of electricity, to more accurately calculate the generated GHG emissions.

In total, 74 gCO_2eq/kWh was deducted from the cost of emissions involved in the generation and installation of photovoltaic plates according to data obtained from table 8 of study by Huld et al. [34] resulting in the 0.308 $kgCO_2eq/kWh$ of this study which fits with the values set out above (taking into account the relation: 1 kWh corresponds to 0.308 kg of CO_2 eq) equaled a total amount of 626 t CO_2 eq (Figure 4).

Water **2020**, *12*, x FOR PEER REVIEW 5 of 18

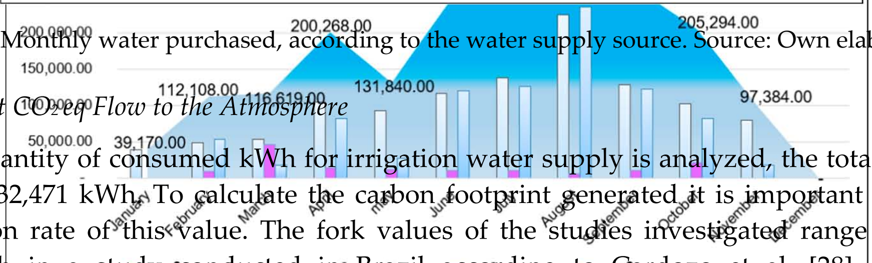

Figure 2. Monthly water purchased, according to the water supply source. Source: Own elaboration.

2.2. Equivalent CO_2eq Flow to the Atmosphere

If the quantity of consumed kWh for irrigation water supply is analyzed, the total amount for 2016 was 2,032,471 kWh. To calculate the carbon footprint generated it is important to know the transformation rate of this value. The fork values of the studies investigated range from 0.0413 $kgCO_2eq/kWh$ in a study conducted in Brazil according to Cardozo et al. [28], up to 0.947 $kgCO_2eq/kWh$ recorded by China in the two studies investigated by Li Cheng et al. [29] and Wan et al. [30] reached a value of 0.780, 0.608 and 0.166 $kgCO_2eq/kWh$ in Iran [31,32] and in Spain [33], respectively.

The values used in this study were based on the annual transformation rates called "electric mix factor ($kgCO_2eq/kWh$)", determined by the National Commission on Markets and Competition (CNMC, www.gdo.cnmc.es). The last 5 years were considered in order to calculate the average value (Figure 3).

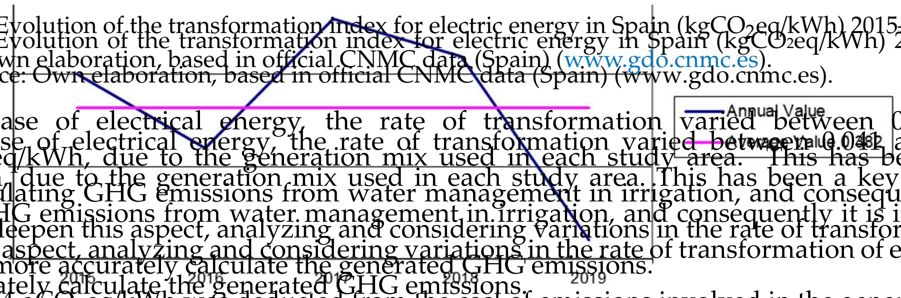

Figure 3. Evolution of the transformation index for electric energy in Spain ($kgCO_2eq/kWh$) 2015–2019. Source: Own elaboration, based in official CNMC data (Spain) (www.gdo.cnmc.es).

In the case of electrical energy, the rate of transformation varied between 0.041 and 0.947 $kgCO_2eq/kWh$, due to the generation mix used in each study area. This has been a key factor in calculating GHG emissions from water management in irrigation, and consequently it is important to deepen this aspect, analyzing and considering variations in the rate of transformation of electricity, to more accurately calculate the generated GHG emissions.

In total, 74 gCO_2eq/kWh was deducted from the cost of emissions involved in the generation and installation of photovoltaic plates according to data obtained from table 8 of study by Huld et al. [34] resulting in the 0.308 $kgCO_2eq/kWh$ of this study which fits with the values set out above (taking

