DES²iRES

Design of desalination systems based on optimal usage of multiple Renewable Energy Sources

ERANETMED NEXUS-14-049

USER'S GUIDE

December 2018

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1. Introduction

DES²iRES is an Internet-based, multi-parametric electronic platform for the optimal design of desalination plants, power-supplied by Renewable Energy Sources (RES). The platform relies upon: 1) a solar, wind and wave energy potential database, 2) statistical algorithms for processing energy-related data, 3) information regarding the inter-annual potable water needs, 3) a database with the technical characteristics of desalination plant units and the RES components, and 4) algorithms for cost effective design, optimal sizing and location selection of desalination plants.

The target of the DES²iRES platform is to derive, among a list of commercially available system devices, the optimal types of RES [i.e. PhotoVoltaic (PV) generators, Wind-Generators (W/Gs) and/or Wave-Energy Conversion (WEC) units, respectively], which should be combined for power-supplying the desalination plant, the optimal number, type and structure of both the RES and the desalination units comprising the target RES-based desalination plant, as well as the optimal location of the RES-based desalination plant, such that the total system cost is minimized and simultaneously the desired water demand is completely covered. **The current version of DES²iRES supports the design of RES-based desalination systems in two regions: Crete (Greece) and Tunisia.**

A diagram of the overall RES-based desalination system is illustrated in Fig. 1. The desalination system under design is power-supplied by RES and its target is to produce enough potable water in order to satisfy the needs of a community or an individual consumer. The RES-based power-supply system comprises multiple PV arrays, multiple W/Gs and multiple WECs in order to produce the electric energy needed for the desalination units to operate. A battery bank is also used in order to store any energy surplus. The PV modules are distributed in multiple PV arrays, each containing PV modules connected in series and parallel. One PV battery charger is connected to the output of each PV array. Also, battery chargers are incorporated in each W/G and each WEC, respectively. Multiple DC/AC inverters are used to provide the AC power required to the desalination units. The desalination system also comprises a Water Tank in order to store the excess water produced when it is not needed by the consumer. Moreover, the AC bus of the RES-based power supply system is interconnected with the electric grid which can provide the system with electric energy if all the other RES generators cannot provide it, or else it can absorb any excess energy produced by the RES and provide it to the general electricity supply. The WECs are connected through AC/DC converters to the DC-Bus in order to be able to provide energy to the battery bank too.

