D4.3. Unije Lighthouse UC-2 report

INSULAE – Maximizing the impact of innovative energy approaches in the EU islands

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ABBREVIATIONS

DER	Distributed Energy Resources
DLV	Deliverable
DoA	Description of Action
EC	European Commission
EU	European Union
RES	Renewable Energy Sources
WP	Work Package

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1 INTRODUCTION

This deliverable collects the main conclusions reached after finalizing the modelling, basic and detail engineering and equipment development activities previous to the deployment of the UC-2: Smart integration and control of water and energy systems, at Unije Island.

The island of Unije is located in Kvarner, in the northern part of the Adriatic Sea, west of Lošinj island. According to the administrative-territorial structure, it belongs to the town of Mali Lošinj, ie the Primorje-Gorski Kotar County. On its western side it is exposed to the open sea, and on its southern side there are Male and Vela Srakane, and Susak islands (Figure 1). The total island area is 16.77 km^2, with a 36.6 km long indented coast. Despite a good geo-traffic position, water sources and extensive fertile soil, the Unije island today is sparsely populated with a negative growth trend. According to the 2011 census, the island has only 88 inhabitants, while today that number is slightly less, and throughout history it ranged up to 1000 inhabitants. According to the mentioned census, there are 47 households in the only inhabited place on the island, while there are a total of 292 privately owned housing units on the whole island.

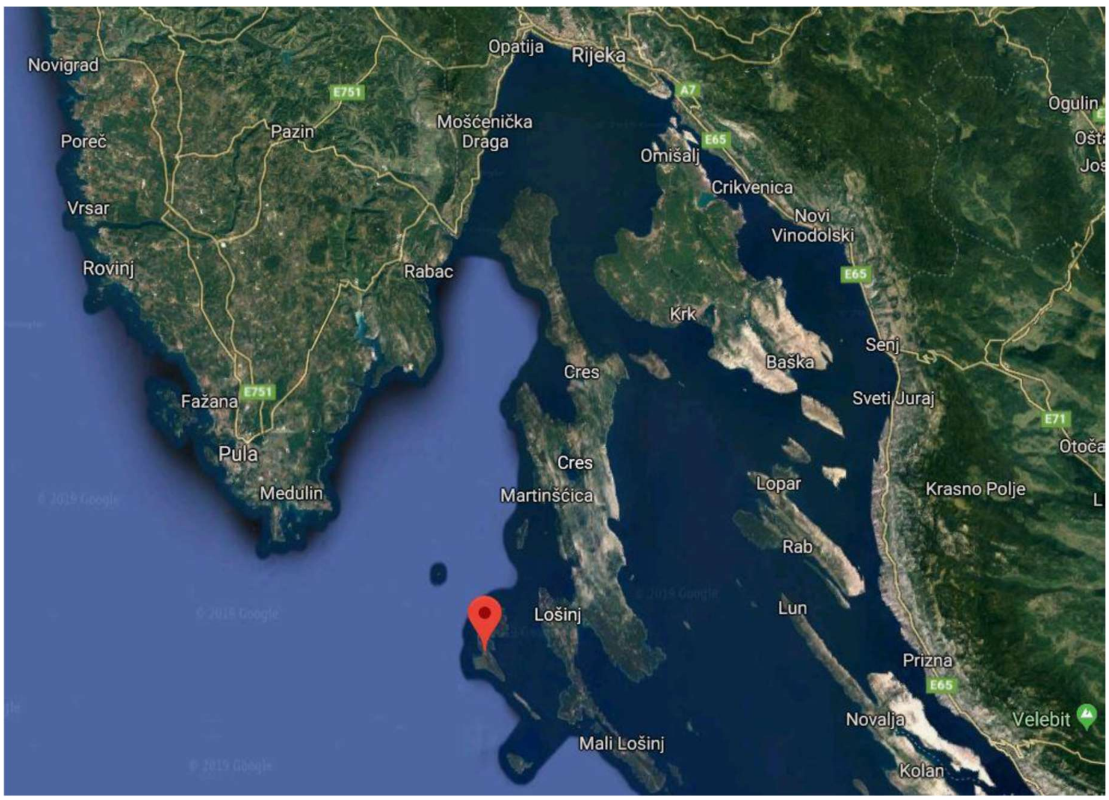


Figure 1. Macro-location of the Unije Island

The island has a predominantly elderly population engaged in agriculture, olive growing and fishing. However, the island is significantly dependent on tourism in the summer months when the number of residents grows significantly (according to estimates between 800-900). The connection to the island with the mainland and other islands is insufficient, because the island is visited by a catamaran from Rijeka once a day, and there is a local boat connection from Mali Lošinj that connect Unije with the local islands Male Srakane, Velike Srakane and Susak. Furthermore, there is a small airfield that can operate smaller aircrafts, but it is currently not in use due to administrative and political reasons, which significantly harms the tourist offer of the island (Figure 2).

Figure 2. Small airfield on the Unije Island

There is only one inhabited place on the island, and there are no roads, except for ordinary white roads (macadam) and some concrete placed roads, such as the road to Maračol Bay. Maračol Bay serves as an anchorage for nautical tourism covering. There are no cars on the island, but only bicycles and small delivery vehicles by which the locals transfer goods from the ship and use them to cultivate the fields.

Figure 3. The Unije settlement on the Unije island

To encourage the island development and achieve energy independence, it is necessary to implement demographic changes, i.e. motivate young people to stay and live on the island and attract young people from other parts of the region to come and live on the island where new jobs will be created. Renewable energy sources today, not only create new jobs, but are extremely attractive in terms of tourism because the island can become self-sustaining and earn profits directly and indirectly. The island has a huge natural potential with a large number of sunny hours, a source of water, as well as large and fertile fields.

1.1 Scope and Objectives

The main goal of INSULAE project is to foster the deployment of innovative solutions aiming to the EU islands decarbonization by developing and demonstrating a set of interventions linked to seven replicable use cases at three Lighthouse Islands, and whose results will validate an Investment Planning Tool that will be then demonstrated at four Follower Islands for the development of four associated Action Plans.

Islands usually face water scarcity problems, which are solved through the use of desalination plants. Given the high energy consumption of these plants, it is crucial to implement smart water management strategies that minimize the need for fresh water and enable the use of RES to power desalination plants.

INSULAE is developing an innovative system which consists of integrating renewable energies in water desalination at Unije Island, Croatia. PV generation is used to make cleaner and more efficient brackish water desalination processes, promoting renewable integration and renewable systems development.

In order to make optimal use of water produced, it is planned to set up a system of smart agriculture/water distribution that will, by monitoring soil and environmental parameters, gather the necessary information and at the same time monitor the water level available in the tanks. Soil and environmental parameters will be collected through stand-alone sensor cells. A certain number of sensor cells will be set up at selected locations. In addition, a weather station for wind speed monitoring, wind direction, and precipitation is set up at desalination unit location.

As part of the WP4's main objective that foresees a need for modeling, designing and development of the innovative equipment required to perform the envisaged interventions at the Lighthouse Islands as example of the seven use cases considered in INSULAE, the Task 4.2. includes the Unije Lighthouse demonstration preparatory activities under which the detail design, model, engineering and development of the innovative solutions that will be implemented in Unije is carried out. In the sense of Task 4.2. main objective, following subtask 4.2.2. addresses the proposed solutions of smart integration and control of water and energy systems at Unije island.

Water scarcity represents one of the main challenges for islands specially during vacation periods when tourism increase the water consumption on the island. The integration of different solutions to manage the water use was studied as part of the mentioned subtask. Smart irrigation systems through smart meters and sensors implemented in the soil to monitor the water necessity for crops, implementation of renewable energy sources as part of the desalination unit, installation of sensing equipment to cover the optimal water production inside the desalination unit, and wireless communication with central unit will establish direct links between telecommunication, water and energy networks.

In order to ensure the interoperability of the sensors with the different communication protocols, an analysis of the commercial devices available was carried out by the Ericsson Nikola Tesla team, while the more detailed information on communication technologies can be found in public deliverable D.4.4 Unije Lighthouse UC-3.

1.2 Structure

This deliverable is structured in 6 sections, with the addition of Section 7 covering the references used.

First section is introduction to the problem where scopes and objectives, and connection to other project deliverables is defined.

In Sections 2 the overall state-of-the-art review of the previous activities and studies done for the Unije location is presented.

In Section 3 includes all the energy and water system modeling done under the INSULAE project. Models developed include the simple model for the hydraulic pipeline calculations, water system modelled in EPANET, and demand response model for the Unije Island and Cres-Lošinj archipelago, while the details of the water-energy nexus for the Unije island is in more detailed discussed in Section 4.6. Implementation of water energy nexus actions.

Besides the proposed water energy nexus model, in Section 4 the existing and planned engineering and equipment development is discussed.

Section 5 takes on the market possibilities of heuristic operation of water and energy systems in general, which will be part of the activities in the second part of the INSULAE project, covering the joint optimal operation of water and energy systems on the Unije island.

Finally, the Section 6 covers the final conclusions of the first part of INSULAE project, regarding the UC-2 implementation, and gives the outlook for the future activities. References used while writing this deliverable can be seen in Section 7.

1.3 Connection to other deliverables

Here we discuss the connection between deliverable D4.3 Unije Lighthouse UC-2 report and several confidential deliverables in chronological order:

- D4.5 Unije energy system models
- D4.6 Unije Lighthouse intervention equipment detail engineering
- D5.1 Unije Demonstration and monitoring plans
- D4.2 Unije Lighthouse UC-1 report
- D4.4 Unije Lighthouse UC-3 report
- D4.7 Unije Lighthouse equipment development

Deliverable D4.5 includes information on modeling the energy system of Unije Island with details concerning the considerations for energy capacity of the battery systems, management of the hybridized RES + BESS, and implementation of water-energy nexus through the desalination unit operation.

Deliverable 4.6 drafts the basic and detail engineering of the use cases that will be demonstrated on Unije Island, namely: UC-1: Joint management of hybridized RES and storage, UC-2: Smart integration and control of water and energy systems and UC-3: Empowerment of islands' energy communities through 5G and IoT technologies for flexibility services.

Deliverable 5.1 outlines results of task T5.1 during which the thorough deployment plan was developed in order to establish the roadmap for the deployment of the different interventions that are to be implemented on Unije, and that were previously defined in T4.2.

Set of public deliverables include deliverables D4.2, D4.3 and D4.4. Deliverable 4.2 collects the main conclusions reached after finalizing the modelling, basic and detail engineering and equipment development activities previous to the deployment of the UC-1: Joint management of hybridized RES and storage, while deliverable D4.4 covers the main conclusions reached after finalizing the modelling, basic and detail engineering and equipment development activities previous to the deployment of the UC-3: Empowerment of islands' energy communities through 5G and IoT technologies for flexibility services, at Unije Island.

Finally, deliverable D4.7 in a form of confidential demonstrator consist of a collection of all the equipment, either brand new developed in Task 4.2, commercially purchased or already available in the location, needed for the demonstration campaign that will take place on Unije island.

2 STATE-OF-THE-ART REVIEW

The islands are largely isolated from the mainland, which implies a high dependence on fossil fuels as energy sources, high transport costs, problems with water supply, limited diversification of economic supply and greater possibility of monopolies of individual market players. By encouraging and implementing renewable energy sources (RES), islands can solve most of the aforementioned problems. With the renewable electricity generation, the islands cease to be dependent on fossil fuels. The construction of a desalination plant that would use renewable energy sources would significantly reduce the cost of water, which is extremely expensive and quantitatively poor on the islands and would reduce dependence on the drinking water supplier. Promoting the island as green or self-sustaining attracts many tourists from predominantly more developed countries where there is a more pronounced awareness of climate change issues.

There are numerous examples in the literature of topics related to smart islands, while specifically for the islands in Kvarner archipelago with a focus on energy system and transport planning, several analyses were made. Specifically for the Unije island, an analysis of energy sustainability and promotion of sustainable island development has been made, as well as an analysis of the integration of renewable energy sources, primarily the use of solar photovoltaic panels. Few studies analyze the use of RES for desalination, as well as the analysis of the consumption of electricity in the water supply system. However, no papers have been found analyzing the link between the power and water systems involving desalination on the smart island. We follow with a brief explanation of some studies in the region surrounding Unije, to put in context the developments in Unije as part of an overall drive to sustainability in the region..

In the thesis [1], the energy planning of the island of Lošinj was carried out using the RenewIslands methodology and using the mathematical model H2RES. The H2RES program was developed to support the simulation of various scenarios proposed by the RENEWISLAND methodology, with the aim of integrating renewable energy sources and hydrogen into the island's energy systems. The H2RES model has the ability to integrate different energy storage systems into the island's electricity system to enable better penetration of electricity from renewable sources into the island's energy system and to create energy systems that are 100% renewable. In thesis [1], 4 scenarios of energy system development on the island of Lošinj are presented. Author concludes that scenarios that promote consumption entirely from renewable sources, while also including hydrogen as possible solution, can be realized on smaller islands, with a smaller population and high intermittent potential.

The thesis Advanced Energy Planning of the Transport Sector on the Island of Krk [2] deals with the analysis of the possible implementation of electricity in the transport of the island of Krk. The open source model SUMO was used as a basis, in which the transport network of the island of Krk was created. As a result of the simulation of the use of electric vehicles in traffic, the electricity consumption of electric vehicles was obtained, as well as the parameters and power of electric charging stations necessary to cover the stated needs. In conclusion, concrete savings in greenhouse gas emissions have been calculated and presented, which can contribute to achieving the goal of making the island of Krk CO_2 neutral.

The thesis [3] aims to demonstrate various new technologies and their implementation on islands in the world and in Croatia. The SWOT analysis was used to provide a basic overview of the technologies used in the development of smart islands. According to the analysis of the available technologies, floating photovoltaic technology was selected and its implementation on Vrana Lake on the island of Cres was studied in more details. A basic technological and economic analysis was made to show the potential of Vrana Lake. Technological and economic analysis covered three scenarios with different ways of financing. The analysis concludes that the installation of FPV on Vrana Lake is a profitable project that results in reduced evaporation of the lake.

For a thesis [4] the aim was to present the potential of the island of Cres as an island that would meet all its energy needs from locally available renewable sources and thus become energy independent of energy imports from the mainland. The current situation on the island was taken as the initial scenario, and through three scenarios gradual implementation of the energy transition towards the 100% self-sufficient island was studied. The total reduction of CO_2 emissions between the studied scenarios was 2 603 t/year, while the consumption of conventional fuels eventually decreased from the initial 41.86 GWh/year to 30.35 GWh/year.

Specifically for the Unije island, the analysis of energy sustainability was studied in several analysis, starting from the first thorough analysis “Sustainable Development of the Unije Island” developed by the professor Starc N. from the Institute of Economics, Zagreb [5]. Mentioned study was a driving force for several future analyses on the topic of sustainable development of Unije Island. In [5], the author discusses the future sustainable and self-sufficient development of the Unije island and observes sustainable development in three components, ecological, economic and social. The expected result in regards the energy sector for Unije island is an optimal RES mix on Unije island (share of wind, solar, biomass, etc.) that will fully meet the island's needs. Within the water supply problem, three solutions were considered. The first solution was based on the construction of a water supply system that would connect islands Lošinj, Vele Srakane, Male Srakane and Unije island, and the construction of an 800 m^3 water tower. The second solution is the supply of water to the island by means of water carriers and the construction water tanks with the same capacity of 800 m^3. As a third solution, a hybrid use of desalination technology and water carrier supply was assessed. As previously mentioned, the [5] report was used as a basis for several future analysis for Unije island, mainly covering its energy potential and achieving the island’s energy sustainability.

In a thesis [6], the energy system of the Unije Island was planned with the numerous projects in order to promote sustainable development. Calculations were performed which showed the required capacity of renewable energy sources to allow the smooth development of the island towards the 100% RES utilization. Energy planning has been done using the software "H2RES". The thesis shows island’s energy balance, possibilities of biomass utilization, possibility of using electric, as well as the usage of desalination unit for water production.

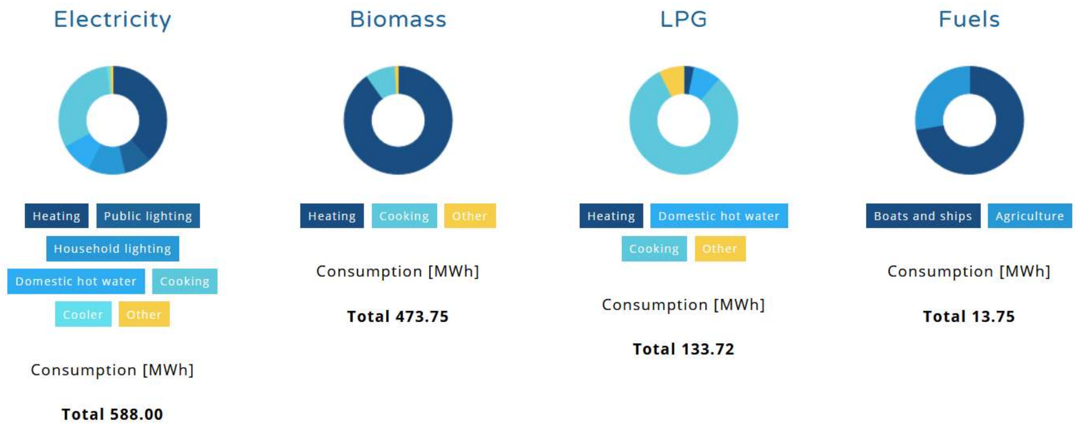


Figure 4. Unije island demand and consumption as results from conducted survey for the study purposes

The thesis tackles the problem through four scenarios of energy development of the island, where each scenario is calculated for the year 2030. Results showed that, based on the scenario, for 100% renewable electricity generation the island would need additional capacities in solar and wind power, with proposed battery storage. The capacities for proposed technologies, based on the studied scenarios, range in between 2.5 -3 MW of solar photovoltaic power, 0.5 - 3.3 MW of wind power, and 5 – 9 MWh of battery capacities to be able to achieve the 100% renewable electricity generation, photovoltaic power and battery energy storage are developed further under use case 1 for the INSULAE project on Unije.

In thesis [7] the aim was to conduct an analysis of the integration of solar photovoltaic power systems into the energy system of the island of Unije by evaluating four scenarios. The scenarios were analyzed in the EnergyPLAN software package. The analysis refers to households on the island that are divided into permanently inhabited and seasonal households. A comparison of scenarios was made, which showed optimal scenario in relation to the share of renewable energy sources in total electricity consumption. The results of the scenario can be seen in Figure 5. Results show how much electricity is covered by the photovoltaic system, how much was imported and exported and what is the share of own electricity consumption from the photovoltaic system.

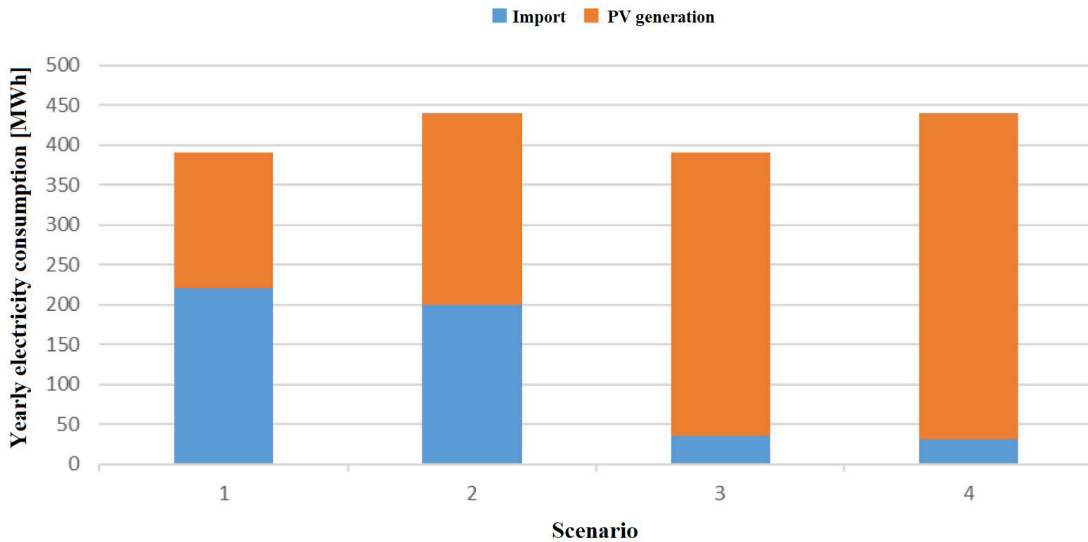


Figure 5. Yearly electricity consumption for four different scenarios

Previously mentioned works included the analysis of renewable energy sources implementation on Unije island covering the integrated and non-integrated implementation of photovoltaic systems. Additionally, implementation of battery system storage was also studied with some older analysis including the wind power too. In next sections we'll cover work done under the holistic approach covering the water-energy nexus for this use case, use case 2, through means of desalination unit operation utilizing the installed renewable energy sources. Furthermore, analysis of future to be installed systems is field of water system, as well as energy system on the Unije island was assessed.