Water **2020**, *12*, x FOR PEER REVIEW 6 of 18

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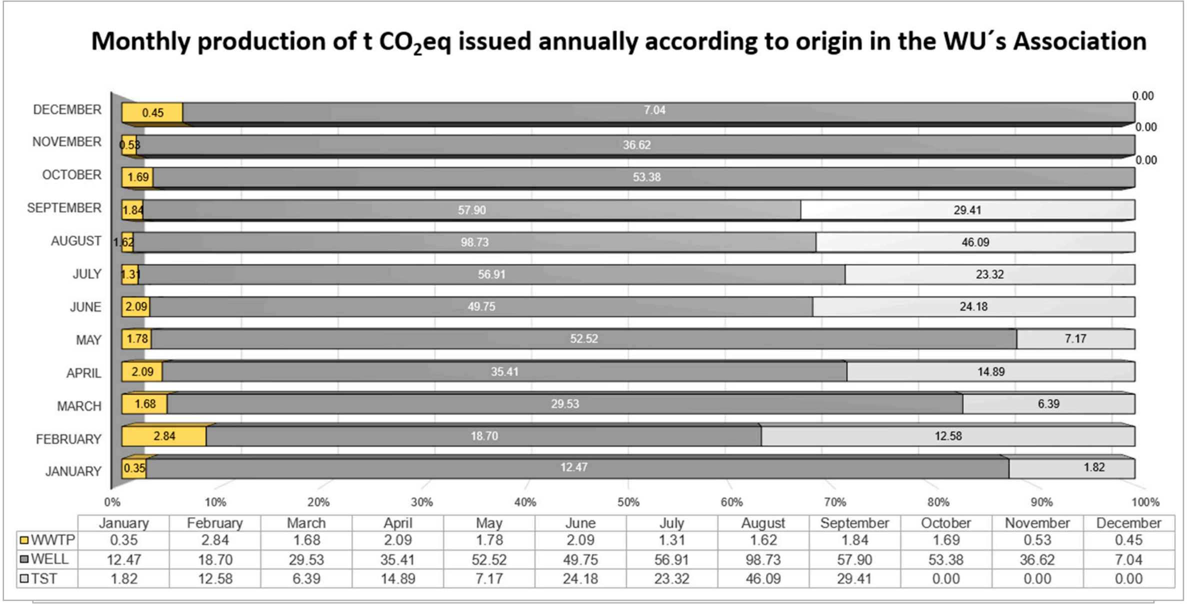


	January	February	March	April	May	June	July	August	September	October	November	December
▨ WWTP	0.35	2.84	1.68	2.09	1.78	2.09	1.31	1.62	1.84	1.69	0.53	0.45
▨ WELL	12.47	18.70	29.53	35.41	52.52	49.75	56.91	98.73	57.90	53.38	36.62	7.04
☐ TST	1.82	12.58	6.39	14.89	7.17	24.18	23.32	46.09	29.41	0.00	0.00	0.00

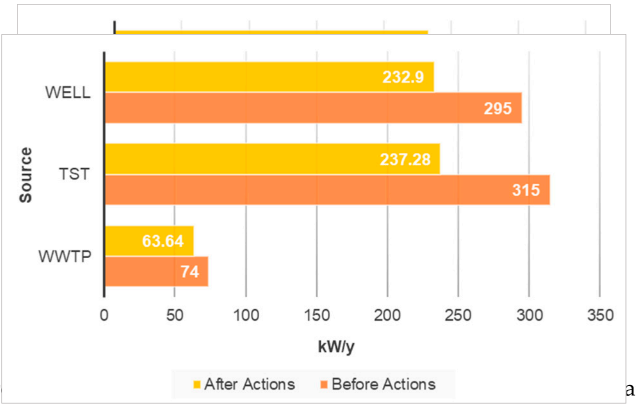
Figure 4. % t CO_2 eq flow rate to the atmosphere. 2016. Source: Own elaboration.

2.3. Adopted Measures for Reduction of the Carbon Footprint

After analyzing the system, framed decisions must be applied within the scope of water governance, in order to eliminate any limitations of the system and improve its exploitation by taking advantage of the available resources and considering weak points. These could refer to reservoirs where the exploitation does not contribute significantly to the system and leads to water loss via evaporation. To take advantage of the surface, photovoltaic plants (or other viable plants) could be introduced to generate clean energies.

2.3.1. Minimization of the Energy

The objectives of the European Climate Law proposal by the European Parliament endorsed the EU's goal of achieving net greenhouse gas emissions by 2050 in its resolution of 14 March 2019 on climate change 4 [35,36]. It is necessary to act on the WUA's energy consumption sources. After analyzing the relevant bills, the points of greatest consumption are the catchment pump systems, in this case there are three (Figure 5).



Figur ation.

Figure 5. Annual consumption by source (kW). Source: Own elaboration.

The first goal towards the reduction greenhouse gas emissions was to improve the efficiency of lifting the water. For this reason, a study of the operating status of the pumps was carried out, comparing this with the optimal requirements of the equipment for use in real conditions. This revealed that all pumps had to be replaced and frequency inverters were required (Table 1). The second goal was to replace the use of conventional energy with renewable energy. This enables the reduction of consumption, together with associated emissions.

Table 1. Pumping equipment power comparison. Source: Own elaboration.

	Current Pump Power (kW)	Future Pump Power (kW)
Well	295	232.9
TST	315	237.28
WWTP	74	63.64

2.3.2. Analysis of the Available Technologies

After a detailed analysis of the different technologies available, photovoltaic generation was identified as the optimal option. This was due to the maturity of the technology, the availability of areas, the elevated irradiation in the area and the close proximity between the zones of generation and consumption. Other considered and rejected options were:

- Wind energy: after examination and according to the wind maps, the main conclusion was that insufficient available power. It would be necessary to complement the same with other alternative and safe energy sources, in order to avoid periods without energy supply.
- Water energy: the irrigation network design takes advantage of the existent overpressures at several points of the system in order to generate electric energy. After a technical study, the incorporation of this technology was evaluated. The solution was the incorporation of two micro turbines linked to the existing pressure reduction valves. Moreover, the installed powers were 10 and 7.5 kW. This option was discarded because of the low power available. Additionally, the large distance between energy generation and the nearest consumption (nearly three kms distance to the filtering system) can generate major losses due to the energy used during transportation.