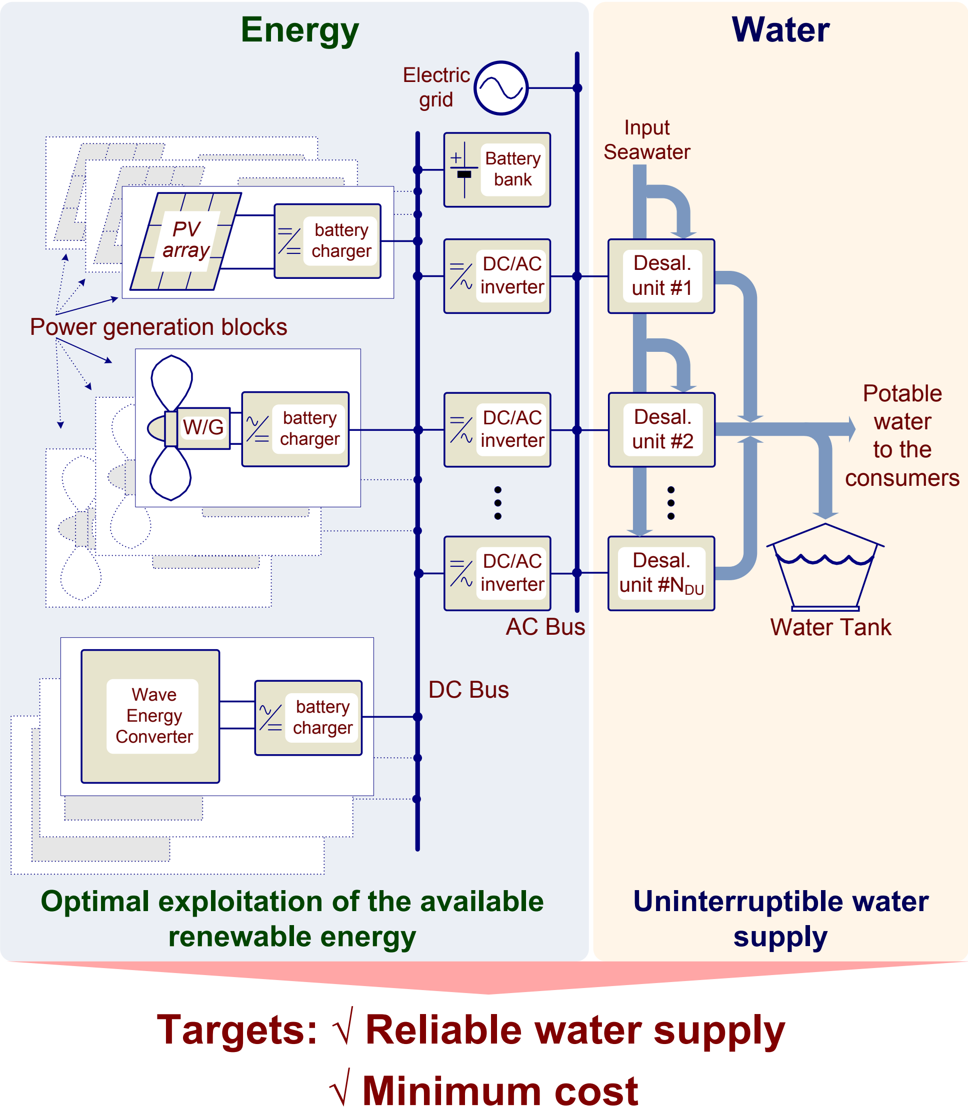


Fig. 1. A general diagram of the RES-based desalination system designed by the DES²iRES platform.

The target of the optimization process for a given location is to minimize the total lifetime cost of the RES-based desalination system, which is calculated as the sum of the following components:

- The total installation and lifetime maintenance cost of PVs, W/Gs, WECs, Batteries, PV battery chargers, DC/AC Inverters, Desalination Units and Water Tank, respectively,
- The replacement costs of Batteries, PV battery chargers and DC/AC inverters due to malfunctions during the lifetime period of the desalination plant,

- The present value of the lifetime cost of purchasing electric energy from the electric grid (if the RES-based power supply system of the desalination plant has been selected to be interconnected with the electric grid, else this value is equal to zero),
- The cost of connecting the desalination plant water production to the general water distribution network,
- The cost of the electric network which transfers the RES-generated energy to the desalination units,
- The total cost of the pipelines transporting seawater to the desalination system installation point and brine disposal back to the sea and
- The cost of the electric line used to transfer the power produced by the WECs to the RES-based power supply system.

The target of the design optimization process performed by the DES²iRES platform is to calculate the **optimal** values of the following design parameters:

- location of the RES-based desalination plant,
- types/models of devices (PV modules, PV battery chargers, batteries, W/Gs etc.) comprising the desalination plant power-supplied by RES,
- number of PV modules connected in series and parallel,
- number of PV arrays and PV battery chargers
- tilt angle of the PV modules,
- number of batteries connected in series and parallel,
- number of W/Gs,
- installation height of the W/Gs,
- number of WECs,
- number of DC/AC inverters,
- number of desalination units and
- volume (in liters) of the water storage tank.

The optimal values of the aforementioned parameters are calculated such that:

(i) the total lifetime cost of the RES-based desalination system is minimized and, simultaneously,

(ii) the desired water demand is completely covered.

The present value of the lifetime revenues obtained by selling excess energy to the electric grid (if the RES-based power supply system of the desalination plant has been selected to be interconnected with the electric grid, else this value is equal to zero), is also calculated and displayed to the user of the DES^{2}iRES platform together with the resulting optimal value of the total lifetime cost of the RES-based desalination system, but it is not included in the lifetime system cost subject to minimization.

The user specifies, through the webpage of the DES^{2}iRES platform (Fig. 2), the values of the required input parameters, as described in the following paragraphs, which are then transmitted to the design optimization algorithm of the RES-based desalination system in order to calculate the optimal design solution. After the optimization process has been finished, a report is sent to the user by the DES^{2}iRES platform via an email containing the optimal design results.