3 WATER SYSTEM MODELLING

Water system modelling included development of models that covered the specifics of the future water system to be installed on the island of Unije. With the proposed water system, the new desalination unit is in a pretesting faze to assess the possibility of flexible operation to cover the future water demand, but also be able to operate flexibly for possible future market opportunities. More on the future opportunities for the holistic operation of water and energy systems can be seen in Section 4.6, continuing with the more general description in Section 5.

This section covers the developed models, ranging from the simple excel model that included hydraulic calculation of pipeline sections, to the final water system model of the whole Unije island developed using EPANET software. Additionally, a model was developed to assess the possibility for implementation of the demand response through the usage of the desalination plant, which showed that overall demand was reduced during the day and the evening hours, while it is increased during the night hours. This means that the energy is used in more optimal way because of the flexibility from the desalination plant, thus overall lower operation costs of the system were achieved.

3.1 Overview of the current situation and future water system plans

Vodoopskrba and odvodnja Cres Lošinj Ltd. (VIOCL) is a for profit public utility (Ltd.) for water supply and wastewater disposal founded and owned by the municipalities of Cres and Mali Lošinj. The company is operating in the municipal areas of Cres and Mali Lošinj which geographically involves the island of Cres (municipal area Cres) and islands Mali Lošinj, Veli Lošinj, **Unije**, Susak, Ilovik, Male Srakane and Vele Srakane (municipal area of Mali Lošinj).

Drinking water is brought to the island of Unije via a water carrier ship and is then distributed through an improvised pipeline system in the village into the individual house water tanks.

The water carrier ship is filled on the island of Lošinj (from the Cres-Lošinj water supply system), and the volume of the water carrier ship depends on the public procurement procedure for transporting drinking water by water carrier from Mali Lošinj to the islands of Susak, Unije, Male and Velike Srakane and Liski Bay.

The subsidized quantity of water delivered to the island of Unije for a period between 2009 and 2017 can be seen in Table 1 below:

Table 1. Monthly water supplied to Unije Island via water carrier ship in a period between 2009 and 2017

Unije Island													
SUBSIDIZED QUANTITY OF WATER SUPPLIED IN m³													
Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2009	0	0	0	266	598	687	938	778	715	210	0	0	4192
2010	0	0	0	280	497	542	757	694	373	0	0	0	3143
2011	0	0	290	305	691	528	735	653	557	370	0	226	4355
2012	0	274	634	0	385	890	873	1005	241	0	0	0	4302
2013	0	0	0	244	0	675	807	758	302	74	0	0	2860
2014	0	0	0	221	245	593	462	250	137	0	0	0	1908
2015	0	0	0	338	445	434	839	657	376	0	0	0	3089
2016	0	0	0	0	142	548	720	714	95	0	0	0	2219
2017	0	0	186	0	265	696	667	665	0	0	0	0	2479
Average	0	30	123	184	363	621	755	686	311	73	0	32	3172

3.1.1 The existing water supply on the Unije Island

The existing water supply on the Unije Island includes the following units:

WATER TANKS:

- Individual house level water tanks (around 230)
- public water tanks
  - 2 near the school (350 and 35 m³) – rainwater

- 2 in local committee building (850 and 80 m^3) – rainwater
- Water tank near church (350 m^3) - connected to a desalination plant
- Water tank near church (300 m^3) – rainwater

WELL U-1:

- Brackish water at depth of 22 m
- Used well capacity 2 L/s
- Water salinity ranging from 400 – 2000 mg/L

SUBMERSIBLE WATER PUMP:

- Nominal power 2.05 kW
- Rated flow 8 m^3/s
- Rated head 60 m

DESALINATION PLANT:

The underground part of the desalination plant has two water tanks, with 40 m^3 water volume each.

One water tank is used as raw brackish water storage connected via pressure line (900 m long) to the existing U-1 well. The brackish water tank allows for the retention of raw brackish water and the required contact time for the best possible coagulation of the constituents carried by the water, with the aim of successful filtration on the sand filters. In the case of increased water turbidity, the dosage agent is used for increased coagulation and flocculation.

The second water tank is freshwater tank used for storing water processed in desalination unit. Two water pumps installed in parallel mode are used for water transportation via pressure line (PEHD DN 110 mm, 104 m long) to the main water tank near church (350 m^3). Rated pump flow is 2.5 L/s, while rated pump head is 60 m. Existing piping system is not certified for a drinking water transportation, hence the freshwater from desalination units is considered as a process water.

Water pump with rated flow of 2.5 L/s and rated head of 40 m is used to transport brackish water to the sand filters, where any turbidity and dirt can be removed from the water. Such filtered water enters the protective pre-filter and reverse osmosis where water desalination takes place. Water afterwards goes through the remineralization process. Water disinfection is done after remineralization, and before entering the freshwater tank (40 m^3). Residual chlorine in processed water is below 200 mg/L.

Figure 6. Outside view of the desalination unit

The outside view of the desalination unit can be seen on Figure 6, while Figure 7 and Figure 8 show the internal parts of the desalination unit. More precisely, Figure 7 shows the sand filters which are used as pretreatment for the reverse osmosis shown on the Figure 8. Both, the sand filters, and reverse osmosis, as well as all the details of the desalination unit can be seen on technical scheme shown in Figure 9.

Figure 7. Sand filters inside the desalination unit

Figure 8. Reverse osmosis system inside the desalination unit

Other characteristics of the desalination unit:

- Nominal power: 27.6 kW
- Electricity consumption for 2017: 4555 kWh
- Efficiency: 0.5-0.55
- Maximum freshwater production 4-4.4 m^3/h

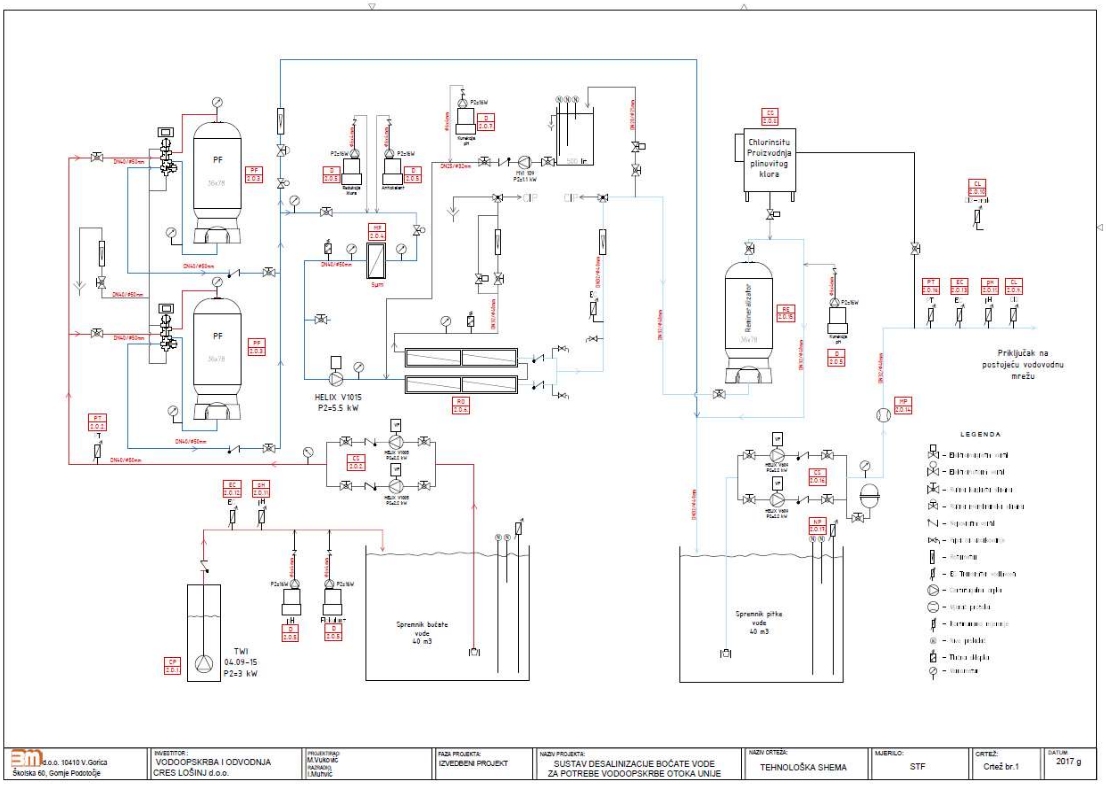


Figure 9. Desalination unit technical scheme

Besides the desalination unit which is in the testing phase of water production, drinking water is brought to Unije Island via a water carrier boat and is then distributed through the village to an individual house level water tanks by improvised pipelines.

3.1.2 Current sewage network

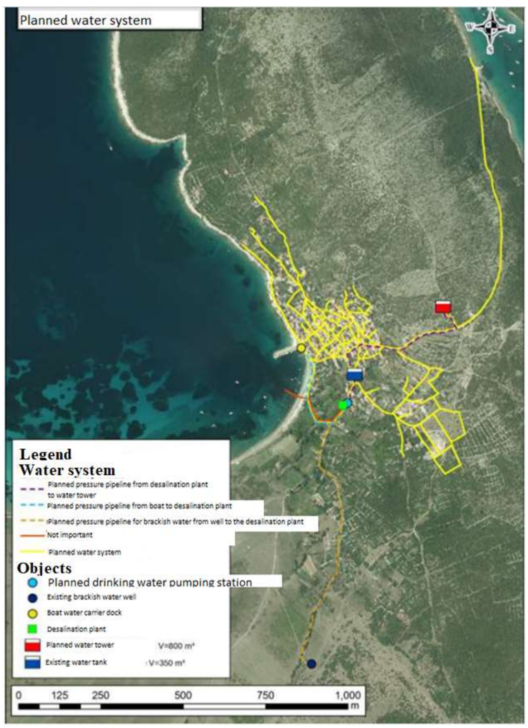
There is work in progress on current sewage network system. So far, a wastewater treatment plant has been built along with the underwater outlet pipeline. Based on the low number of population equivalent (P.E. = 900) to which it has been designed, pre-treatment technology is sufficient for effective wastewater treatment. Pre-treatment of this Unije wastewater treatment plant (WWTP) is consisted of a coarse screen designed to trap solids (such as plastic bags, rocks, etc.) and a combined grease – grit trap device that will extrude grease and fine grit from non-treated sewage water. After the treatment, wastewater is pumped through pressurised wastewater pipeline 531 meter long after which it's fed to underwater outlet pipeline that reaches 600 meters from shore, at the depth of 32 meters.

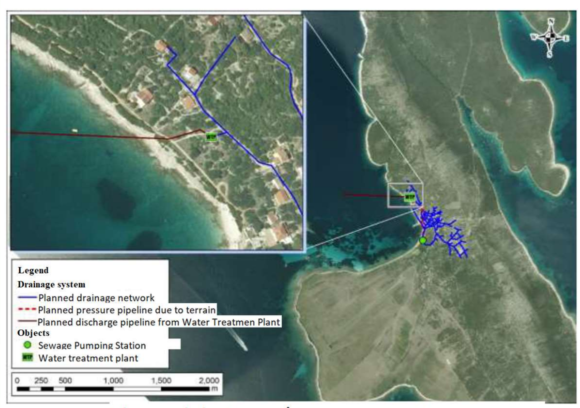
Currently, there is a main sewage collector (568 m) that has two shorter collectors connected to it (108 m and 168 m). Altogether, that makes for 844 m of sewage that is ready for 50 objects on island to be connected to it. With the main collector and WWTP finished, sewage network is ready to be expanded in the next stage of project.

3.1.3 Planned water and drainage system

The conceptual design of the "Water Supply and Sewerage and Sanitation Wastewater Treatment System of the Unije Island" was developed, and includes:

1. Installation of a new pumping station in the desalination plant that would transport water to the planned water tower
2. Water supply distribution network (6500 + 950 m)
3. Water reservoir/tower (800 m^3, 65 MAMSL) – connected to desalination unit
4. Water carrier boat dock as back up –for possible downtime in the operation of the desalination unit, or inability to produce water on the island a water carrier ship will be used. Dock will be connected via pressure pipeline (DN 150 mm, 380 m long) with freshwater tank (40 m^3) in desalination plant.
5. Sewage network (5.500 m)
6. Water treatment plant
7. Sewage water pumping station and pressure pipeline due to the terrain composition
8. Sea discharge





Planned drainage/sewerage system

Figure 10. Planned water system network (left); Planned drainage system (right)

3.2 Hydraulic pipeline calculation

As there is no operating water system on the island, two models were developed for a future water system based on the "*Water Supply and Sewerage and Sanitation Wastewater Treatment System of the Unije Island*" document.

The first model included simple excel hydraulic calculations of pipeline sections. The calculation was divided into sections:

1. From brackish water well to brackish water tank in desalination unit (Section 1)
2. From brackish water tank to the pre-treatment process in desalination unit (Section 2)
3. Reverse osmosis process (Section 3)
4. From water tank in desalination unit to existing 350 m^3 water tank (Section 4)
5. From planned water tower/reservoir 800 m^3 water tank to the consumers via future water system (Section 5)

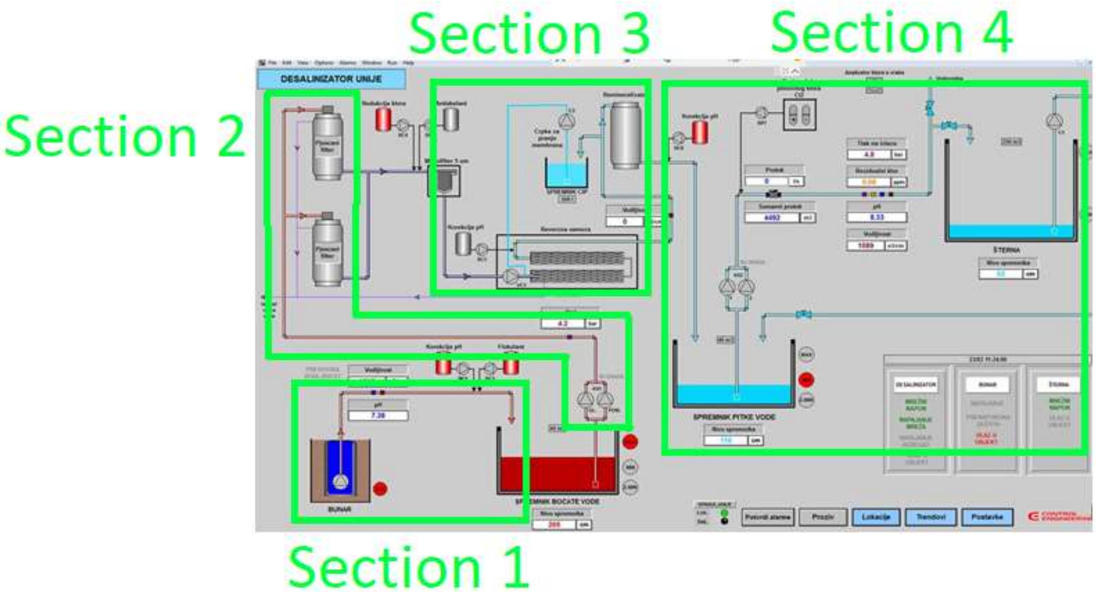


Figure 11. Sections of the modelled desalination unit and water system as part of the hydraulic pipeline calculations

Sections ranging from brackish water well to future water system can be seen in **Error! Reference source not found.** (from Section 1 to Section 4), while the Section 5 can be seen on a **Error! Reference source not found.**.

Figures ranging from **Error! Reference source not found.** to **Error! Reference source not found.** are showing inputs and results of the hydraulic pipeline calculations divided into beforementioned sections. Each figure shows results in a form of total pressure drop (in Pa), pumping power needed and the total electricity consumption in kWh/m^3.

After all pump capacities have been selected, based on the proposed water demand throughout the months, one can find monthly electricity demand and total cost associated with the water system operation. Final results can be seen in **Error! Reference source not found.**.

Defined model was used as pre-model to test the proposed solutions that are installed in desalination unit, and that are to be installed for the future water system expansion. For an initially proposed water demand of 1077 m^3, electricity demand is estimated to be around 5300 kWh with the total operation costs of 766 EUR/year. With taking into the account possible rise in water demand over the next several years due to the higher tourism on the island, one can estimate that for an annual water demand of 3800 m^3, the electricity consumption is 18580 kWh, with the total operation cost of 2670 EUR.

Sizing of the Pump 1:

Extracting of the brackish water from the source to the Desalination Plant

INPUTS:

Element of pipes:	
Geometry:	circular section
Diameter of pipe D (m) :	0.05
Lenght of pipe L (m) :	890
Roughness (m) :	2.50E-04
Vertical elevation (m)	50
Number of valves :	50
Resistance coeficient valves :	1
Number of elbows :	200
Resistance coeficient elbow :	1
Resistance coeficient tank entrance	1

Flow medium :	
Flow medium :	Water 23°C
Condition :	Liquid
Volume flow (m3/h) :	8
Weigh density (kg/m3) :	1024
Kinematic viscosity (m²/s) :	9.86E-08

Data pump :	
Power (kW)	3
Efficiency	0.8
Rated flow (m3/h)	8

RESULTS :

Electricity consumption (kWh/m3)	0.360
Total pressure drop (Pa)	1035506
Power pump needed (kW)	2.30
Real electricity Power (kW)	2.88

CALCULATION :

Pressure drop :	
Velocity of fluid flow (m/s) :	1.13
Reynolds Number :	573728
Characteristic of the flow :	Turbulent
Pipe friction coeficient :	0.032
Linear Pressure drop (Pa) :	368623
Singular Presure drop (Pa):	164611
Gravity Pressure drop (Pa)	502272

Friction coefcicien calculation when the flow is turbulent using an iterrative scheme : (Colebrook equation)

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\varepsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right)$$

Friction coeficient f	0.032
Colebrook left side	5.695
Colebrook right side	5.723
Objective	0.001

Only for Turbulent Flow !