2.4. Solar Photovoltaic System

To calculate the energy generated in each of the photovoltaic systems, the Database of the Satellite Application Facility on Climate Monitoring (CM SAF), belonging to the European Organization for the Exploitation of Meteorological Satellites, was used, and as a calculation tool, the PVGIS was used (Photovoltaic Geographical Information System) [37,38] and PVWatts [39,40] provided solar radiation databases on the web for calculating photovoltaic potential in various countries. This software uses all the climatic values (irradiation, temperature, among others) and geographical values of the area. This enables the energy generated by each of the photovoltaic plants was obtained. To design the system, the separation between rows and modules and the optimal inclination of the panels as a function of latitude were considered.

The system is designed to use accumulation reservoirs to meet instantaneous demands, thus avoiding the use of batteries that must be renewed and ultimately generating a carbon footprint during production and subsequent disposal. Pumping will be fed from the photovoltaic field, programming the inverters according to the levels in the existing reservoirs and the required production level.

The photovoltaic plants were calculated using the PVGIS software from the CM SAF database, obtaining the daily and annual electricity production supplied by each of the calculated plants [27,41] (see Table 2). Optimization of solar panels was designed considering their position, inclination and orientation.

Table 2. Summary of the calculation of the solar photovoltaic installations. Source: Own elaboration.

Photovoltaic Installation	Projected Power (kW)	Annual Generated Energy (kWh)	Units of 250 Wp, c/u
Pumping Well	232.9	543,200	1400
Pumping TST	237.3	360,971	1400
Pumping WWTP	63.64	108,640	280,000

It is important to consider that the monthly operation periods of the pump must adapt to the monthly generation curve of a photovoltaic installation, redistributing the peak consumption in the consecutive months and taking advantage of the existence of reservoirs for regulation and the quota that functions as systems for the accumulation of potential energy, thus, the installation of batteries of capacitors is ignored, equaling a significant saving for increasing the efficiency of the solar installations (Figure 6).

Figure 6. Reservoirs and Solar installations. Source: Own.

2.5. Water Footprint

Once the actions of the electrical component of the system have been calculated, the value of the water footprint must be studied, by analyzing the balance sheets of the water purchased for irrigation and the real cost of the same for farmers (Figure 7). The difference equals the losses in the system and conforms the water footprint, divided as follows: (1) the losses due to evaporation during storage in the reservoirs and (2) the losses due to the state of the hydraulic network.

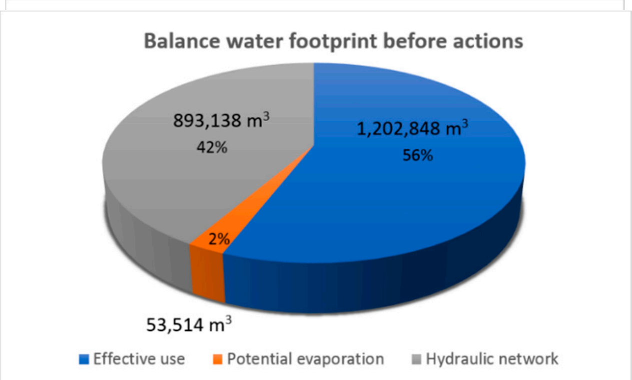


Figure 7. Balance water footprint before actions. Source: Own elaboration.

2.5.1. Direct Consumption Reduction by Governance

After evaluating these losses, several actions can be taken to reduce the water footprint. First, the system is analyzed, based on principles of efficient water governance (see blue area of the diagram, Figure 1). To this end, the farmers must be advised regarding the permissible crops, as well as the maximum endowments per plot, and the shifts established that are linked to the manometric heights of the plots in both sectors. To make this viable, it is necessary to use the ICTs that provide us information in real time such as enabling the possibility of changing the irrigation programs depending on the data provided by the meteorological stations (see article quote), or adjusting of provided by the meteorological stations (see article quote), or adjusting of water supplied to the plot, applying the data of the weighing lysimeter (see reference) (audio-slide can be added of the operation of the weighing lysimeter), and completing this with the information provided by the soil moisture sensors (see article quote) (Figure 8).