Figure 12. Desalination plant excel model - sizing of the pump 1

Sizing of the Pump 2:

Feeding of the brackish water from the brackish water tank to the pre-treatment process

INPUTS:

Element of pipes:	
Geometry:	circular section
Diameter of pipe D (m) :	0.05
Lenght of pipe L (m) :	100
Roughness (m) :	2.50E-04
Vertical elevation (m)	10
Number of valves :	5
Resistance coeficient valves :	1
Number of elbows :	20
Resistance coeficient elbow :	1
Resistance coeficient tank entrance	1

Flow medium :	
Flow medium :	Water 23°C
Condition :	Liquid
Volume flow (m3/h) :	4
Weigh density (kg/m3) :	1024
Kinematic viscosity (m²/s) :	9.86E-07

Data pump :	
Power (kW)	2.2
Efficiency	0.86
Rated flow (m3/h)	4

RESULTS :

Electricity consumption (kWh/m3)	0.037
Total pressure drop (Pa)	115072
Power pump needed (kW)	0.13
Real electricity Power (kW)	0.15

CALCULATION :

Pressure drop :	
Velocity of fluid flow (m/s) :	0.57
Reynolds Number :	28686
Characteristic of the flow :	Turbulent
Pipe friction coeficient :	0.032
Linear Pressure drop (Pa) :	10355
Singular Presure drop (Pa):	4263
Gravity Pressure drop (Pa)	100454

Friction coefcicient calculation when the flow is turbulent using an iterrative scheme : (Colebrook equation)

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\varepsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right)$$

Friction coeficient f	0.032
Colebrook left side	5.443
Colebrook right side	5.469
Objective	0.001

Only for Turbulent Flow !

Figure 13. Desalination plant excel model - sizing of the pump 2

Sizing of the Pump 3:

Reverse Osmosis Process

INPUTS:

Data pump :	
Power (kW)	5.5
Efficiency	0.892
Rated flow (m3/h)	4

Data RO process	
Pressure operating (bar)	20
Recovery	0.4

RESULTS :

Electricity consumption (kWh/m3)	3.854

CALCULATION :

Fresh water flow (m3/h)	1.6
Brine water flow (m3/h)	2.4

Figure 14. Desalination plant excel model - sizing of the pump 3

Sizing of the Pump 4:

Extracting of the drinkable water from the Desalination Plant to the existing water tank of 350m3

INPUTS:

Element of pipes:	
Geometry:	circular section
Diameter of pipe D (m) :	0.05
Lenght of pipe L (m) :	700
Roughness (m) :	2.50E-04
Vertical elevation (m)	50
Number of valves :	50
Resistance coeficient valves :	1
Number of elbows :	200
Resistance coeficient elbow :	1
Resistance coeficient tank entrance	1

Flow medium :	
Flow medium :	Water 23°C
Condition :	Liquid
Volume flow (m3/h) :	8
Weigh density (kg/m3) :	998
Kinematic viscosity (m²/s) :	9.35E-07

Data pump :	
Power (kW)	3
Efficiency	0.8
Rated flow (m3/h)	8

RESULTS :

Electricity consumption (kWh/m3)	0.324
Total pressure drop (Pa)	932517
Power pump needed (kW)	2.07
Real electricity Power (kW)	2.59

CALCULATION :

Pressure drop :	
Velocity of fluid flow (m/s) :	1.13
Reynolds Number :	60531
Characteristic of the flow :	Turbulent
Pipe friction coeficient :	0.032
Linear Pressure drop (Pa) :	282567
Singular Presure drop (Pa):	160431
Gravity Pressure drop (Pa)	489519

Friction coefcicien calculation when the flow is turbulent using an iterrative scheme : (Colebrook equation)

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\varepsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right)$$

Friction coeficient f	0.032
Colebrook left side	5.573
Colebrook right side	5.600
Objective	0.001

Only for Turbulent Flow !

Figure 15. Desalination plant excel model - sizing of the pump 4

Sizing of the Pump 5:

Distribution of the water to the consumers from the water tank of 800m3

INPUTS:

Element of pipes:	
Geometry:	circular section
Diameter of pipe D (m) :	0.05
Lenght of pipe L (m) :	1000
Roughness (m) :	2.50E-04
Vertical elevation (m)	50
Number of valves :	50
Resistance coeficient valves :	1
Number of elbows :	200
Resistance coeficient elbow :	1
Resistance coeficient tank entrance	1

Flow medium :	
Flow medium :	Water 23°C
Condition :	Liquid
Volume flow (m3/h) :	8
Weigh density (kg/m3) :	998
Kinematic viscosity (m²/s) :	9.35E-07

Data pump :	
Power (kW)	3
Efficiency	0.8
Rated flow (m3/h)	8

RESULTS :

Electricity consumption (kWh/m3)	0.366
Total pressure drop (Pa)	1053617
Power pump needed (kW)	2.34
Real electricity Power (kW)	2.93

CALCULATION :

Pressure drop :	
Velocity of fluid flow (m/s) :	1.13
Reynolds Number :	60531
Characteristic of the flow :	Turbulent
Pipe friction coeficient :	0.032
Linear Pressure drop (Pa) :	403667
Singular Presure drop (Pa):	160431
Gravity Pressure drop (Pa)	489519

Friction coefcicien calculation when the flow is turbulent using an iterrative scheme : (Colebrook equation)

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\varepsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right)$$

Friction coeficient f	0.032
Colebrook left side	5.573
Colebrook right side	5.600
Objective	0.001

Only for Turbulent Flow !

Figure 16. Desalination plant excel model - sizing of the pump 5

Energy consumption (kWh):

Calculation of the electricity consummption in function of the water demand during one year

RESULTS :

	Electricity consumption (kWh/m3)
Pump 1	0.360
Pump 2	0.037
Pump 3	3.854
Pump 4	0.324
Pump 5	0.366
TOTAL	4.940

Electricity cost (€/kWh) 0.144

	Water demand (m3)	Electricity demand (kWh)	Cost (€)
January	30	148.2	21.34
February	50	247.0	35.57
March	70	345.8	49.80
April	57	281.6	40.55
May	100	494.0	71.14
June	143	706.4	101.73
July	168	829.9	119.51
August	158	780.5	112.40
September	111	548.3	78.96
October	80	395.2	56.91
November	70	345.8	49.80
December	40	197.6	28.45

TOTAL :

Water Demand (m3)	1077
Electricity Demand (kWh)	5320.4
Cost (€/year)	766.14

Figure 17. Desalination plant excel model - energy consumption

3.3 EPANET water system model

Unije Island future water system was developed using open source software EPANET.

Software is free to use and download using link: https://www.epa.gov/water-research/epanet
Basic EPANET workspace can be seen in picture below:

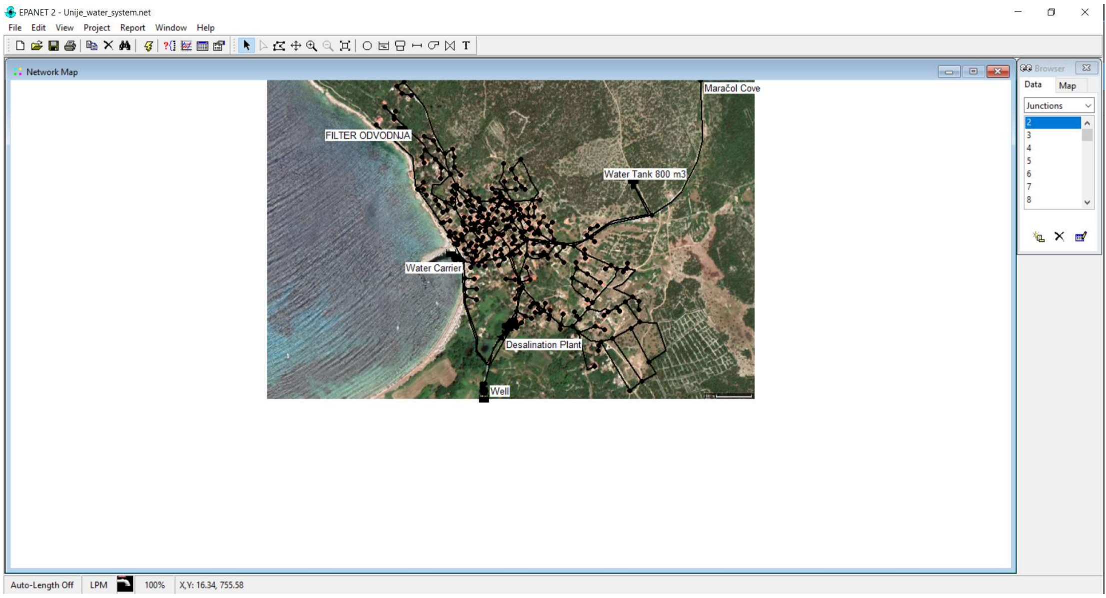


Figure 18. EPANET model of Unije water system

EPANET is a software that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality throughout a system, which can include:

- altering pumping and tank filling/emptying schedules
- targeted pipe cleaning and replacement
- altering source utilization within multiple source systems
- use of satellite treatment, such as re-chlorination at storage tanks

The method used in EPANET to solve the flow continuity and head loss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. In [8] and later in [9] authors chose to call it the "Gradient Method". Similar approaches have been described by authors in [10] and in [11]. The only difference between these methods is the way in which link flows are updated after a new trial solution for nodal heads has been found.

Additional information on how the network components are modeled, and how the "Gradient Method" is applied can be found in EPANET user manual.

Developed water system can be seen on a Figure 19 below:

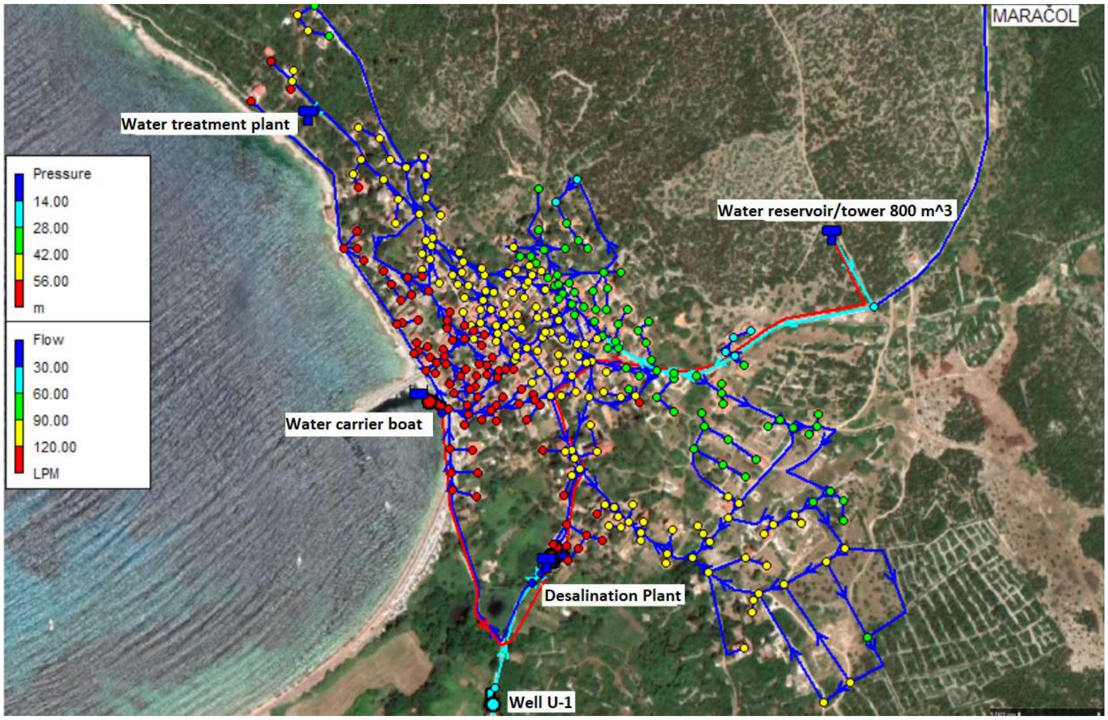


Figure 19. Overview of the future Unije water system

3.4 Demand response model

The synergy between the energy and water sector is becoming increasingly important on islands for two reasons. Firstly, there is a need for increased integration of renewable energy sources and decarbonization of energy sector and water system can be used as a flexibility provider for the energy system. Secondly, water scarcity is often the issue on the islands, thus there is need for securing the water supply on the islands at affordable prices. The desalination plants can be used as the implementation technology for achieving the water-energy nexus. Island of Unije, together with other islands in the Kvarner archipelago represent potential test beds for these technologies. Because desalination technologies are present on many islands of Kvarner archipelago, a study described in this chapter was conducted in order to assess the possibility for implementation of the demand response through the usage of desalination plant. A specific form of demand response program based on the day-ahead electricity market prices was conducted, however other programmes can be implemented as well. This study observed financial parameters as well as technical parameters in order to quantify the benefits of using the desalination plants as demand response[1].

3.4.1 Energy system model

Developed energy system model is implemented as non-linear and non-convex AC OPF model. This means that no global optimum can be guaranteed as a solution to this problem. However, since the observed system is small enough, the conventional solvers can be used for achievement of sufficiently accurate solutions. The detailed model can be found in the study[2].

3.4.2 Demand response model

The demand response program implemented in the desalination plants is based on the day-ahead electricity market prices. The model observes the differences between the two consecutive house price difference. Higher day-ahead market price difference between the two hours often means higher changes in the system operation. Thus, model is defined in such way that it allows more possibility for the demand response during these periods so it can provide support for the system. This is mathematically formulated in the study[2]. Flexibility factor is introduced as well in order to reflect the psychical possibilities for the implementation of the demand response (e.g. existing desalination capacity). Lower value of flexibility factor means higher possibility for the demand response. The proposed demand response model is incorporated in the environment of Kvarner archipelago with a substation on Lošinj island representing a feeder for other islands. The topology is presented in Figure 20.

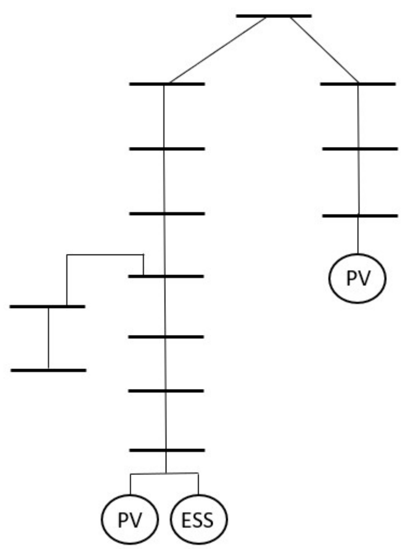


Figure 20. Analysed system

[1] M. Mimica, D. F. Dominković, T. Capuder, G. Krajačić, On the value and the potential of demand response in the Smart island archipelago, *Renewable Energy (under review), 2021.*

Several scenarios were considered for the analysed case study of Unije and Kvarner archipelago. Scenario A is reference scenario without the implementation of demand response (DR) and energy storage system (EES) usage. Scenario B adds the implementation of EES, while scenario C allows for DR in all nodes of the system. Finally, scenario D adds them both, EES implementation and DR in all nodes of the system. Scenarios are also presented in a Table 2.

Table 2. Scenarios included in the analysis

Scenario	A	B	C	D
Description	Scenario without DR and ESS	A + ESS	A + DR in all nodes	A + ESS + DR in all nodes

3.4.3 Analysis results

The change of operation cost for different scenarios and flexibility factor *k* values are shown in Figure 21. The implementation of the demand response and energy storage system resulted with savings in the overall operation of the system. The savings are more expressed for the more optimistic *k* values which allow higher implementation of the demand response. This result clearly illustrates the benefits for the consumers of the demand response implementation, especially with regards to water-energy nexus as is case in this use case on Unije island.

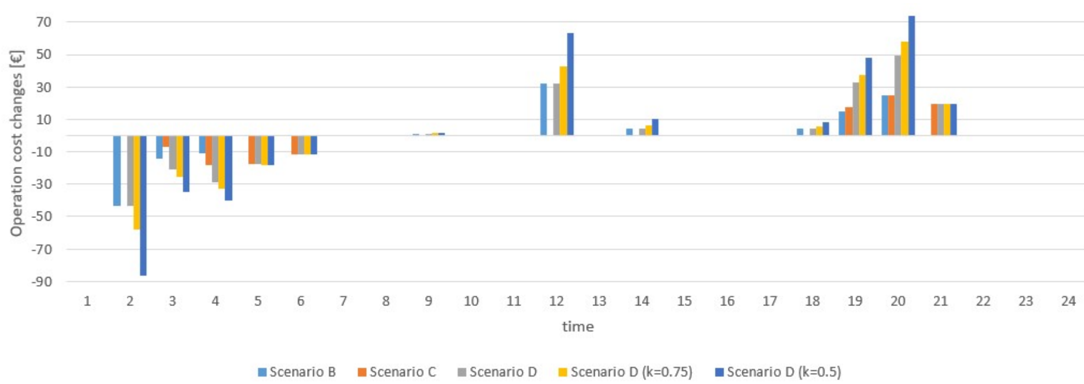


Figure 21. Operation cost changes for different scenarios and *k* values

The demand response operation can be observed in Figure 22. The overall demand is reduced during the day and the evening hours, while it is increased during the night hours. The demand response values increase as the allowed flexibility increases which confirms the benefits of the demand response for the system operation.

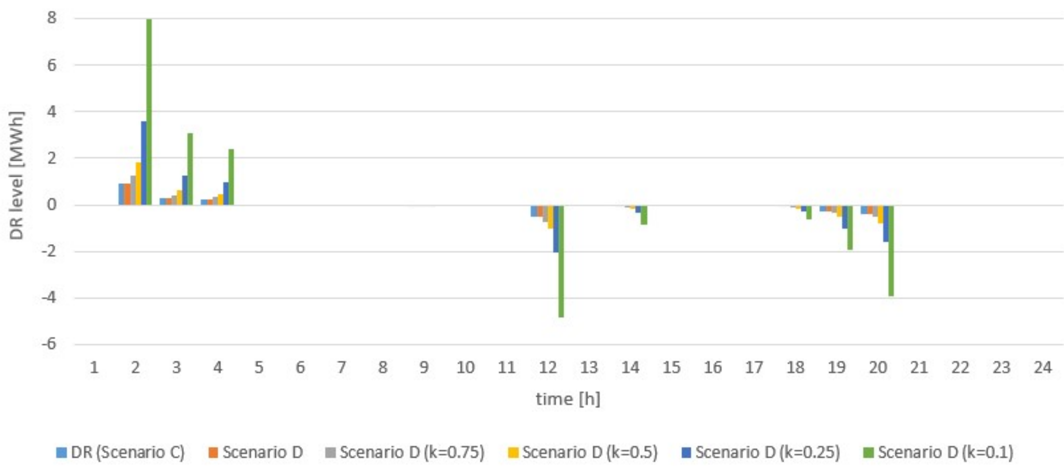


Figure 22. Demand response values for different scenarios and flexibility values

The demand response operation was observed for different PV values in the system as well. The system operation is observed for fixed *k* = 0.5 and the share of 25% of PV corresponds to initial value of the PV share in the system. Figure 23 shows the demand response and battery operation for different share of PV. It can be observed that the battery operation is mostly affected by the change in the PV share, while demand response had similar operation pattern for all shares. This can be explained by the fact that the demand response is mostly influenced by the prices on the day-ahead market. Detailed results are presented in Figure 23.

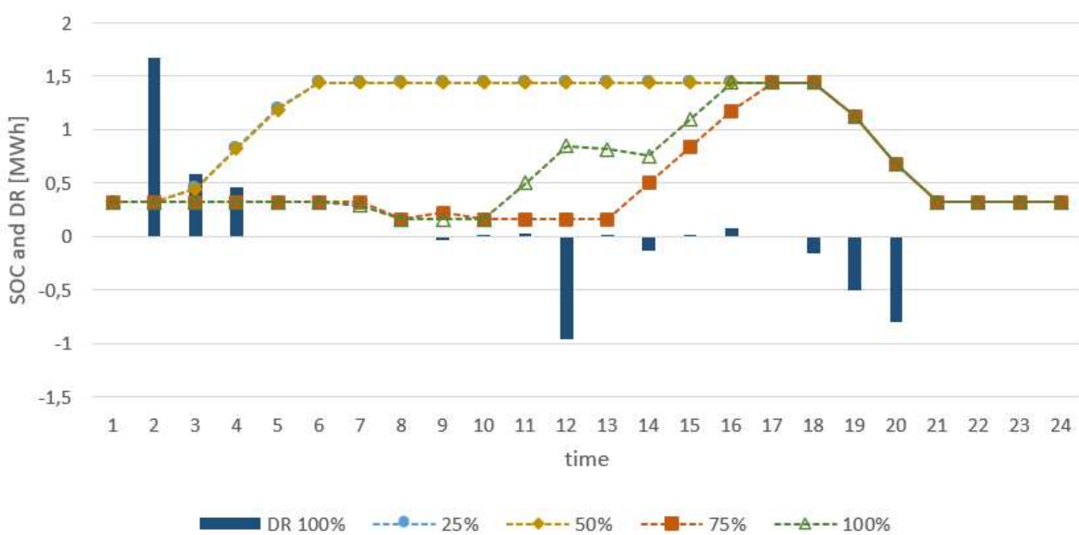


Figure 23. Battery and demand response operation for k = 0.5 and different PV share

This study also analysed the impact of different incentive values μ on the system operation. Figure 24 presents the operation of the demand response for different flexibility values and incentive values. The results showed that increased incentive value would be favourable option for increase of the demand response values in systems with low flexibility. The results also showed that, when incentive is higher than 23% of the day-ahead market prices, the system did not choose to use the demand response. This means that this is the upper level of incentive at which the demand response is no longer activated. Moreover, the study also showed that, when there is less devices that can provide demand response present in the archipelago, the demand response service should be more incentivized in order to stimulate the consumers to participate in demand response programs.

It should be also noted that the impact of the demand response on the technical parameters was also observed by calculating the voltage for different incentives and flexibility values. It was shown that minimum and maximum voltage in the system did not change significantly which means that the demand response program did not represent a technical issue for the system.

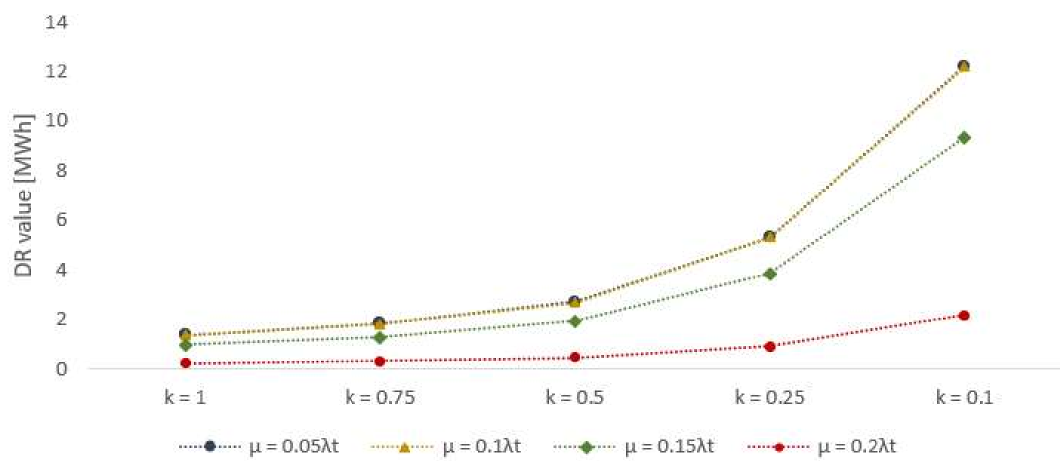


Figure 24. Demand response operation for different incentives and flexibilities

4 ENGINEERING AND EQUIPMENT DEVELOPMENT

Engineering and equipment development is covered through several points regarding the water/energy system. The sections include descriptions of current and planned water system, desalination unit with PV plant on the roof, smart agriculture and modelled implementation of the water-energy nexus actions. With the available equipment including smart water system, desalination unit, PV plant and battery storage, the optimal joint operation of the water and energy system is discussed. The proposed objective function minimizes the total system cost giving the optimal operation of the water and energy system.

4.1 The existing water supply on the Unije Island

The current situation on the island of Unije includes a desalination unit, a PV power plant on the roof of the desalination unit, and a part of the water supply system under construction. The 0.4 MW/1.6 MWh battery and 1 MW photovoltaic power unit is still in the planning stage, while the rest of the water supply system is under construction. The existing and planned condition of the water supply system is described hereafter.

The current state of water supply on the island of Unije includes a brackish water well, a desalination plant, a distribution network in the settlement currently under construction, its own sources of water collection (rainwater), public tanks, and water supply by water carrier ship .

Private water tanks as part of residential households are used to store rainwater and freshwater brought to Unije via water carrier ship. Water is pumped from house cisterns with a house hydrophore and distributed to the distribution installation. Public cisterns are of large volume and are located near the school (350m^3), church (350 m^3) and local committee building (850m^3). Until the construction of the desalination unit, the cistern near the church was the main one and was replenished with water from water carrier ship, while the other cisterns were replenished with rainwater.

The brackish water is pumped from the existing U-1 well in the field with new pumps with a capacity of 2 l/s. The previous pumps were powered by a diesel generator, and the newly installed ones were connected to a low-voltage distribution system. The water from the well is forced into a pressure pipeline that goes all the way to the desalination unit. Tests have shown a minimum well yield of about 3.5 l/s. These tests were conducted as early as the 20th century, so new tests will be needed to determine how feasible it is to add additional capacity to the existing desalination unit to cover potentially increased future demand. After the desalination unit, the water from the 40 m^3 purified water tank within the desalination unit is transported all the way to the tank near the church.

The current distribution network does not connect the hydrophore with residential houses, but with 10 hydrants that are spread throughout the settlement. If necessary, hydrants and house cisterns are connected by surface distribution. Prior to the start of works, the settlement was supplied with water from a tanker with a volume of 250-1000 m^3, depending on the need. Apart from Unije, the tanker is also used on other islands of the Cres-Lošinj archipelago where there is a lack of water in the summer months. The tanker connects to a shaft located on the waterfront and the water is distributed throughout the village to an individual house cistern by improvised surface distribution.

4.2 Desalination unit

The desalination unit is an 8.0 x 6.0 m building, divided into two parts. On the ground floor there is equipment for desalination, namely pressure pumps for sand filters, reverse osmosis plant, remineralizer, pressure pumps for the water distribution, electrical equipment and other smaller equipment. In the underground part there are two water tanks, with an individual volume of 40 m^3. The brackish water tank which is supplied by the existing connection from the well pumps, and the purified water tank which is intended for further use in the water supply system.

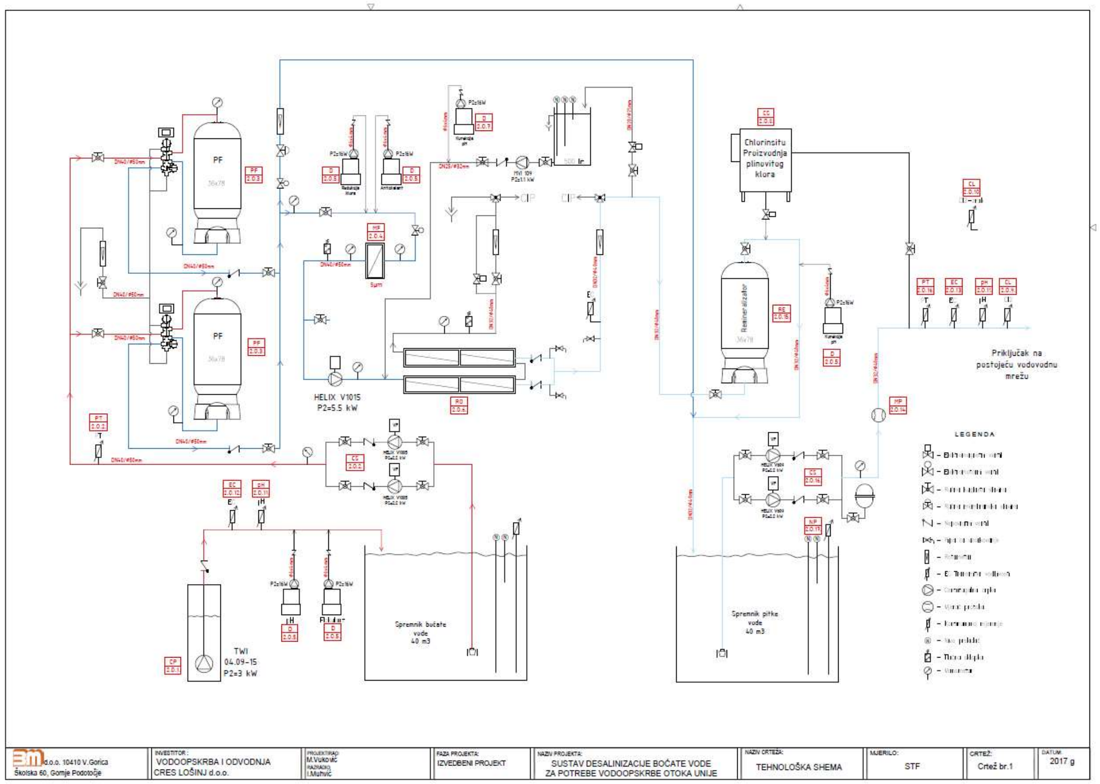


Figure 25. Desalination unit scheme

One can differentiate two different desalination unit system operation. One includes normal system operation, meaning only filling the main water storage tank located near the church, from where the water demand is being covered. On the other hand, second system operation includes filling the private water storage tanks directly from desalination unit. The first system operation can be divided into few steps showing the water flows between the desalination unit and main water storage tank:

1. Reverse osmosis unit is producing fresh water and storing it to freshwater storage tank in desalination unit (40 m^3). Freshwater tank has a water level sensor
2. When water in freshwater tank reaches around 50 cm from the upper water level limit, the electric motor driven three-way valve opens the connection between the main water storage tank and desalination unit, and the pump start the operation. The reverse osmosis is in operation at all times, filling the freshwater tank
3. The filling capacity of the main water tank is approximately 3 L/s (the pump is frequently regulated, so additional adjustments are possible), while the reverse osmosis production of drinking water is approximately 1 L/s, meaning that pump will fill the main storage tank discontinuously
4. The main storage tank has the ultrasonic water level sensor, and when the water level reaches the upper level, the pump in desalination unit stops, while three-way valve closes the connection between desalination unit and main storage tank. Three-way valve opens the connection between the desalination unit and consumers directly.

5. If the water level in the freshwater storage tank in desalination unit is below the upper limit, reverse osmosis unit continues producing freshwater until the upper water level is reached
6. If the main storage tank and freshwater tank in desalination unit are both full, the reverse osmosis stops with the operation

The monitoring and control system of the desalination plant is in the phase of pretesting, ie. the aim is to enable the control of the desalination unit from the administrative building in Mali Lošinj via a 3G/4G connection. The SCADA preview can be seen in Figure 26 below.

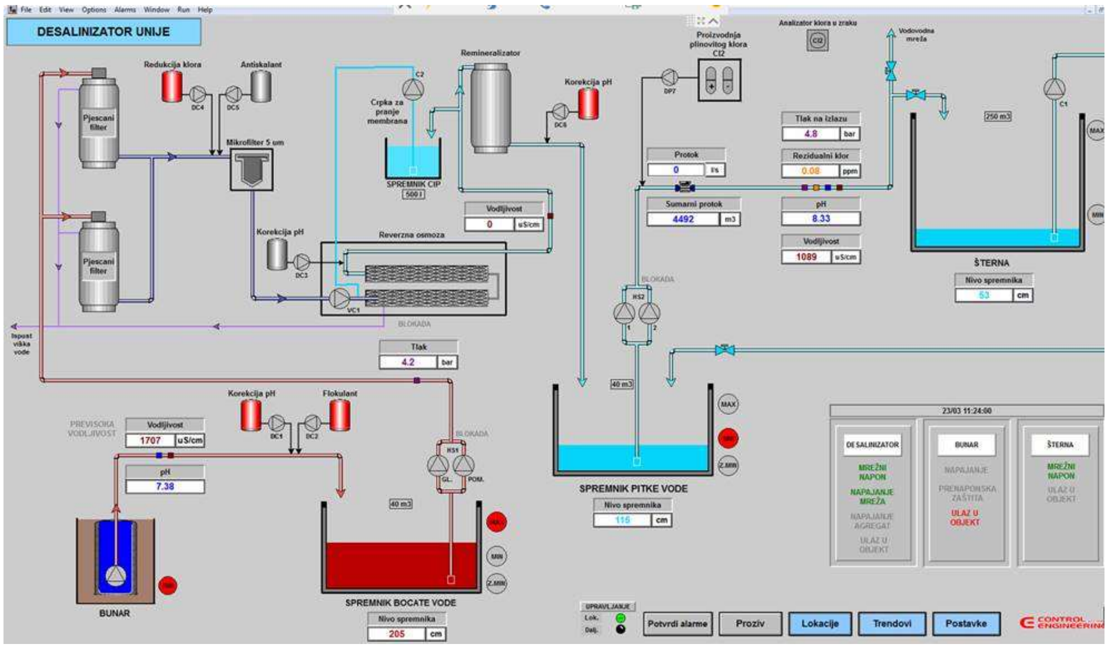


Figure 26. SCADA system preview of the desalination unit at Unije island

The second system, meaning private water tanks filling, is done in steps below:

1. Precondition: three-way valve open in the direction of the settlement.
2. Switch on the pump in the desalination unit, and in case of closing three-way valve, the pump is switched off.
3. If the water level in the freshwater tank drops below half the tank height, the electric motor gate valve between the desalination unit and main storage water tank opens.
4. The existing pump at the main storage tank is switched on, which lifts the water from the main water tank and goes through the PEHD DN 160 pipeline towards freshwater tank in desalination unit
5. Re-chlorination of the mixed water from main water tank and existing freshwater in freshwater storage is performed
6. The reverse osmosis module is in operation at all times
7. If the water level in the main water storage tank is at a minimum level or the supply of private water tanks is interrupted for some reason, the main water storage pump is switched off and the electric gate valve on the inlet to the desalination unit is closed. The

three-way valve opens connection between the desalination unit and main water tanks near the church

8. Return to normal system operation

4.3 PV on the desalination roof

A 7 kWp photovoltaic power plant was built on the roof of the desalination building on the island of Unije. The photovoltaic power plant produces electricity from renewable sources, and is connected to the existing low-voltage electricity distribution network with the aim of electricity production for self consumption. The nominal power of the photovoltaic power plant inverter is 7.5 kWp, but is limited to 7 kWp. Top view of the installed PV unit on the roof can be seen in Figure 27 below.

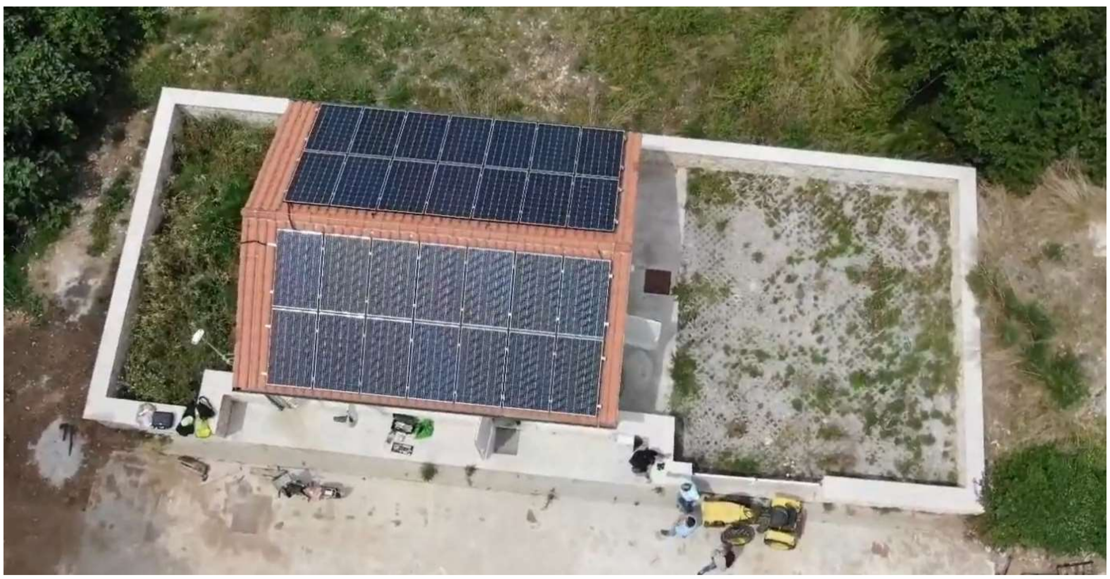


Figure 27. Top view of the installed PV system on a roof of desalination unit

The estimate of the expected electricity production of the planned photovoltaic power plant was made using a program that was made available as a publicly available PVGIS service.

The location of the object in question is:

- Latitude (N): 44º38'6"
- Longitude (E): 14º14'57"

As can be seen in Figure 27, the PV plant is in two parts of equal nominal power, but parts differ in their orientation. The southeast part is oriented towards the 127° azimuth angle, while the northwest part has the 307°azimuth angle orientation. The PV system is mounted as a fixed, pre-assembled load-bearing substructure that is at a roof pitch of 22° relative to the horizontal (parallel to the roof). The expected average total solar radiation at the location for the 307° azimuth angle orientation is 1287 kWh/m^2, while for the second oriented part it is expected to have 1595 kWh/m^2. Hence, the expected annual power generation from the 307° azimuth-oriented part is 3628 kWh, while the 127°azimuth-oriented part is expected to produce 4608 kWh. Calculation results using PVGIS can be seen in Figure 28 and Figure 29.

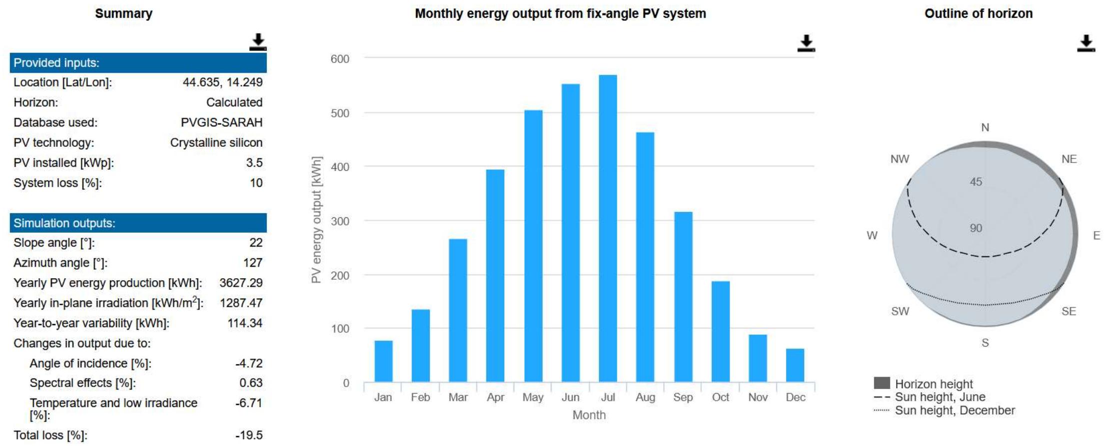


Figure 28. Data and expected power generation from the northeast (307°) part of the PV plant on a desalination roof

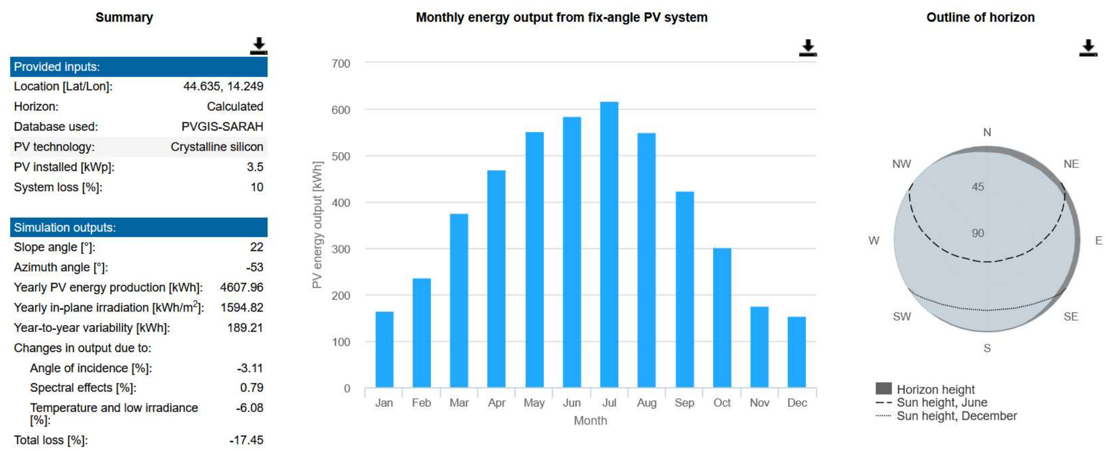


Figure 29. Data and expected power generation from the southwest (127°) part of the PV plant on a desalination roof

Photovoltaic power plant is in parallel mode of operation with the grid, therefore the power plant must be equipped for parallel operation with the distribution network, in all regular and extraordinary operating circumstances, without compromising the distribution network and other users.