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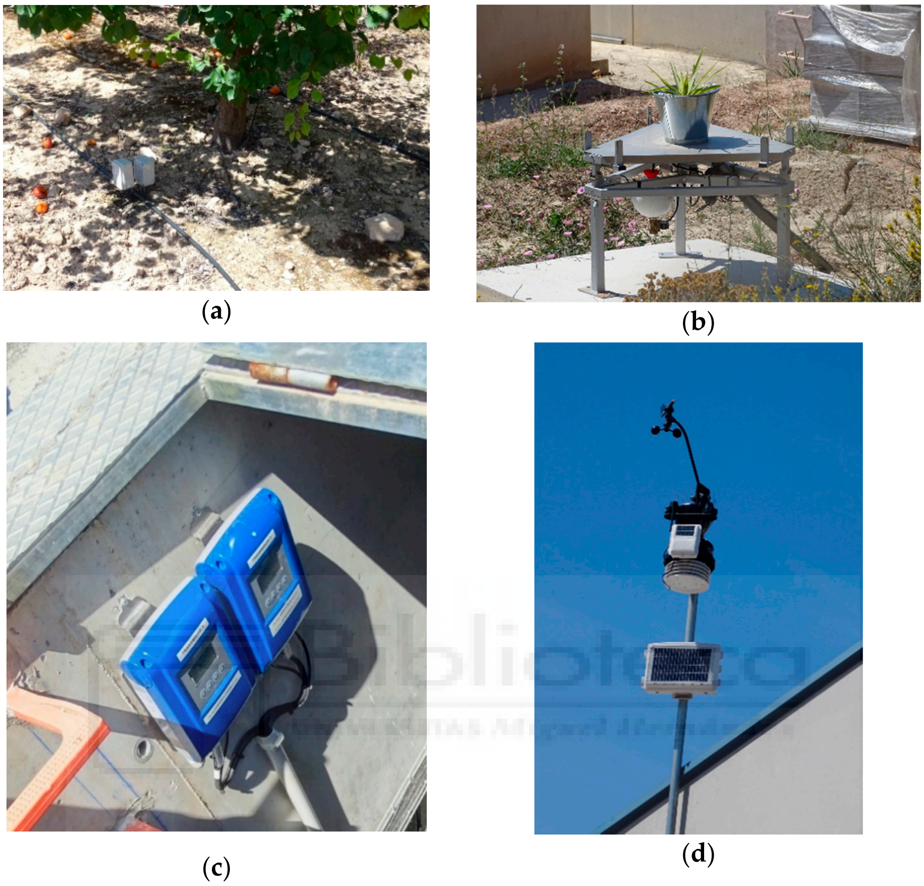
(**a**) (**b**) (**c**) (**d**)

Figure 8. (**a**) Capacitive soil sensor, (**b**) Weighing lysimeter, (**c**) Water quality analyzer, and (**d**) Agrometeorological station. Source: Own.

Figure 8. (a) Capacitive soil sensor, (b) Weighing lysimeter, (c) Water quality analyzer, and (d) Agrometeorological station. Source: Own.

It is also possible to program the irrigation to stop if certain moisture values are delimited in the terrain. All these actions lead to a savings regarding the direct consumption of water (which, in our case, equaled approximately between five to 10% of the actual consumed water). This saving is quantified by not wasting water that does not benefit the crop. In turn, this leads to a loss of indirect energy associated with water, which requires energy from the system to extract, distribute, and use the water in a plot, albeit with the minimum pressure, in order for the localized irrigation systems to work (see article quote). Furthermore, it is important evaluate and quantify the effect on the carbon footprint. The efficiency in the application represents the water that is used by the crops, compared to that applied to the plot. This will depend on the irrigation system used and the losses caused by deep percolation, runoff and lack of uniformity. The evaluation was carried out for the whole community of irrigators, establishing the weighted average, based on the proportional distribution of the irrigation systems used by surface, and considering the following values (Table 3) (values obtained from the efficiencies in the irrigated areas considered in ORDER ARM/2656/2008, of 10th September, approving the hydrological planning instruction [42]).

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Table 3. Efficiency of water use according to the type of Irrigation System. Source: Ministry of the Environment, and Rural and Marine Affairs (Spain).

Type of Irrigation System Value	% of Efficiency
Irrigation by surface with total coverage (blanket), with good management	60
Irrigation by surface with partial coverage (by furrows), with good management	60–90
Irrigation by sprinkling, with good management	80
Irrigation by dripping on the surface, with good management	90
Irrigation by underground drip, with good management	95

The current network has a surface irrigation system with total coverage (blanket irrigation) from the endowments from ditches. This provides a value of efficiency in the application of 60% or, in some cases with drip irrigation on the surface and good management the efficiency is set at 90%. This means that the reduction by indirect consumption amounts to, at least 35% of the water actually consumed (1,020,848.10 m^3).

2.5.2. Indirect Consumption Reduction (ICR)

The reduction of the water footprint by losses via direct consumption has been differentiated into two sections:

- ICR by evaporation potential: losses due to evaporation on the surface of the ponds during storage (these represents the losses associated with the insulation received by the water sheet surfaces of the ponds and whose value has been estimated at 0.5 m^3/m^2) [43]. To estimate this, the initial losses must first be evaluated with the rafts that are available before applying the reductive actions. After applying these actions, the new exposed surfaces are calculated. The rafts and two others have been covered with a TPO polypropylene sheet reinforced with polyester mesh inside, which is estimated to be reduced by 95%. With the difference in volume of evaporated water W_{eBA} = 53,514 m^3 before and after the corrective actions W_{eAA} = 27,492 m^3, the water footprint that is generated has been quantified, obtaining a value of W_{eR} = 26,022 m^3 representing the volume of water annually saved by covering rafts and the reduction of surface exposed to insolation, by eliminating two of the rafts and transforming these into photovoltaic plants (Table 4).