The conditions of parallel operation ensure mutually harmonized protection of the power plant and the distribution network. In case of deviation from the prescribed conditions for parallel operation, the protection must separate the power plant from the parallel operation.

For parallel operation of the power plant by the network, the power plant must have:

a) protection that ensures the conditions of parallel operation
b) protection against disturbances and breakdowns in the power plant
c) protection against disturbances and failures in the network

The producer is obliged to take the necessary measures in order to deliver the standard level of electricity quality to the electricity distribution network.

In order to ensure safe and uninterrupted operation of the photovoltaic power plant throughout its lifetime. It is necessary to provide complete protection against atmospheric and induced voltages already in the design phase of the photovoltaic power plant. Protection must be provided not only on the output side of the inverter, but also on the output side of the photovoltaic module. A photovoltaic system installed on large surfaces is initially more likely to be struck by lightning. The effects of lightning strikes on photovoltaic modules will also have consequences on other electrical equipment, due to the electrical connection between the photovoltaic power plant and the electrical installation, leading to financial losses.

In order to ensure better monitoring of the operation of the PV plant and to enable efficient data sharing, the PV monitoring system was integrated into the Smart Island Platform within the project (Figure 30).

The integration is realized via an ABB controller and data is collected at 15-minute intervals. Within the central system, a correlation is made with meteorological and other data, in order to better plan the operation of the power plant itself and the optimal use of energy inside the desalination.

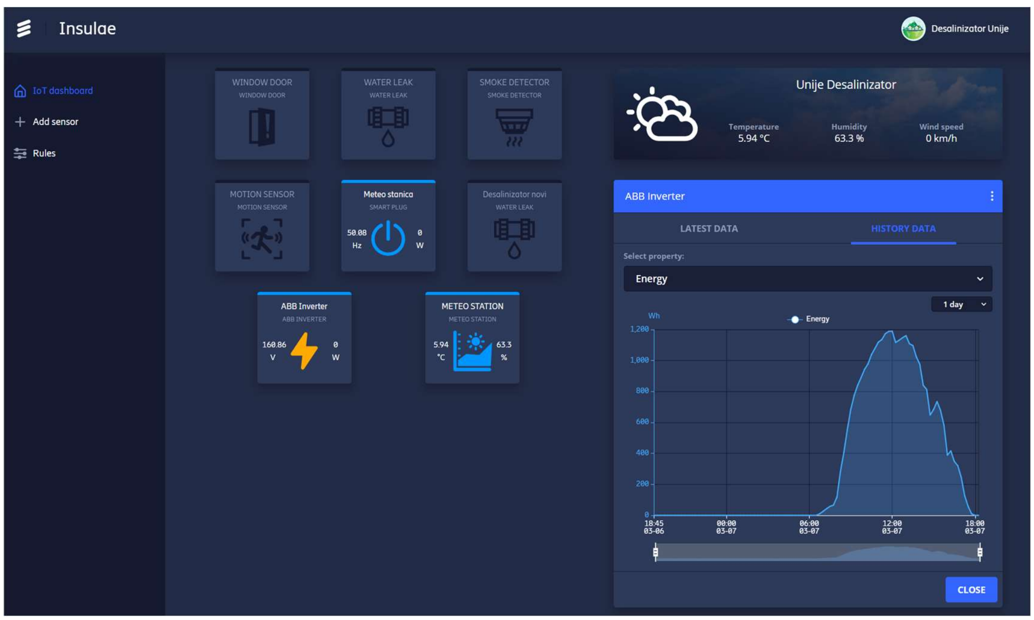


Figure 30. PV plant integrated in Insulae Smart Island Platform

Figure 31 shows the location of the installed PV system, while Figure 32 and Figure 33 show the technical drawings of the installed PV system on the desalination roof. Figure 34 shows the model of installed PV modules.

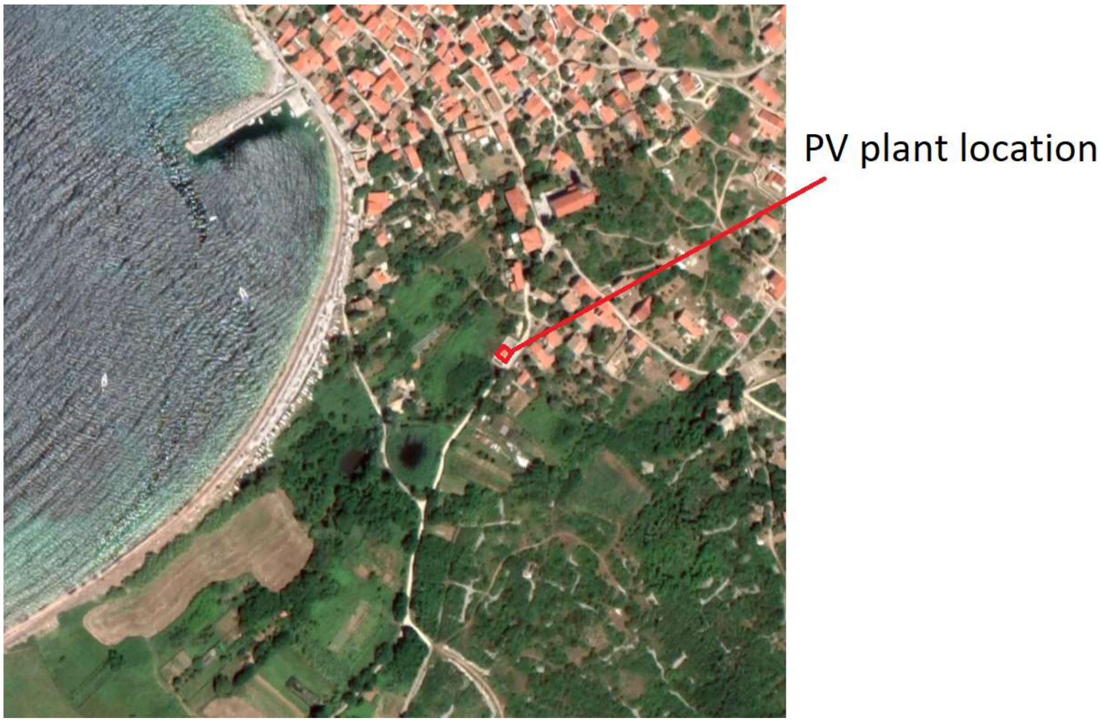


Figure 31. Location of installed PV plant (roof of desalination unit)

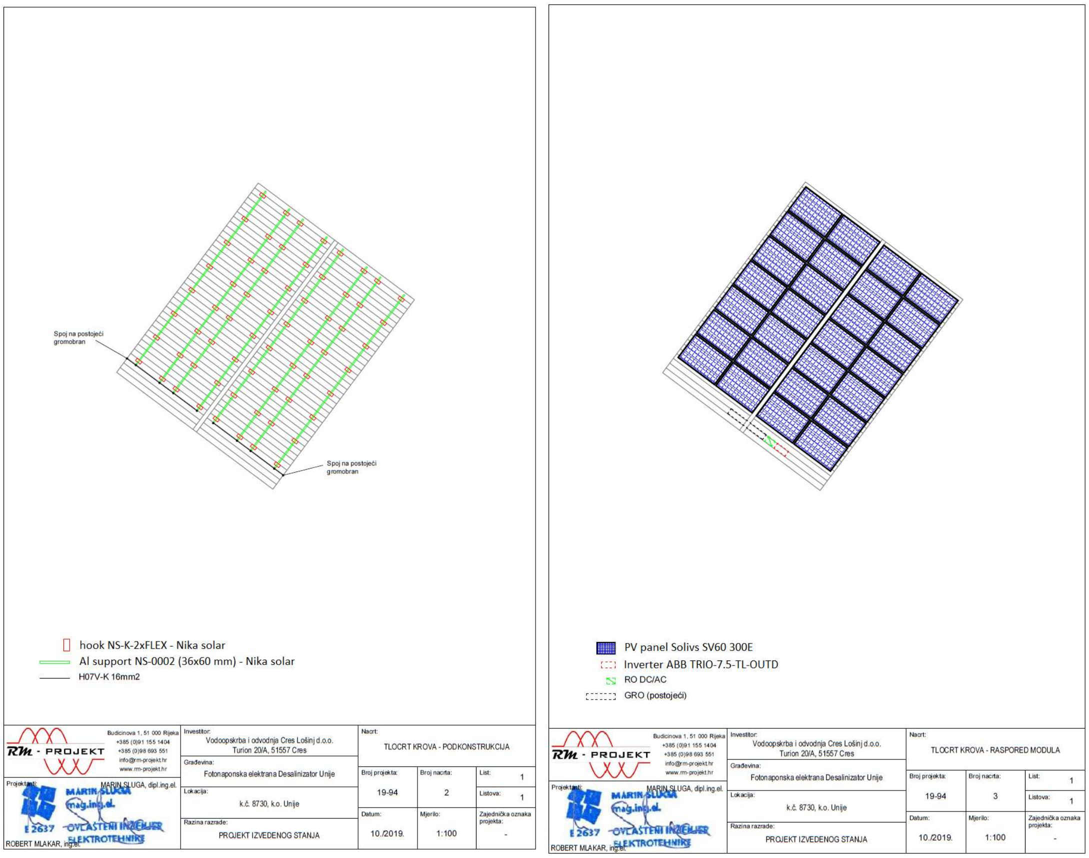


Figure 32. PV plant support construction (left); PV modules (right)

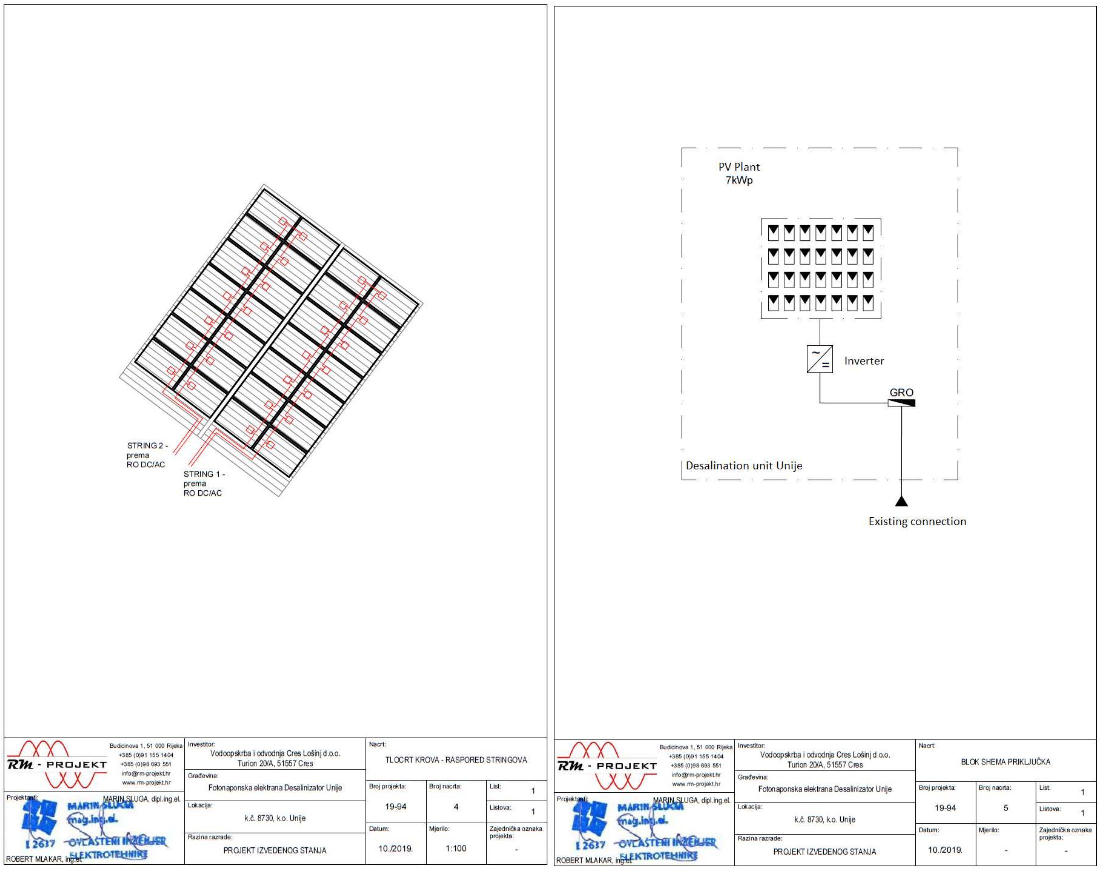


Figure 33. PV panel connections (left), block diagram of the PV plant connection

Figure 34. Installed PV modules

4.4 Future water and drainage systems

Future water and drainage drawings are symbolically shown on Figure 35 and Figure 36. More detailed view can be seen in pdf files Technical_drawing_1_Unije_water_system.pdf and Technical_drawing_2_Unije_water_system.pdf.

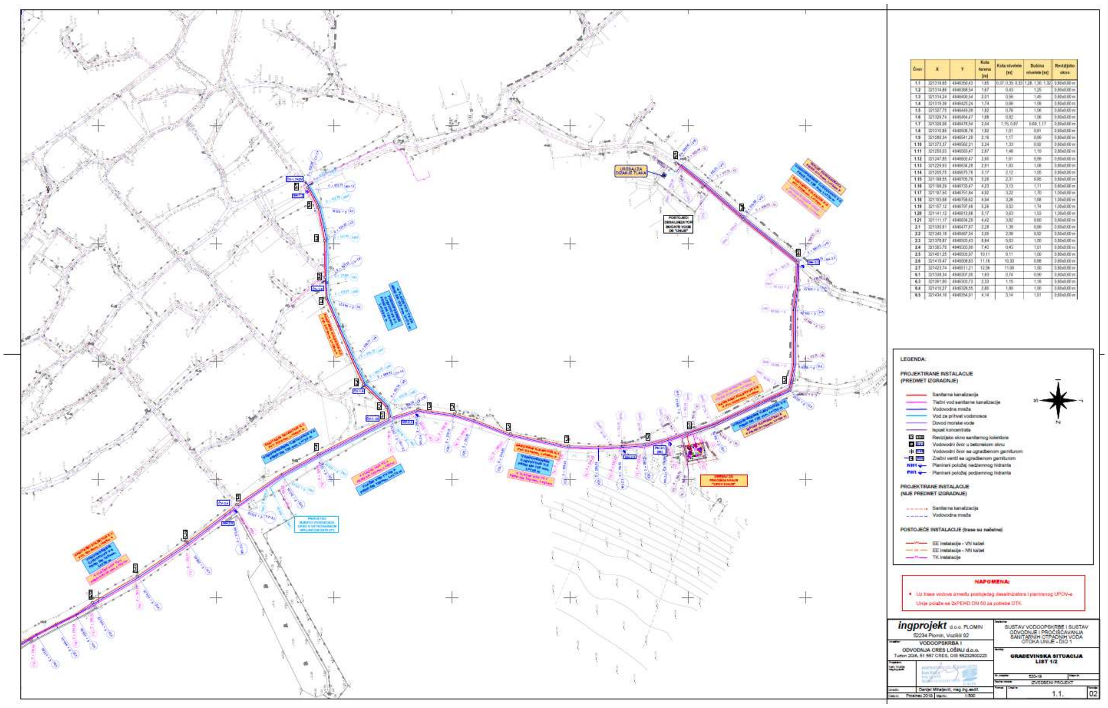


Figure 35. Technical drawings of future water and drainage system on island of Unije

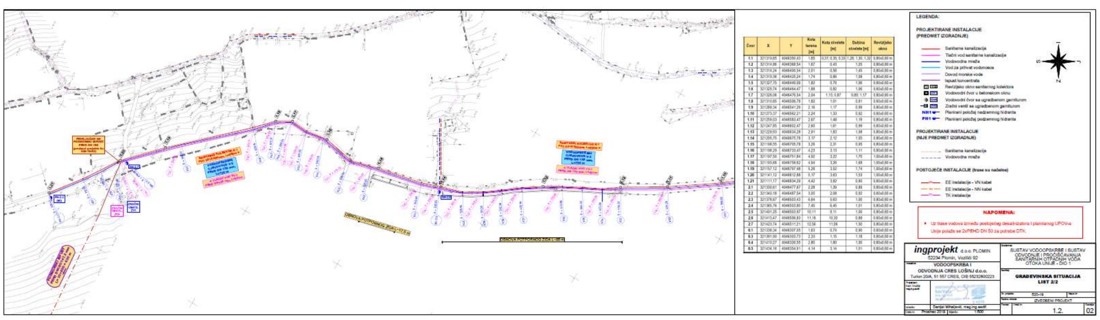


Figure 36. Technical drawings of future water and drainage system on island of Unije

Water meters that will be installed are ultrasonic water meters optimized for residential use by Kamstrup company. For the households, the MULTICAL 21 ultrasonic water meter will be used, while the ultrasonic water meter FLOWIQ 3100 will be used for higher pipe dimension connections.

MULTICAL 21 is an ultrasonic water meter optimized for residential use. Contrary to traditional mechanical meters, MULTICAL 21 is a static meter protected against water ingress with no moving parts. Therefore, it maintains a high and stable accuracy throughout its lifetime of up to 16 years. MULTICAL 21 has a very low error margin, an industry-leading accuracy and an optimized low start flow which ensures that even the smallest consumption is measured accurately.

MULTICAL 21 comes with built-in communication and the remote reading is handled easily through either a drive by solution or a fixed network. This significantly decreases data collection time and avoids time-consuming follow-ups on lacking or imprecise readings. Remote reading is easy and expansion or upgrade of the system is possible.

Intelligent alarms from the ultrasonic water meter detect leaks and bursts or other irregularities such as tampering attempts or reverse flows quickly and effectively. This limits water loss as well as any collateral damage and enables more proactive customer service. MULTICAL 21 provides the foundation for hourly calculations of the water loss.