Table 4. Summary of potential water evaporation. Source: Own elaboration.

By Evaporation Reduction								
				Before Actions (W_{eBA})		After Actions (W_{eAA})		
	Surface (m^2)	Volume (m^3)	Manometric Eight (m.c.a.)	Annual Evaporation m^3 (0.5 m^3/m^2)	Source	Annual Evaporation m^3	Source	Actions
Raft 1 “Cota” San Quintin Well	7534	45,000	440	3767	Well	75	Well, TST, WWTP	
Raft 2 Anguilas Cherro 1	7667	24,000	415	3834	Well, TST	-		Solar sector 1
Raft 3 Anguilas Cherro 2	6731	26,400	410	3366	Well, TST	-		Solar Well
Raft 4 Regulation Huerta Baja	30,878	237,675	411	15,439	Well, TST	309	Well, TST, WWTP	
Raft 5 Regulation Huerta Alta	45,929	317,380	413.55	22,965	Well, TST	22,965	Well, TST, WWTP	
Raft 6 La Esperanza	5761	12,000	424	-		-		Eliminated
Raft 7 WWTP Pliego	8285	39,464	372	4143	WWTP	4143	Well, TST	
Total Potential Water Evaporation				53,514			27,492	

- ICR for water improvements: The new improvement introduced in the system as the doubling of the pipes enabled a more adequate exploitation and the distribution in open ducts has been eliminated in front of pressurized pipes while remote control systems with controlled solenoid valves have been installed. Solenoids and counters in the irrigation head enable a balance of water inlets and outlets which helps clarify which sectors and networks suffer from water loss and require repair. This type of improvement reduces the total volume of losses (V_{ls} = 946,651.90 m^3)

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Figure 9. Waterproof sheet in reservoir to reduce evaporation. Source: Own.

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Table 5. Summary of water footprint reduction after actions. Source: Own elaboration.

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Origin of the Consumption		**Water Footprint Reduction after Actions (m^3)**
Direct consumption	By governance & ITC	420,996.84
Indirect consumption	By evaporation	26,022.00
	By hydraulic actions	283,995.57
Total		731,014.41 m^3

3. Results

3.1. Reduction of Carbon Footprint by Water Footprint

In this study, by using data from electricity bills, the total energy consumption by origin has been calculated. Thanks to this financial data, the total volume of water that has moved within the system has also been determined. This clarifies the carbon footprint that generates the water footprint required to obtain a kWh/m^3 ratio (IE-W). This ratio will change annually and, if there is an adequate monitoring of the movements of the water when it is operating, the telecontrol scale can be determined with greater accuracy and value. In this study, it is used the average value of the three ratios according to origin and divided this by the total water purchased. The final value obtained was (IE-W) 0.62 kWh/m^3 and, considering that the volume of water reduced by water footprint is 731,014.41 m^3, a reduction of CO_2 eq emissions is obtained (0.382 kgCO_2eq/kWh), equivalent to 139 t CO_2eq/y (Figure 10) (it should be noted that for our study, only emissions associated with energy consumption, water handling for irrigation, have been considered, it is actually superior because the reduction of water in the water footprint is associated with a lower consumption of fertilizers that would increase this value by about a third).

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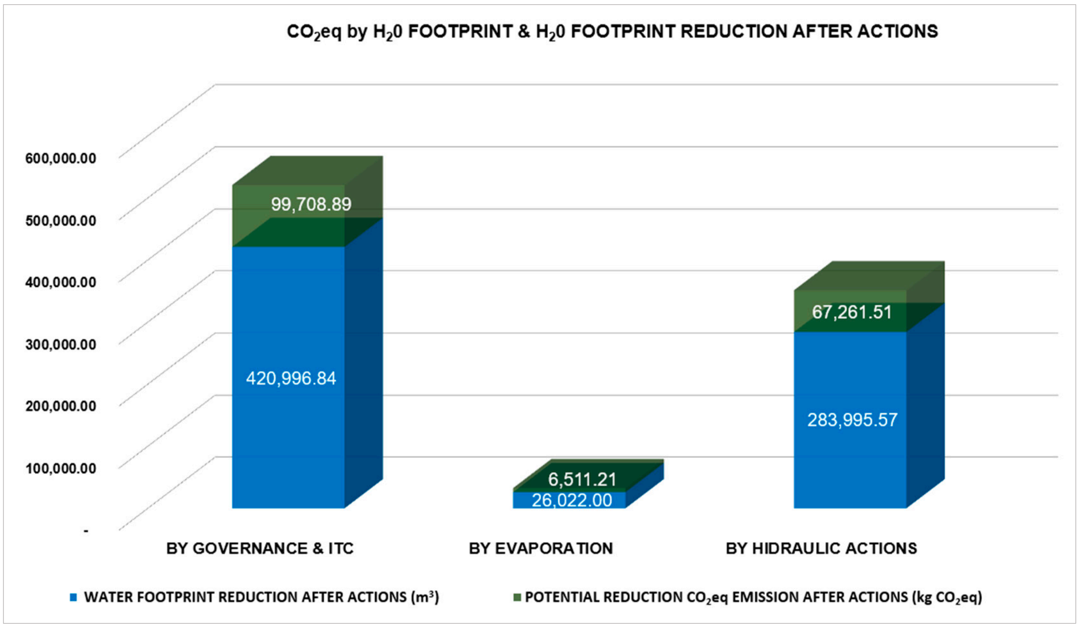

Figure 10. CO_2 eq reduction by water footprint after actions. Source: Own elaboration.

3.2. Sequestration of CO_2 eq by Crops

Given that the purpose of a WUA is the production of food based on growing crops, determining the amount of CO_2 eq sequestered by this community of farmers is sought. Consequently, this work is based on the study of the typology of the existing crops and irrigation varieties in the area, as well as their evolution over the last 10 years, both in the municipality of Pliego and in the municipality of Mula. See Annex 6 for the agronomic report of the project for the adaptation of Sector I "Huerta Alta" of the community of irrigators of Pliego (Murcia, Spain) [44].

This study shows the slight regression of irrigated land cultivated in the municipality of Pliego, as well as the low diversification of existing crops. Based on this data, the distribution of crop units by area differing from the plant, from the farmland has been estimated and the annual carbon values abducted in accordance with the study of Carvajal et al. [45] for the carbon accumulated in the plant have been applied. These values have discounted the CO_2 eq generated during the existence of the plant, since half the day is spent purifying CO_2 eq by day, transforming it into Carbon, emitting an approximate third of CO_2 eq at night [46]. For the purposes of the farmland more than accumulated on the land (approx. 6% of the total abducted) taking as reference values the contents in the publication of Visconti et al. [47]. As displayed, the annual CO_2 eq reduction for crops (Table 6) of a WUA is high, with 7007 t CO_2 eq sequestrated from the atmosphere.

Table 6. Summary of the footprint of CO_2 eq sequestration by crops. Source: Based on [44–47].

Cultivation	Surface (%)	Surface Area (ha) [44]	Annual Estimate Sequestered kgCO_2eq/ha		Annual Estimate of Emissions kgCO_2eq/ha		Captured tCO_2eq/y	Emission tCO_2eq/y	Sequestrated tCO_2 eq
			Plant [45]	Field [47]	Plant [46]	Field [47]			
Citric trees	25	199.90							1696
Lemon	19	151.93	16,040	590	4812	520	2527	810	1717
Orange half session	2	15.99	9869	565	2961	515	167	56	111
Orange total session	4	31.98	6220	565	1866	515	217	76	141
Fruit trees	71	567.73	-						4940
Apricot tree	16	127.94	8450	825	2535	740	1187	419	768
Peach tree	37	295.86	14,463	835	4339	740	4526	1503	3023
Almond tree	18	143.93	11,356	475	3407	445	1703	554	1149
Vegetables	4	31.98	-						98
Lettuces and similar	4	31.98	4225	830	1268	735	162	64	98
Total	100	799.61							7007

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Apricot tree	16	127.94	8450	825	2535	740	1187	419	768
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Total	100	799.61							7007

3.3. Total CO_2 eq Balance of Our W-E SYSTEM in a WUA

The total balance of our water-energy system provides us with many benefits, as shown in Figure 11.

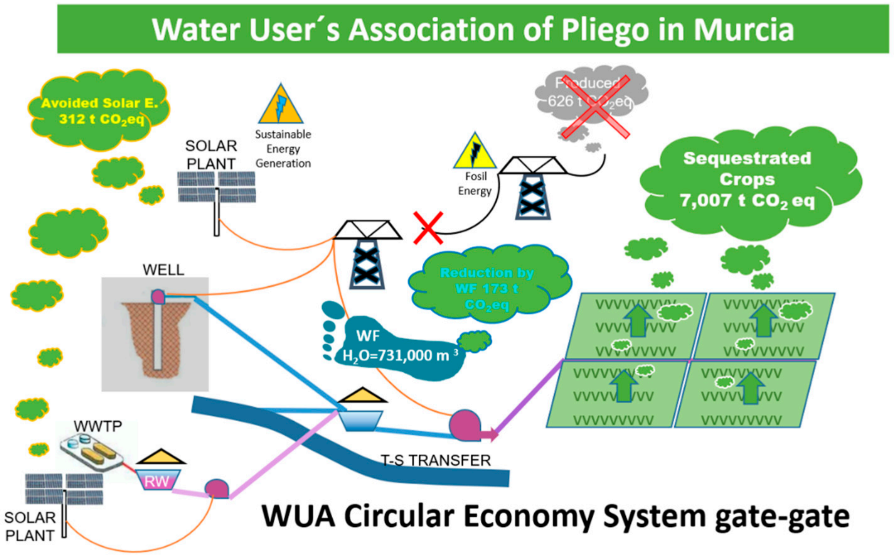

Figure 11. Summary of the environmental effects generated in the WUA. Source: Own elaboration.

Note that there are savings in annual CO_2 eq emissions after the implementation of these three photovoltaic installations, as follows:

- 111.88 t CO_2 eq for the TST pumping.
- 167.31 t CO_2 eq for pumping Well.
- 33.46 t CO_2 eq for pumping WWTP.