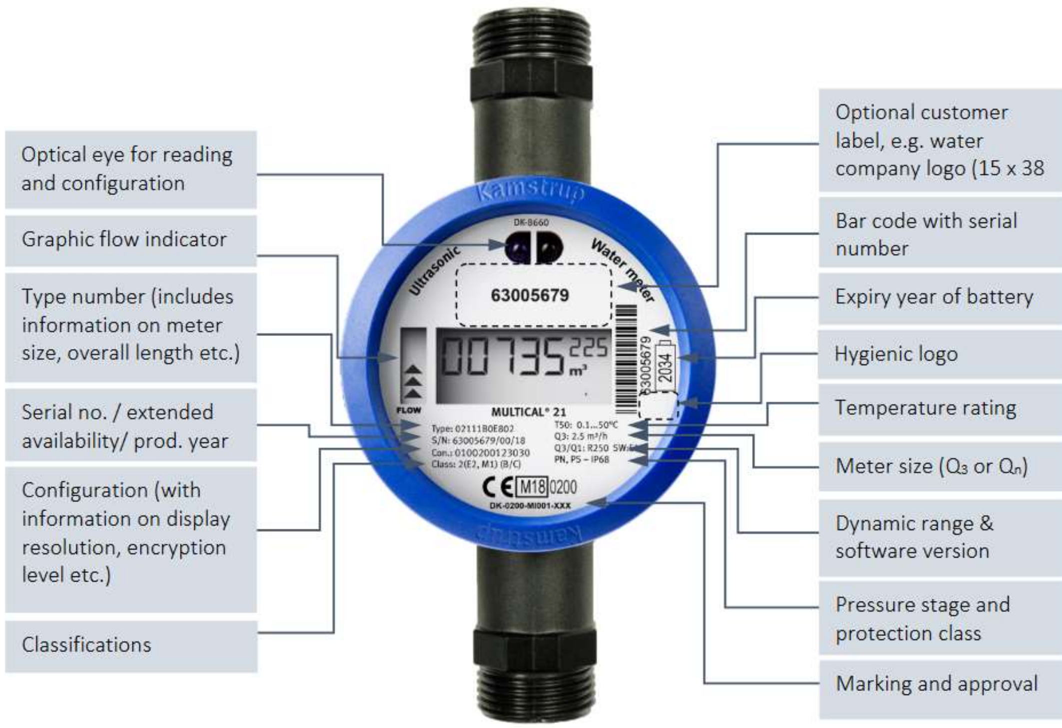


Figure 37. Kamstrup MULTICAL 21 ultrasonic water meter

Besides the abovementioned advantages such as intelligent alarms for the leaks, bursts or other irregularities, smart meters will all be connected to the ENT IoT platform by means of Energy boxes that will be installed in the houses. Hence, the residents will be able to closely monitor their water consumption and be alarmed if something goes wrong. On the other hand, the water distribution company will use the available smart meters to create water system zones that can be monitored, and used to optimally run the desalination unit in cooperation with PV plant and battery storage. As an addition, the ambient as well as the water temperature is being recorded using the abovementioned smart meters, which can be used for the future development of the models that would give forecasts for the future water demand.

More details on the development of the blockchain technologies that will be implemented in the local water/energy systems can be found in publicly available deliverable D4.4 Unije Lighthouse UC-3 report.

4.5 Smart Agriculture

As on every island that does not have the abundancy of water supply, this vital resource (water) is of great importance. Using it in a smart way can improve the life of the local population. As this use case in project (INSULAE) is aimed towards the smart resources' management (energy, water) it is of crucial importance to examine and validate any potential mechanism for resource usage optimization. Equipment deployed in UC 2 should help optimize water use in small scale vegetable gardens and orchards for self-consumption, as well as allow pilots for larger scale agricultural exports from the island, such as vineyards.

Almost every home on the island has its own small garden, providing them fresh fruits and vegetables that are otherwise very difficult and expensive to obtain from the mainland via standard supply mechanisms (e.g. Local grocery store). Due to the water supply shortage (especially during the long dry summer periods) one must be careful how to use water, and usually the gardening gets low priority status. If smart watering mechanism could provide more effective usage of scarce water resources, it would allow local population to grow their own gardens, thus improving the quality of life.

Figure 38. Vineyard sensory installation

Another case is related to greater-scale agriculture, namely vineyards. Unije as an island with excellent climate conditions for wine production has virtually no active vineyards at the moment, at least not the ones that are producing anything important. Using technology to produce, store and efficiently use water supplies and surpluses on a greater scale during the year could make vineyards viable and profitable business, bringing rather important additional source to local economy.

Other than watering, modern sensory and IoT technology can be used to monitor plants, soil and atmosphere to enable remote supervision and modernization of the crop health control system. Analyzing real-time data from the field to predict and prevent possible crop diseases can greatly improve the final product quality and provide the local farmers with additional branding mechanisms.

In general, entire eco-system is based on the following main system elements (Figure 39 Smart Agriculture Infrastructure):

- Central unit

- Sensor unit
- Meteorological station
- Pump and valve / valve control unit
- Measuring unit on water tanks
- Cloud based analytics and control system

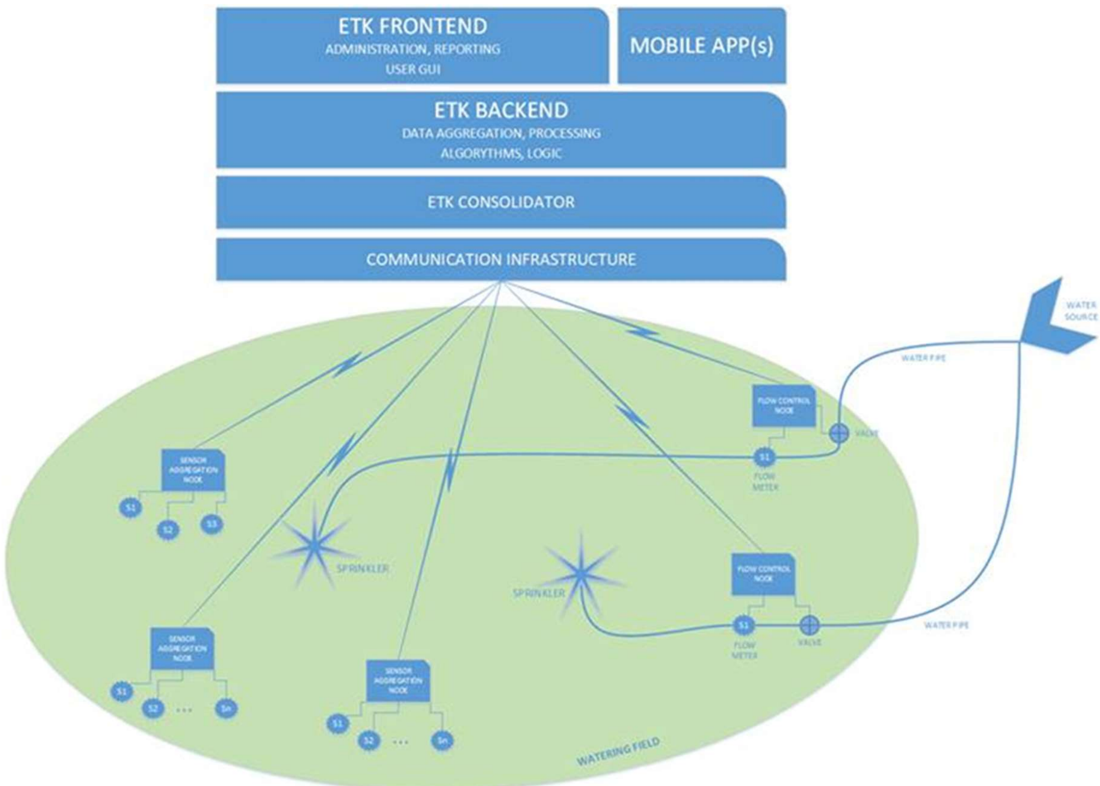


Figure 39 Smart Agriculture Infrastructure

The communication between the sensor cells and the central unit at the location is wireless and will be defined depending on the topology of the location and the required density of the stationary sensors. Different communication protocols will be finalized depending on functionality in the field. The 4G network currently in operation will be used, and later with the correct agreements and 5G NB IoT availability the technology will be updated to run on these networks.

Communication between the central unit and the pump and valve management unit is also wireless. At the later stages, depending on the agreements with the operator and the availability of 5G infrastructure and technical capabilities, this communication will be performed via the 5G / NB IoT network.

Communication between the metering unit on the water tank and the central system is defined through the GPRS / 3G / 4G /5G network.

Communication between the central unit and the central system is also defined through the GPRS / 3G / 4G /5G network.

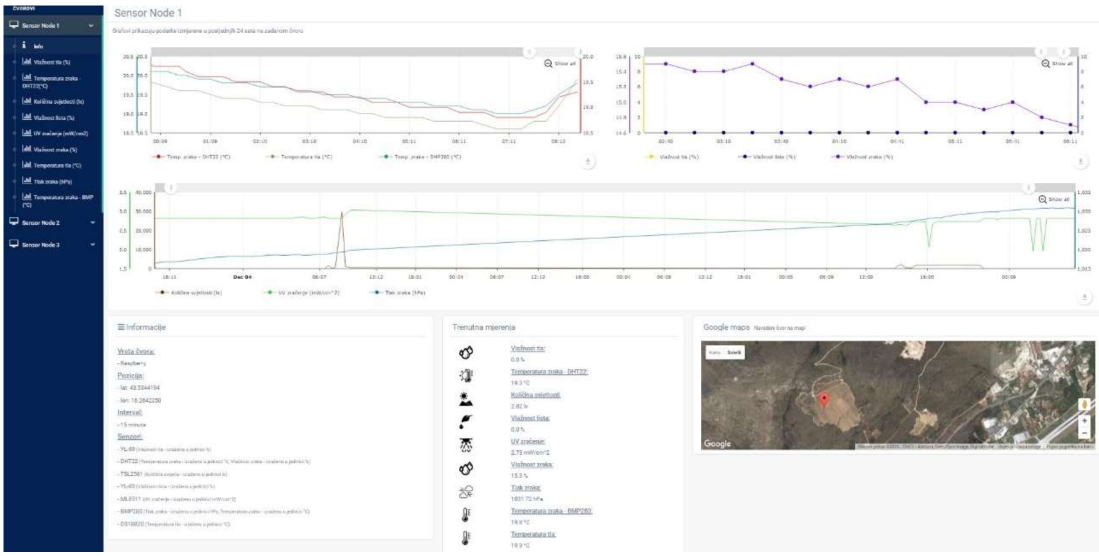


Figure 40 Smart Agriculture Dashboard

Central system (IoT platform) gathers all the data from different sensor nodes and stores them in the database (as defined by data model). Data is constantly processed by the central system using special adaptive algorithms and information on the available water reservoir status, in order to determine when and how long the irrigation of a particular part of vineyards will be performed in the location where the system is located. Irrigation is controlled only through special pump and valve control units at the site.

Besides the input measurement data, the algorithm takes into the consideration also the specific parameters for each sort of grape (or vegetables in the garden), soil types and certain topographic specifics. However, the true value of information provided by the algorithm depends directly on the quality of input data.

Input data is measured in two different sampling frequencies:

- While irrigation is switched off, measurements are longer (15 to 30 minutes)
- During irrigation the measurement intervals are shorter (1 min) to better monitor soil moisture growth during irrigation. For optimal exploitation of the system, the algorithm can be adapted to use variable sampling time (while the parameters followed beyond the default threshold sampling may be less frequent and as more parameters approach the threshold, sampling should be more frequent)

Other data may be collected like overall assessment of leaves/grapes (for vineyards) health based on AI (neural networks) visual analysis and may not have imminent repercussions on day-to-day irrigation systems functionality but will be used in bigdata analysis and improving overall quality of systems.

Data visualization is and reporting is provided via Smart Agriculture Dashboard, where all relevant information is provided to end users (Figure 40   Smart Agriculture Dashboard)

4.6 Implementation of water energy nexus actions

With available measures of water quantity (flow, pressure, water levels in desalination unit water tanks) and quality (conductivity, oxidation, dissolved oxygen, water temperature, oxidation-reduction potential, pH, turbidity) on a desalination unit side, water consumption (flow and pressure) on a consumers side, water quantity (flow, pressure, water levels in water storage(s)) in a water network, and with connection via Energy box, the measurements from the energy sector side will allow for the implementation of water energy nexus, or power to water linkage.

For successful analysis of the connection between the water supply and energy system, two available software packages were used, one of which simulates water flows and phenomena in the water supply system, and the other is used for the optimization analysis of connected water and energy systems. For this purpose, free open source software was chosen, which leaves the possibility to further upgrade or modify the code with more advanced programming. EPANET software for simulation of water supply network, and Calliope for optimization of proposed connection.

EPANET is a software application used throughout the world to model water distribution systems. It was developed as a tool for understanding the movement and fate of drinking water constituents within distribution systems, and can be used for many different types of applications in distribution systems analysis. Today, engineers and consultants use EPANET to design and size new water infrastructure, retrofit existing aging infrastructure, optimize operations of tanks and pumps, reduce energy usage, investigate water quality problems, and prepare for emergencies. It can also be used to model contamination threats and evaluate resilience to security threats or natural disasters.

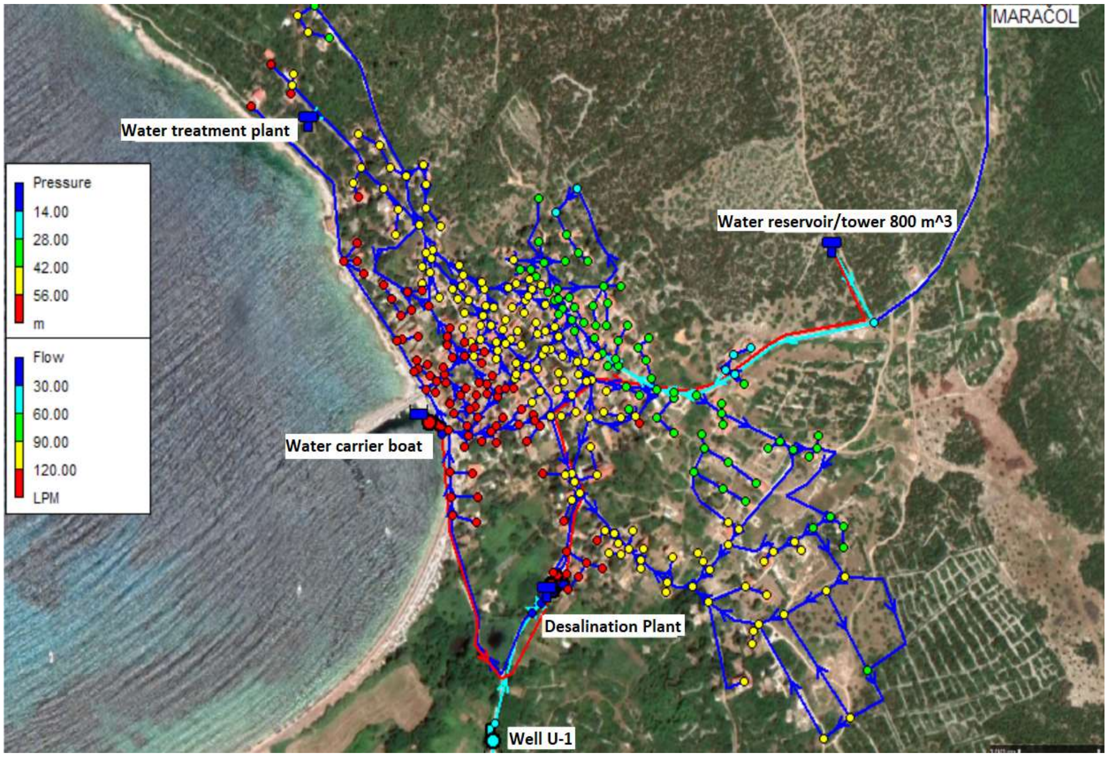


Figure 41. Overview of the future Unije water system modelled in EPANET

Calliope is an open source development tool for modeling energy systems, based on Python programming language [12]. Calliope focuses on flexibility, high spatial and temporal resolution, the ability to execute many runs based on the same base model, and a clear separation of framework (code) and model (data). Its primary focus is on planning energy systems at scales ranging from urban districts to entire continents. In an optional operational mode it can also test a pre-defined system under different operational conditions. A model based on Calliope consists of a collection of text files (in YAML and CSV formats) that define the technologies, locations and resource potentials. Calliope takes these files, constructs an optimization problem, solves it, and reports results in the form of xarray Datasets which in turn can easily be converted into Pandas data structures, for easy analysis with Calliope's built-in tools or the standard Python data analysis stack. Key features of the Calliope model can be divided into:

- Model specification in an easy-to-read and machine-processable YAML format
- Resolved in space: define locations with individual resource potentials
- Resolved in time: read time series with arbitrary resolution
- Generic technology definition allows modelling any mix of production, storage and consumption
- Able to run on high-performance computing (HPC) clusters
- Uses a state-of-the-art Python toolchain based on Pyomo, xarray, and Pandas
- Freely available under the Apache 2.0 license

Energy system models allows modelers to form internally coherent scenarios of how energy is extracted, converted, transported, and used, while covering the problem of how these processes might change in the future. These models have been gaining renewed importance as methods to help navigate the climate policy-driven transformation of the energy system. Design goals of the Calliope energy model can be divided into:

- Designed from the ground up to analyze energy systems with high shares of renewable energy or other variable generation
- Formulated to allow arbitrary spatial and temporal resolution, and equipped with the necessary tools to deal with time series input data
- Allow easy separation of model code and data, and modular extensibility of model code
- Make models easily modifiable by using well-defined and human-readable text formats
- Able to run stand-alone from the command-line, but also provide an API for programmatic access and embedding in larger analyses
- Simplify the definition and deployment of large numbers of model runs to high-performance computing clusters
- Have a free and open-source code base under a permissive license

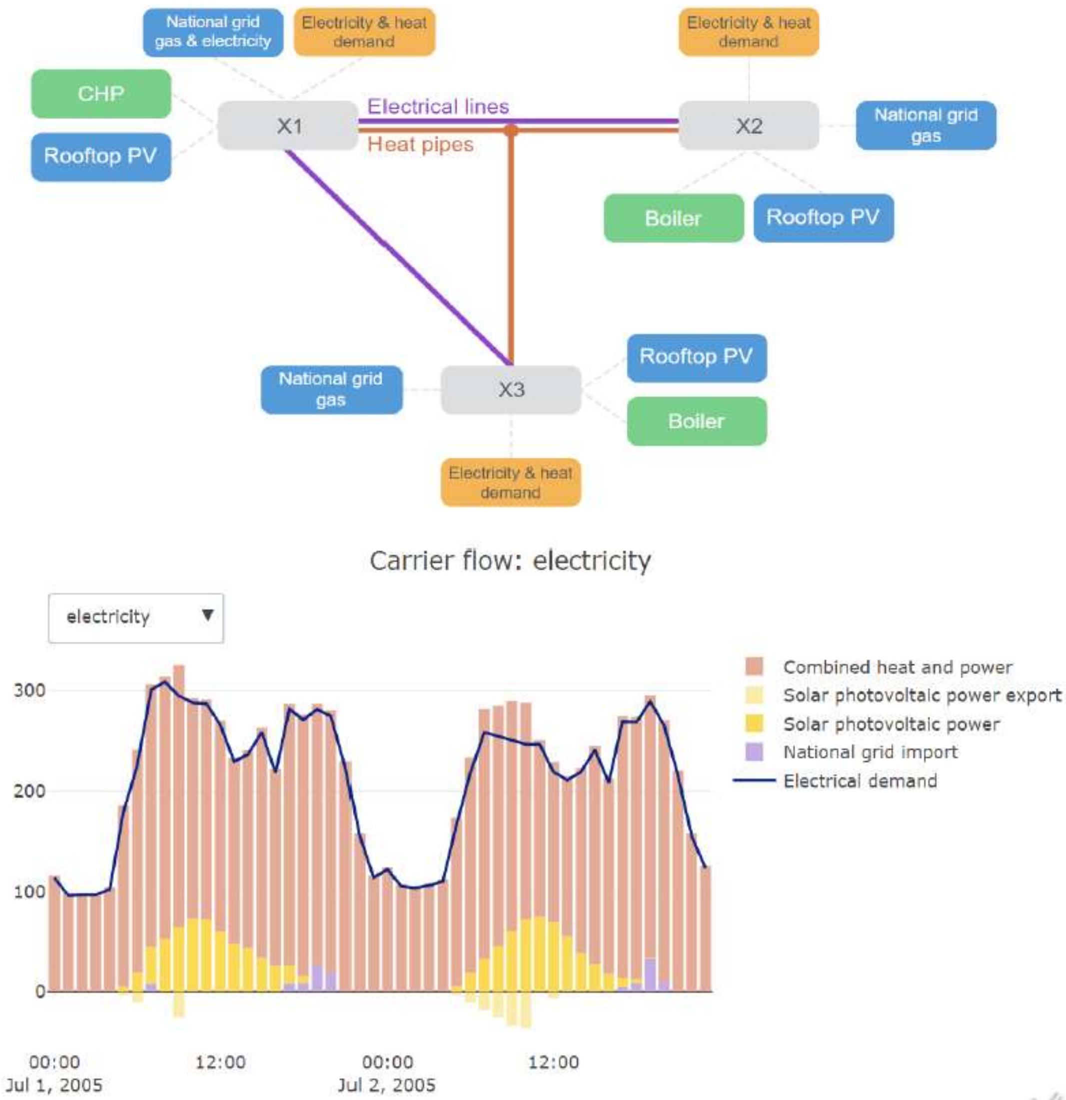


Figure 42. Calliope modelling framework

Calliope builds the model in a way that supply technologies take resources that are outside the domain of the model and convert them into specific energy carriers in the system. It is necessary to enter the locations where these technologies are located. Transmission technology allows energy to move through a carrier from one location to another, while conversion technologies can convert one carrier to another. Demand technology removes the energy carrier from the system, while storage technology can store it in a specific location and return it to the system.