These three actions significantly improve the energy capacity of the Community of Irrigators and will they reduce annual maintenance costs once the break-even point has been reached for the installation, as well being totally unconnected with the Electric Fee factor. Furthermore, it is important to highlight the reduction of the water footprint (731,014.41 m^3) that contributes to reducing CO_2 eq emissions by 173 t per year. However, the key piece of agriculture in Murcia is the sink of CO_2 eq that must be preserved by reducing, in this case, up to 7492.08 t CO_2 eq per year which, in the authors' opinion, is a magnificent contribution to the environment (Figure 12).

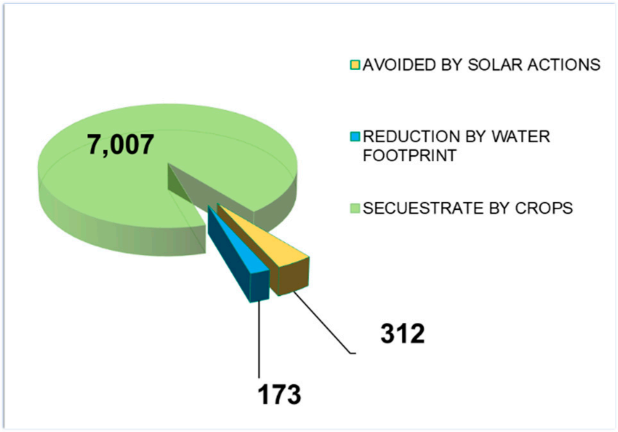

Figure 12. Summary new future reduction t CO_2eq/y after actions. Source: Own elaboration.

4. Discussion

After consulting the literature, the GHG indices and emissions during irrigation water management have been summarized, applicable to this case study, (Table 7) the values are in the range of 0.166 in Spain [33] with surface source water used in localized irrigation, at 0.341 kgCO_2eq/kWh, in China [48] where the water used for winter wheat irrigation came from

4. Discussion

After consulting the literature, the GHG indices and emissions during irrigation water management have been summarized, applicable to this case study, (Table 7) the values are in the range of 0.166 in Spain [33] with surface source water used in localized irrigation, at 0.341 $kgCO_2eq/kWh$, in China [48] where the water used for winter wheat irrigation came from underground, passing through the sum of 0.062 $kgCO_2eq/kWh$ of electrical origin plus 0.732 $kgCO_2eq/L$ of fossil fuel consumption in Pakistan [49], also of underground origin. The starting data were annual consumption of 2,149,500 m^3 and 2,032,471 kWh in 2016, resulting in an emission index of 0.361 $kgCO_2eq/kWh$ per m^3, before carrying out the improvement actions described in this article. After the actions, there is a consumption of 1,012,811 kWh/y of photovoltaic renewable origin, a reduction due to an improvement in the performance of the pumping equipment equivalent to 1,019,660 kWh/y and a water consumption of 1,418,485 m^3 per year after reducing more than 34% its water footprint. Given that the emissions are from renewable energy, it is possible to affirm that the emissions index by electrical origin associated with the water-energy binomial has been reduced to zero "0".

Table 7. Review of published values for emissions per m^3 of irrigation water.

Authors	Country	Source Energy Supply	Irrigation Type	Water Source	GHG Emissions
[49]	Pakistán	Electricity-Diesel	Located	Underground	0.732 $kgCO_2eq/L$ 0.062 $kgCO_2eq/kWh$
[33]	Spain	Electricity		Surface	0.166 $kgCO_2eq/kWh$
[48]	China	Electricity		Underground	0.341 $kgCO_2eq/kWh$

Additionally, the carbon footprint sequestered thanks to the crops of this WUA (7000.7 t CO_2eq/y) provides a value of 8.7 t C/ha per year against the threat of desertification and abandonment of farmland must be weighed. Due to the great contribution that this makes to mitigating climate change, Pinus pinaster forests are capable of sequestering 1.58 t C/ha, compared to Eucalyptus globulus forests, which are capable of sequestering up to 5.14 t C/ha [50], providing an idea of the great value of the vegetation cover provided by agriculture in the southeast of Spain.

Agriculture is the basis of our development, we cannot eat electronic chips or consume digital food. The evolution of the digital society and globalization are a reality that must be compensated in a manner that does not unbalance the ecosystems in which we operate. Developing countries should not lose control of the agricultural production that feeds their citizens. Thus, new technologies help us to control the quality of our food, how it is produced, where it is produced, when it is produced, who produces it and under what phytosanitary conditions. Most importantly, a footprint is produced in nature during the generation of these foods. Governance as a management tool is capable of articulating the reduction of GHG, starting from the allocation of certain water resources, to certain lands, and promoting the use of green energy during production. This article shows how farmers in eastern Spain, inspired by the astronauts living in space stations, are able to reuse reclaimed water from WWTPs, optimize and reduce energy consumption in their fields as much as possible, and take advantage of the energy resources generated. Nature provides resources (in this case solar energy), for improving their irrigation system and taking advantage of the advances in ICT to be able to maintain the artificial forests (fruit orchards) of the Mediterranean countries that serve as a lung to renew CO_2 eq in southern Europe while acting as a barrier to the threat of desertification as a consequence of climate change. Currently, as the global COVID-19 pandemic has drastically restricted people's mobility, the importance of having locally grown products has been highlighted, to avoid possible shortages affecting local markets.