The advantage of Calliope is the ability to add arbitrary variables, such as water in this case, although Calliope is primarily designed to work with energy carriers such as electricity or gas. Water is added as a carrier whose source in the system is conversion by desalination technology from electricity, and the sink is the demand for water, while it can be stored in water tanks. This opens the possibility for connecting the power and water supply system and optimizing work while minimizing costs.

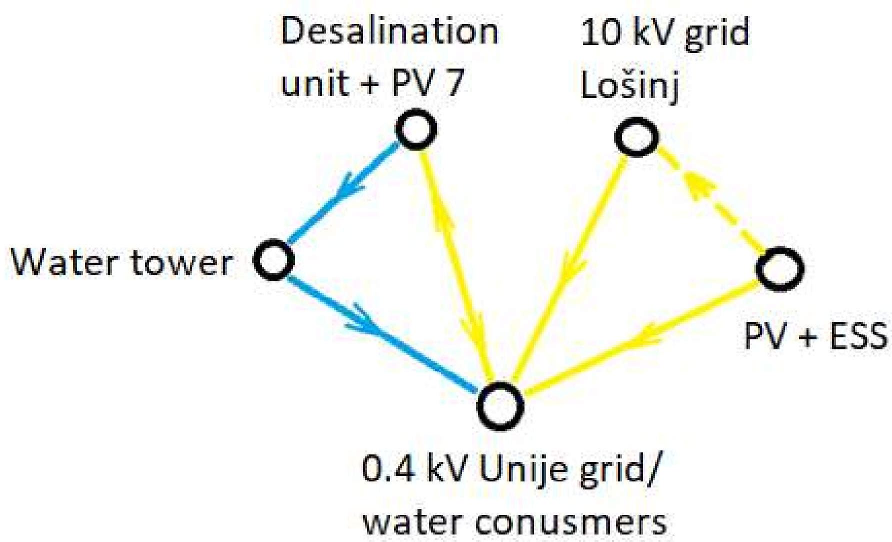


Figure 43. Unije Island connection Calliope scheme

Results were obtained in following order:

- Run the first optimization in Calliope with available input data. The result of the optimization is a diagram of the desalination unit operation
- Run a simulation in EPANET to validate the results in Calliope, display the water network results (flow, pressure) and obtain pump operation values
- Run the second optimization in Calliope with the pump operation values as input and get the final results

As an input data to Calliope, it is necessary to set an hourly electricity production from the photovoltaic power plant P_{PV}. The PVGIS, estimates of solar electricity generation online application, was used to create the electricity generation curve and can be seen in Figure 44.

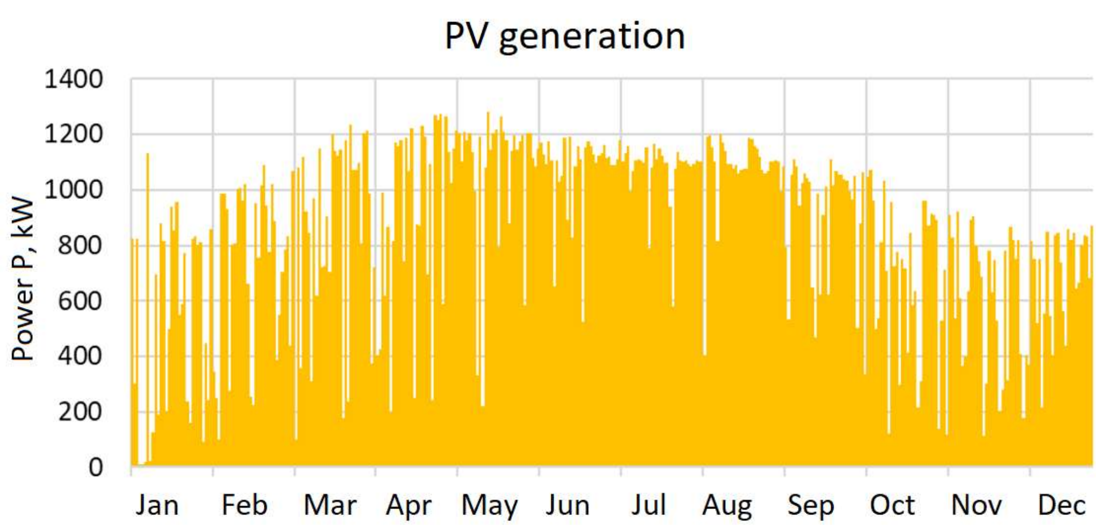


Figure 44. PV power generation throughout a year

Besides power generation from PV plant, the demand for the power and water is crucial input needed for the developed Calliope model. Data is modelled for a year 2019. Total energy demand at the level of the whole year is 589 MWh, the highest hourly demand is 229.7 kW on August 17th at 8 p.m., and the lowest 41.9 kW in April 28th, at 4 p.m. Power demand curve can be seen in Figure 45.

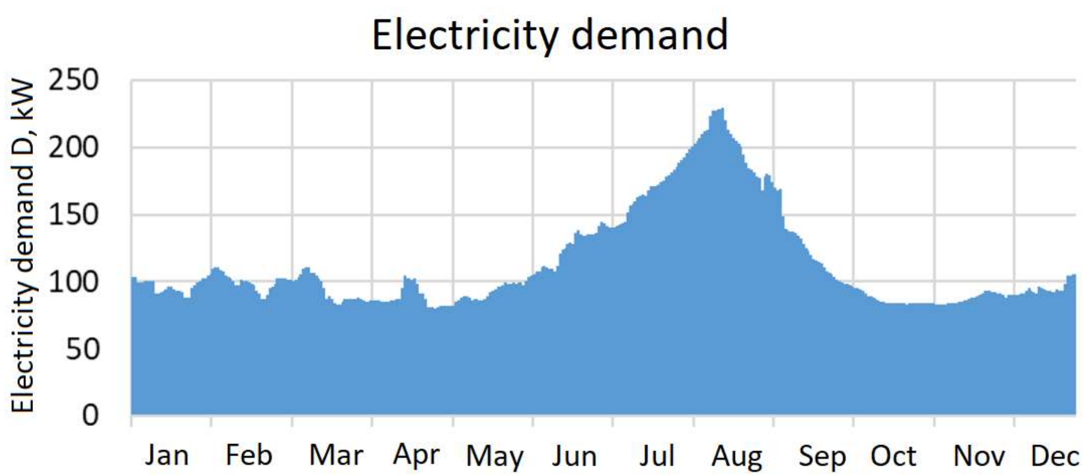


Figure 45. Modelled electricity demand for the Unije island

As there is no operating water system at the Unije island, the nonexistence of metered water consumption makes the water demand modelling crucial. Given that no data were available on water consumption at the island, certain assumptions had to be made. The initial assumption in water modelling was the water supply norm of 130 l/person/day. Based on the known, or modelled, number of people on the island, the need for water can be estimated. With the help of estimating the number of tourists on the island during each month, adding to them a permanent population, it is possible to get an approximate water consumption, which can be seen in Figure 46

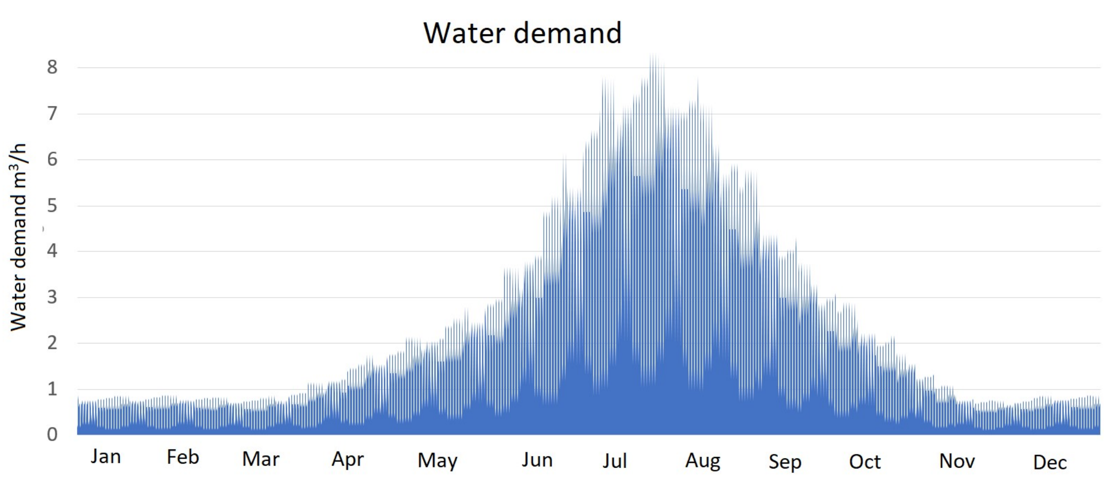


Figure 46. Modelled water demand for the Unije island

Simple mathematical LP model was created that included the joint operation of the water and energy system through means of desalination operation. Desalination unit is being optimally operated based on the provided actions of the energy side problem.

Below are the results of the first optimization step in Calliope model, on electricity consumption of the desalination unit (Figure 47).

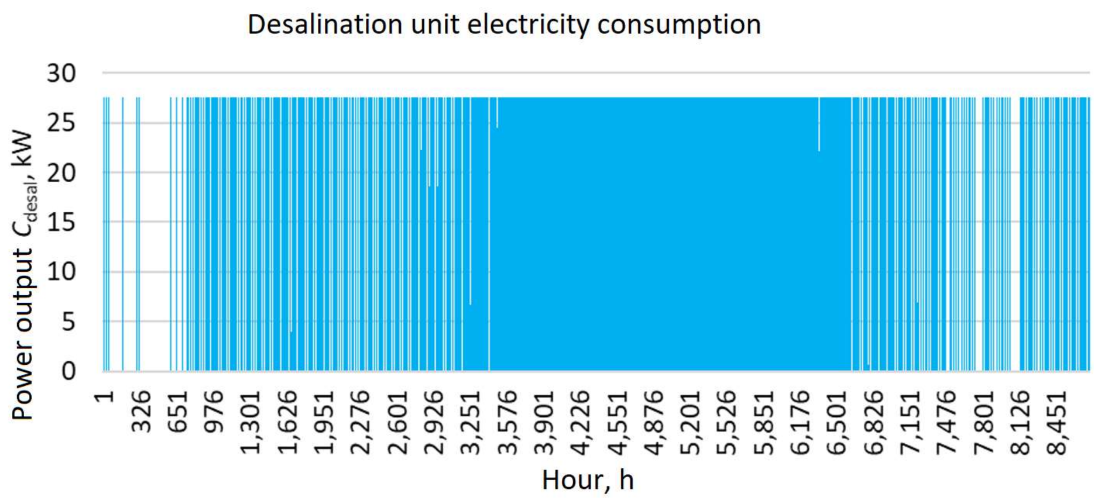


Figure 47. Desalination unit electricity consumption in a first step of the analysis (1 year)

Graph on a Figure 48 shows operation of desalination unit for a week in March based on the electricity prices. It can be seen that the operation of the desalination unit follows the electricity price trend by not producing water during the day in the area of high tariffs, and at maximum capacity working at night in the area of low tariffs.

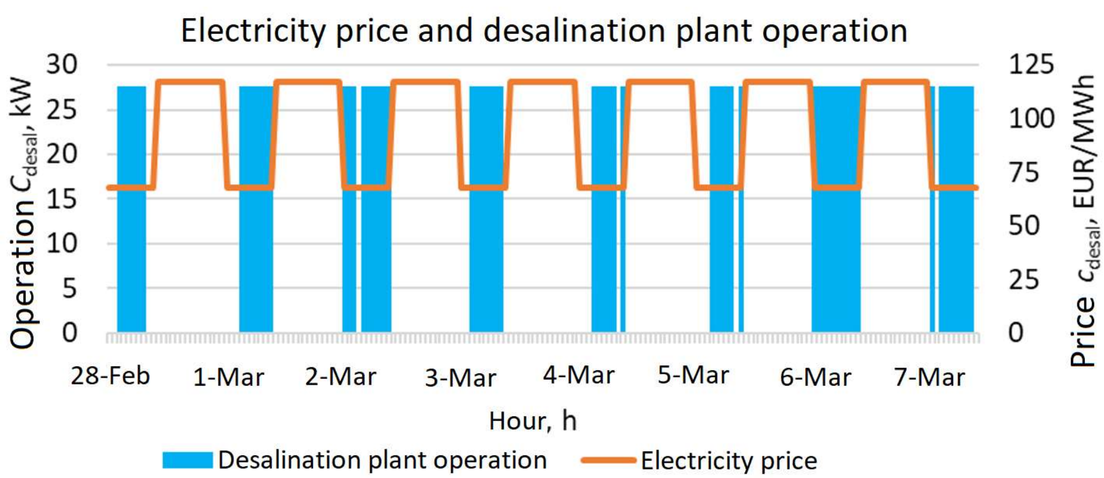


Figure 48. Desalination unit operation based on the electricity price

Figure 49 shows optimized electricity flows for a typical summer week in August.

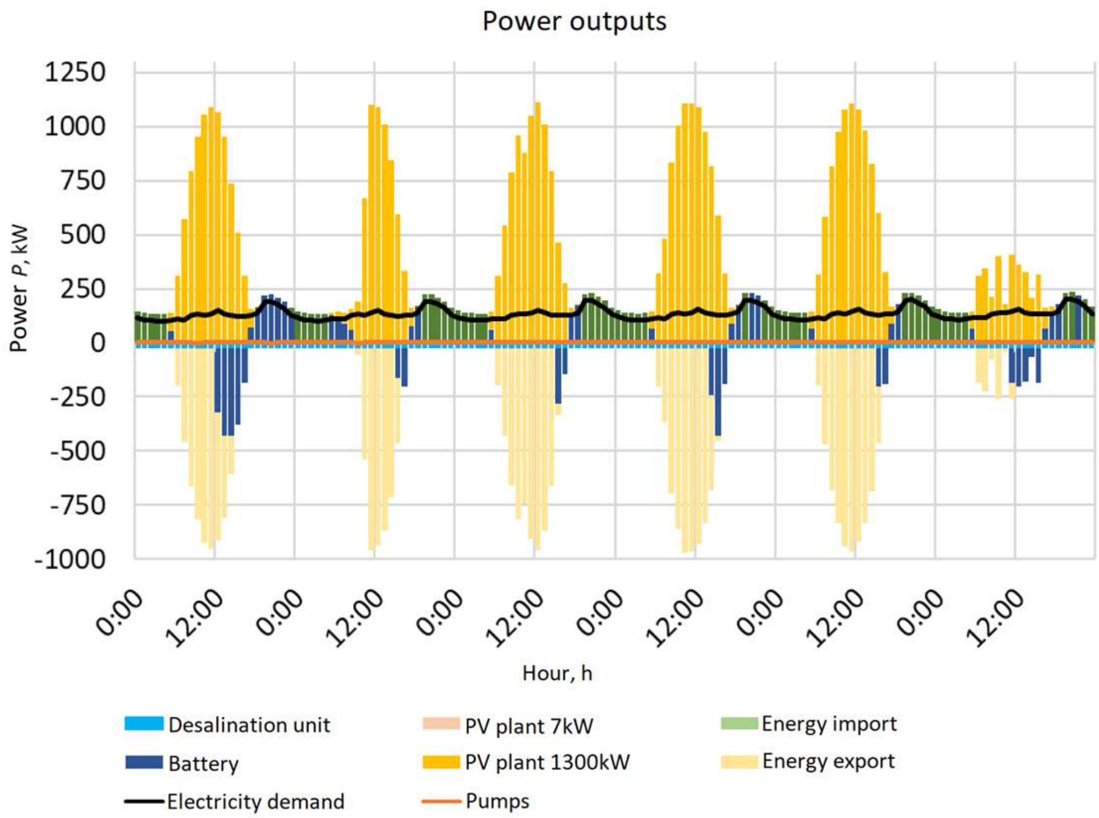


Figure 49. Electricity flows for a typical summer week in August

Graph in a Figure 50 shows hourly reservoir levels for a one year time period.

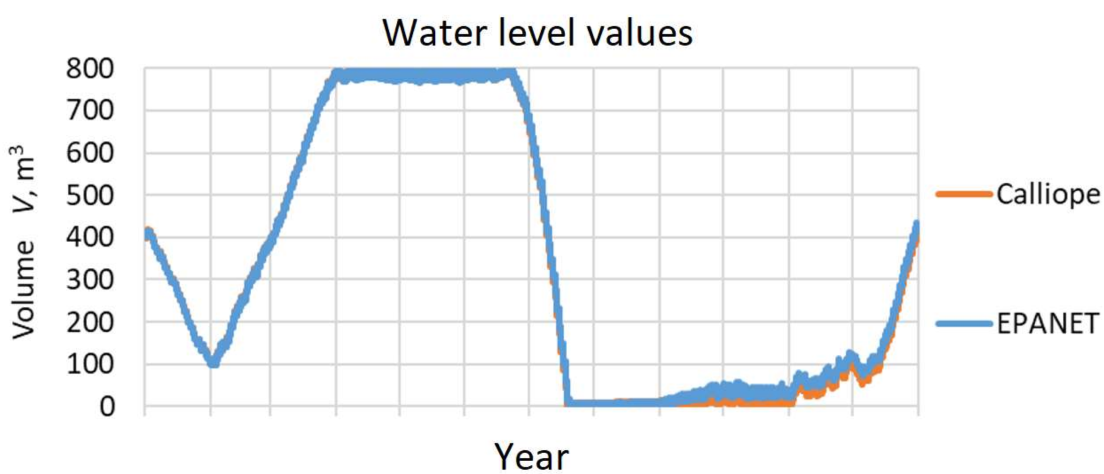


Figure 50. Water level values for propose water tank with capacity of 800 m³

The production of a 1300 kW PV power plant for each hour is summarized on a monthly value for the clarity reasons (Figure 51). The total energy produced from a PV power plant is 1971 MWh, while the energy used to charge the battery is 411.04 MWh.