5. Conclusions

Agriculture maintains the forests of fruit trees and vegetable plantations, allowing us to breathe cleaner air. It also avoids the abandonment of arable land and translates into a socio-economic redistribution that offers a niche market for women. This is thanks to the governance of the different administrations that must plan the availability of resources, the allocation of endowments for crops and the ICTs that optimize management and control of these resources. It should be noted that in semi-arid areas of the Mediterranean, fruit/agricultural plantations should be considered not only as the main means of production, but also as an ecological method of protection against climate change, concretely, against desertification.

In summary, and after appreciating the data presented in Section 4 discussion, this study seeks to collaborate in the fulfillment of the three objectives of European policy within the Climate and Energy Framework for 2030:

- reduction of at least 40% of greenhouse gas emissions (relative to 1990 levels).
- increase of at least 27% in the share of renewable energies.
- improve energy efficiency by at least 27%.

It also contributes to the fulfillment of the following SDGs:

- SDG 6 (sections 6.3 and 6a), the use of reclaimed water using alternative energies and ICTs is promoted, as well as actions to cover reservoirs that produce a better efficient use of the water resources of this WUA.
- SDG 7 (sections 7.2 and 7.3), the increase in the proportion of renewable energy in our system is evidenced).
- SDG 12 (sections 12.2 and 12.4), the set of actions described produces sustainable management and an improvement in the efficient use of natural resources, in our case water. All the actions described in this paper are aimed at reducing emissions to the atmosphere.
- SDG 15 (section 15.3), the lands included in this study and during its preparation (last 4 years) have been affected, by periods of drought and floods, which, if it were not for the aid articulated by the European Union, would be led to abandonment and subsequent desertification.

Thus, primary production methods, such as agriculture, must be integrated into sustainable technological development, serving as an example of development to other semi-arid regions that need accessible solutions. The need to import energy from other countries must also be reduced and create new opportunities for sustainable growth through the use of renewable energies.

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Escuchar atentamente a alguien, incluye hacer un hueco en tu cabeza e ideas para poder incorporar satisfactoriamente la información recibida.

Reconocer públicamente el aporte intelectual y conocimiento recibido por mi participación en los siguientes proyectos europeos:

1 Nombre del proyecto: AQUARES (Water reuse policies advancement for resource efficient European regions)
Entidad de realización: Dirección General del Agua
Ciudad entidad realización: Murcia, Región de Murcia, España
Nombres investigadores principales (IP, Co-IP,...): Jesús Pedro Chazarra Zapata
Nº de investigadores/as: 20
Entidad/es financiadora/s: EUROPEAN REGIONAL DEVELOPMENT FUN
Tipo de entidad: Fundación
COMUNIDAD AUTÓNOMA DE LA REGION DE MURCIA
Ciudad entidad financiadora: España
Fecha de inicio-fin: 04/06/2018 - 04/06/2022
Cuantía total: 268.666,3 €

2 Nombre del proyecto: ALICE — H2020-MSCA-RISE-2016/H2020-MSCA-RISE-2016
Grant Agreement number: 734560
Identificar palabras clave: Biología; Abono; Agricultura intensiva; Cultivo de regadío
Identificar palabras clave: Física química y matemáticas; Ciencias naturales y ciencias de la salud; Ingenierías; Humanidades y ciencias sociales
Modalidad de proyecto: De actividad de desarrollo precompetitiva
Ámbito geográfico: Unión Europea
Grado de contribución: Investigador/a
Entidad de realización: Consejería de Agricultura y Medio Ambiente
Tipo de entidad: Organismo
Nombres investigadores principales (IP, Co-IP,...): Neil Hewitt; Francesca Spigarelli; Pilar Fernandez Ibañez; Alberto Longo; Lorna Fitzsimons; Karen McDowell; Anil Markandya; Despo Fatta-Cassinos
Nº de investigadores/as: 13
Entidad/es financiadora/s: European Union
Tipo de participación: Coordinador
Nombre del programa: H2020-MSCA-RISE-2016/H2020-MSCA-RISE-2016
Cód. según financiadora: 734560
Fecha de inicio-fin: 01/01/2016 - 31/12/2020 Duración: 5 años
Cuantía total: 900.000 €
Porcentaje en subvención: 100
Régimen de dedicación: Tiempo parcial

Aportación del solicitante: Exposición y explicación de las buenas prácticas del uso del agua regenerada empleada en la agricultura, uso de tanques ambientales para minimizar el efecto de las lluvias torrenciales en el medio ambiente, contribuyendo a la reducción del cambio climático, y mostrar y explicar funcionamiento de EDAR y Planta Desaladora, así como sus consumos energéticos y costes. También se promueve el uso de energías renovables aplicadas al binomio agua-energía aplicada a las comunidades de regantes.

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