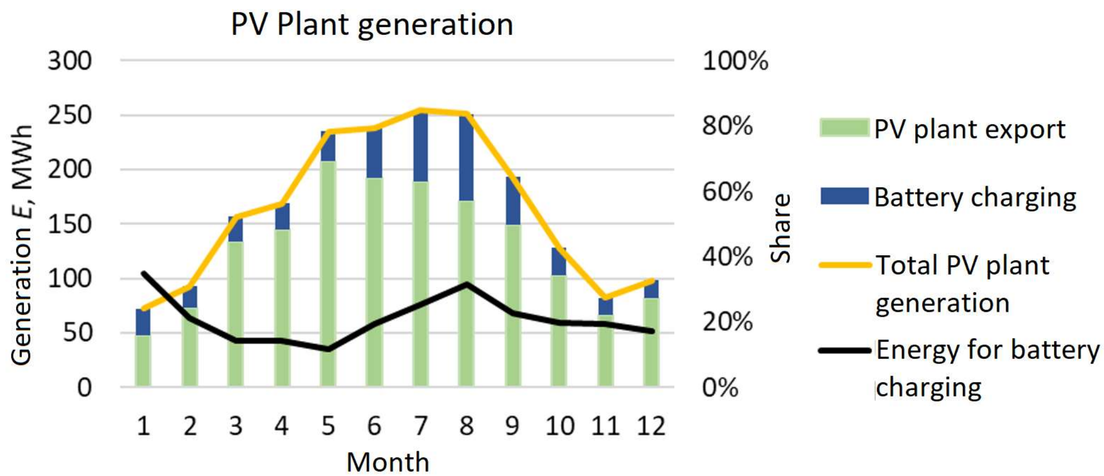


Figure 51. PV plant generation and battery SOC

With implementation of measurement equipment that will be installed at the Unije locations, and with the already available sensors and actuators in a desalination unit, the above results of the implementation of optimization software will be compared to the real time operation.

5 MARKET OPPORTUNITIES

Desalination is increasingly put forward as a sustainable local (decentralized) solution to water scarcity in combination with the exploitation of renewable energy sources, such as wind and solar energy. However, while desalination can certainly be an essential option for resource security purposes in isolated and islands areas, an effective assessment of the performance of desalination in relation to nexus security requires a comprehensive understanding of the nature of the entanglement over water, energy, and food flows. Literature on the water-energy-food-environment (WEFE) nexus shows that there is a need to improve the process of generation and use of scientific information relative to the nexus (Figure 52). The WEFE Nexus is an approach that integrates management and governance across the multiple sectors of food, energy, water, and ecosystems. The Nexus corroborates the need to not view water, energy, food and ecosystems as being separate entities, but rather as being complex and inextricably entwined. Globally as well as locally, there is a growing realization of the interconnectedness between Water, Energy, Food Security, and Ecosystems. In simple terms, direct inputs of water are needed in the production of food and energy while energy is required for the storage and distribution of food as well as in water extraction, conveyance, and treatment. Natural resources and ecosystems services also underlie water, food, and energy security. Any limitation in one of the inputs would disturb the availability of one of the others. Applying the WEFE Nexus approach helps to improve understanding of the interdependencies across sectors and the Ecosystems with a view to improving integrated solutions in the field that improve achievement of sustainable development goals.

In particular, it is essential to integrate the information about two different types of trade-offs. One is between the ecological and socio-economic side; and the second within the socio-economic process among different social actors, both within—e.g., producers and consumers—and across hierarchical levels—e.g., administrators and tax-payers.

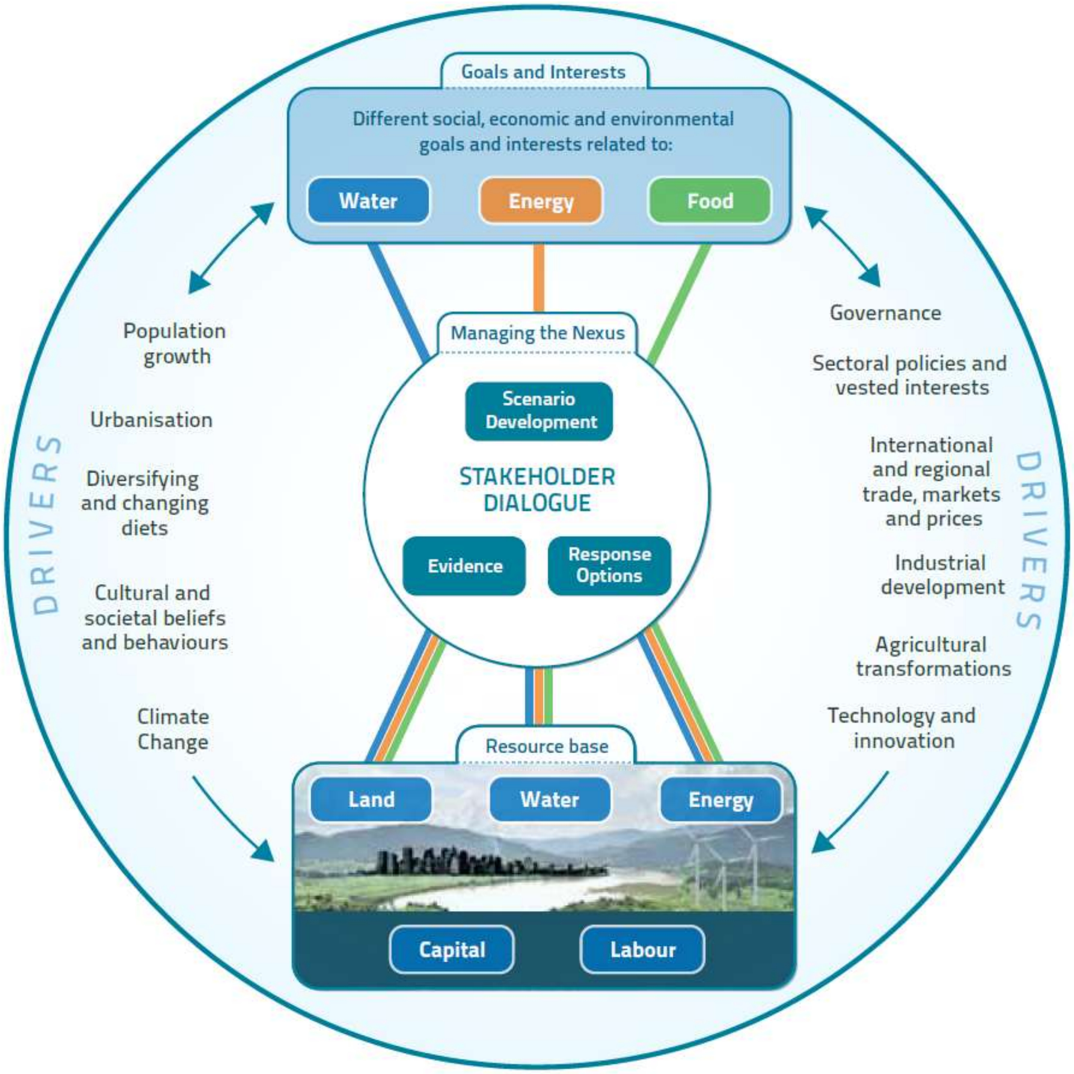


Figure 52. WEFE nexus [13]

As population continues to grow, freshwater resources are projected to decline. As a result, the dependence on desalinated water to meet the growing water demand will increase. Although the need for utilizing desalinated water to prevent future water vulnerabilities is well recognized, broader adoption of desalination is still impeded by its high electricity costs. To address the problem of high electricity cost, key opportunities have been recognized. Improvements can be divided into technological based improvements and operational based improvements.

While technological advancements can indeed lower the energy intensity of the desalination process, their implementation costs are still considerable. On the other hand, operational optimization frameworks have recently gained a great deal of attention, as they present a cost-effective option tapping on the flexible operation of desalination components and provide a range of flexibility services in power systems operation. Such frameworks could pave the way for water system operators to explore synergistic benefits with grid operators to offer their flexibility to both demand response programs aiming at shifting or reducing electricity use and frequency regulation markets to support the integration of intermittent energy resources.

As an energy-intensive infrastructure, desalination plants represent good candidates to participate in demand response programs and frequency regulation markets. These plants are equipped with filtration systems as well as high-pressure variable speed pumps and are part of a broader water distribution system, which also include water storage tanks. These components can operate flexibly to balance water load fluctuations or provide backup water supply. If properly controlled, this operational flexibility could be utilized by water system operators to either shift pumping loads and provide energy flexibility capacity, or make frequent small load adjustments to provide fast grid services, such as frequency regulation up and down reserve capacities

Energy flexibility is procured in energy markets via demand response programs. In these programs, the water system operator is remunerated to shift its pumping load by a specific quantity and for a specific duration. This is accomplished via operating the pumps to increase freshwater production and stored water capacity in the tanks during low electricity prices or reduce freshwater production and release water from tanks when electricity prices are high (Figure 53). In essence, the combination of desalination plants and tanks operates as pumped-storage hydropower that provide the demand response service in the market. Under sufficient freshwater storage capacity and freshwater production capability, demand response services can lead to considerable profits that can help water system operators to offset a portion of their energy costs.

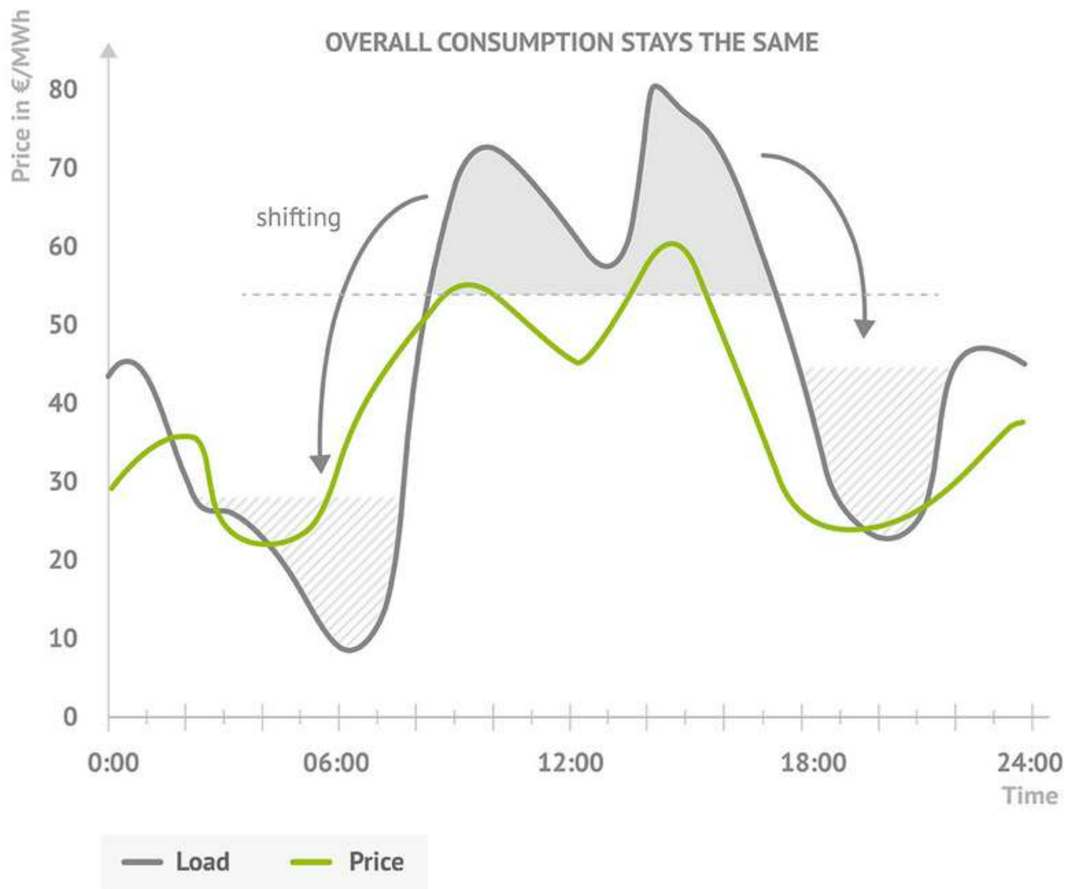


Figure 53. Example for load shifting scenario

Besides the demand response activation, desalination units can provide frequency regulation capacity through their fast-response variable speed pumps and receive day-ahead capacity awards or real-time deployment remunerations for balancing active power supply and demand over short time frames. Hence, the desalination units could participate in ancillary service market providing valuable primary or secondary reserves (Figure 54). This is done by responding to regulation control signals and rapidly adjusting the power consumption of pumping stations. In most regulation markets, the service provider must be able to make their committed capacity available within 5 min of receiving the signal. For a larger time frames the high amount tertiary reserve is activated. Based on the specific market, the reserve can be divided into reserve up (capacity available to reduce pumping consumption) and reserve down (available capacity to increase pumping consumption).

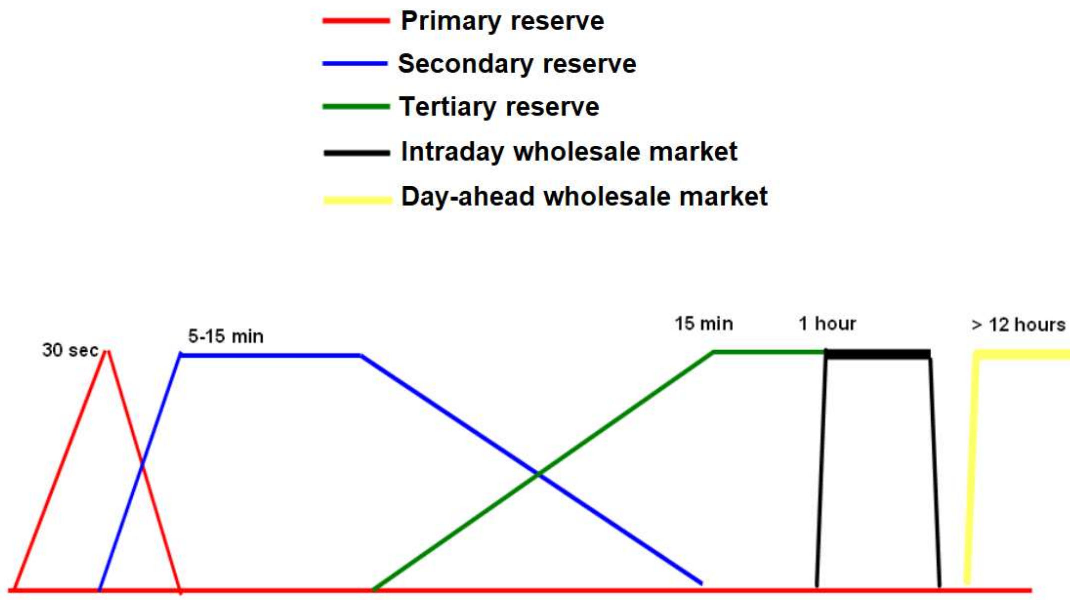


Figure 54. Representation of the electricity market organization

Photovoltaic powered reverse osmosis desalination units are considered very promising for providing fresh water in isolated, arid and remote regions. The success of solar-PV as a driver for desalination units can be attributed to four factors. Firstly, the modularity of PV systems offers implementation with desalination process on different scales and their capacity can be increased after initial installation. Secondly, PVs require low maintenance and offer a long lifetime of 20-25 years. Thirdly, areas that demand high water consumption usually have high solar radiation intensity which makes PVs well matched to the application. Lastly, the somewhat predictable bell-shaped solar irradiance curve, compared to the random variation for, e.g. wind power, makes it easier to schedule the plant operation during daytime and use water storage instead of energy storage to meet night-time demand.

In particular, wind and solar energy are volatile energy sources. The energy system must react not only to variations in demand, but must also compensate for the difference between the fluctuating energy input and the prevailing demand as a result of the increasing integrations of renewable energy sources. An imbalance between electricity generation and consumption can lead to frequency instability or fluctuations in voltage. These effects endanger the operational safety of the power system. While large interconnected systems can compensate for high shares of fluctuating renewable energy sources better, isolated island systems may face major challenges. To meet the fluctuating nature of renewable energy sources, demand side management, as well as energy storage systems are promising solutions. Demand side management covers almost all measures that have an impact on electricity demand of customers. Although demand side management has been pushed by utilities in the past, in the future it will be driven more by individual customers.

Beside others demand side management includes demand shifting measures in general and demand response in particular. The objective of demand shifting is to adapt the electricity demand to the electricity generation. Besides price signals, different incentives or regulatory might cause the control of the demand. In addition to sea/brackish water desalination, the water distribution system is linked to the energy system, too. Particularly on mountainous islands, electric driven pumps are used to distribute water. Both the water extraction and distribution influence the electricity demand. Since water is easily storable, water systems are utilizable and well-suited for demand shifting.

Several analyses showed that the assessment of demand shifting within the analyzed sector leads to increased degrees of self-sufficiency and renewable energy utilization. Additional future uncertainties like climate change, population movements and economic development, might affect planning for optimal water distribution systems, and make flexible design one of the promising research areas over the next few decades. In conjunction with the fact that desalination unit and storage capacities already exist, a fast and economically feasible realization of the analyzed potentials is possible and would help the island society on their way to a sustainable island.

The demand response can be generally categorized into two groups. Explicit demand response is in line with the supply in the wholesale, balancing and ancillary services markets through the service of aggregators or single large consumers. On the other hand, implicit demand response refers to consumers choosing to be exposed to time-varying electricity prices or time-varying network tariffs that partly reflect the value or cost of electricity and/or transportation in different time periods and react to those price differences depending on their own possibilities.

In Croatia, there are few available tariffs that distinguish higher and lower electricity tariffs. Higher tariff is usually imposed between 7 am and 9 pm, while the lower tariff is between 9 pm and 7am. Hence, once can say that Croatia has a low-level type of demand response for a wide household level use. One can observe the desalination unit generation based on the two-tariff electricity price in the Figure 48. The same principle is used for the electricity consumption of the main pumps at the Vrana lake location. VIOCL company uses the lower tariff as much as it is possible, but in the summer times, there is no enough capacity to store the water needed, so pumps must operate with the higher tariff. Here the possible solution could be in the future implementation of explicit demand response which is still in developing faze.

The Croatian Transmission System Operator (HOPS) started the pilot project in 2018 called "*Ensuring the tertiary reserve regulation with demand response technology*". With the 14th of December 2020, HOPS is implementing the procedure of procurement of tertiary power reserve and/or balancing energy for system security through public bidding as an improvement of the previous pilot project. Here the balancing service contracts may be concluded with the Transmission System Operator by all individual network users and/or aggregators who have proved that they are technically qualified for this (who have met the conditions defined by the pre-qualification procedure). Unfortunately, the smaller individual users have a harder time meeting the conditions to be able to provide the balancing service. Also, the minimum bid offer is 3 MW, so the individual consumer on a household level could only participate through aggregator, which is still the unknown in the Croatian energy market. However, the newly proposed Electricity Market Act, which is now in public consultation faze, brings the creation of new legal forms that participate in the energy services market and aim to enable all end customers to participate in the energy transition by managing their own electricity consumption and implementing measures to improve energy efficiency, with the aim of achieving energy savings.

6 CONCLUSION AND OUTLOOK

This deliverable collects the main conclusions reached after finalizing the modelling, basic and detail engineering and equipment development activities previous to the deployment of the UC-2: Smart integration and control of water and energy systems, at Unije Island.

Water scarcity represents one of the main challenges for islands specially during vacation periods when tourism increase the water consumption on the island. The integration of different solutions to manage the water use was studied as part of the subtask “Smart integration and control of water and energy systems”.

Developed models as part of the beforementioned subtask showed the possible future operation of the water and energy system. Developed water system models will allow allocation of possible water and energy savings for future water system development. Moreover, water system and its integration with electricity grid will allow for optimal design of future water system that will act as energy buffer using water reservoirs, as well as usage of demand response operation of water pumps for energy and water savings.

Models showed that when operating with two electricity tariffs, desalination unit due to the available storage option can operate in lower tariff which showed approximated savings of 16% in total electricity consumption. Moreover, demand response model showed that implementation of the demand response and energy storage system resulted with savings in the overall operation of the system. The savings are more expressed for the more optimistic k values which allow higher implementation of the demand response.

Next step in the INSULAE project is to continue deployment, installation and commissioning as part of the work package 5, that is built on the conclusions of the previous tasks under the finished work packages. The equipment to be installed will be used to measure real test performance, which will allow the comparison between the modelled and measured data.

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