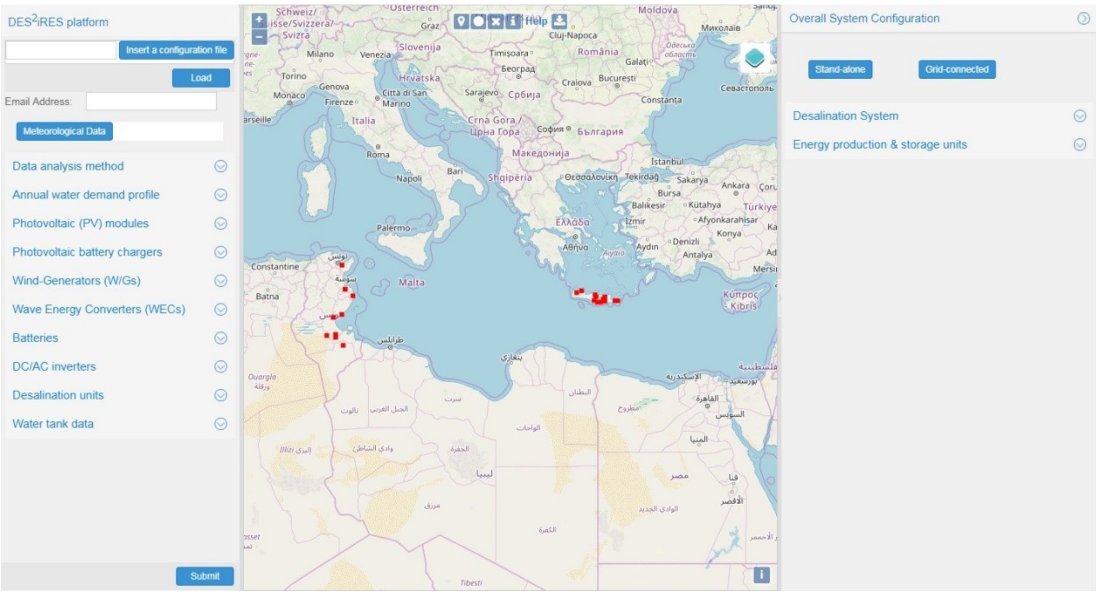


Fig. 2. The web-GIS interface of the DES^{2}iRES platform that is used by the user for specifying the required operational parameters of the RES-based desalination system.

2. How to use the DES^{2}iRES platform

Initially, the email address of the user where the design results of the DES^{2}iRES platform will be sent to, is provided in the field shown within the red box in Fig. 3. If an email address is not provided, then the design optimization process is not executed by the DES^{2}iRES platform.

The water consumption to be satisfied by the RES-based desalination system under design is selected in the field shown in Fig. 4. The user may select the predefined water consumption of a single household or the predefined water consumption of a community of houses. The corresponding values are depicted in the diagrams of Fig. 5. Alternatively, the user is able to import a .txt file containing the hourly values of the desired water consumption (in liters per hour) during each hour of the entire year (i.e. 8760 values) to be considered in the design optimization process. An example of such a file is presented in Fig. 6. Each value should be placed in a separate line of the .txt. file. If a water consumption profile is not specified by the user, then the default setting "Typical residential" is used by the DES²iRES platform during the design optimization process.

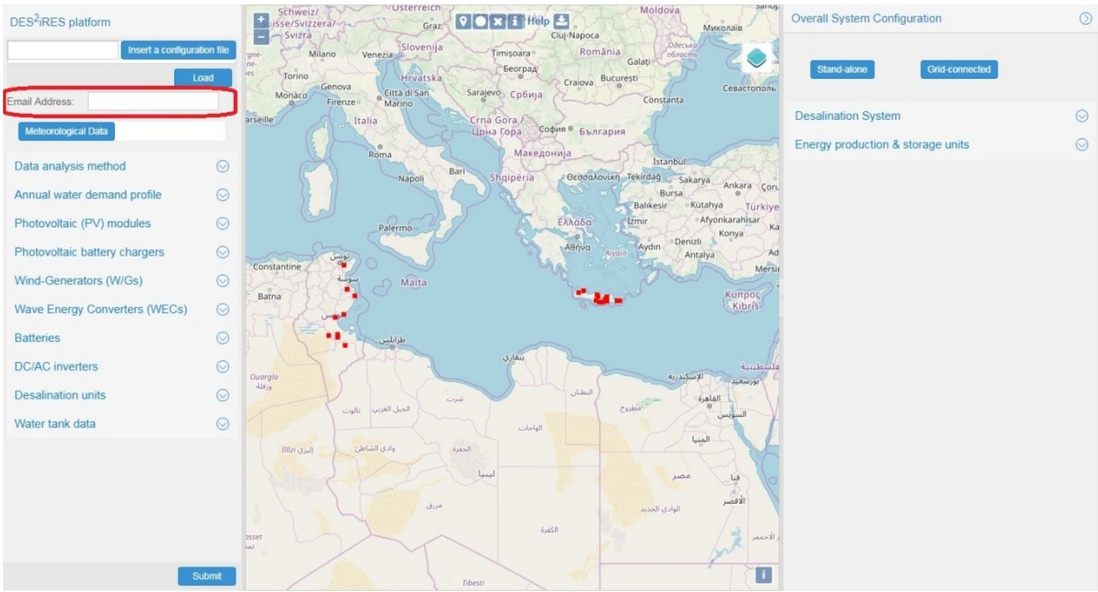


Fig. 3.The form where the email address for sending the design optimization results, is provided by the user.

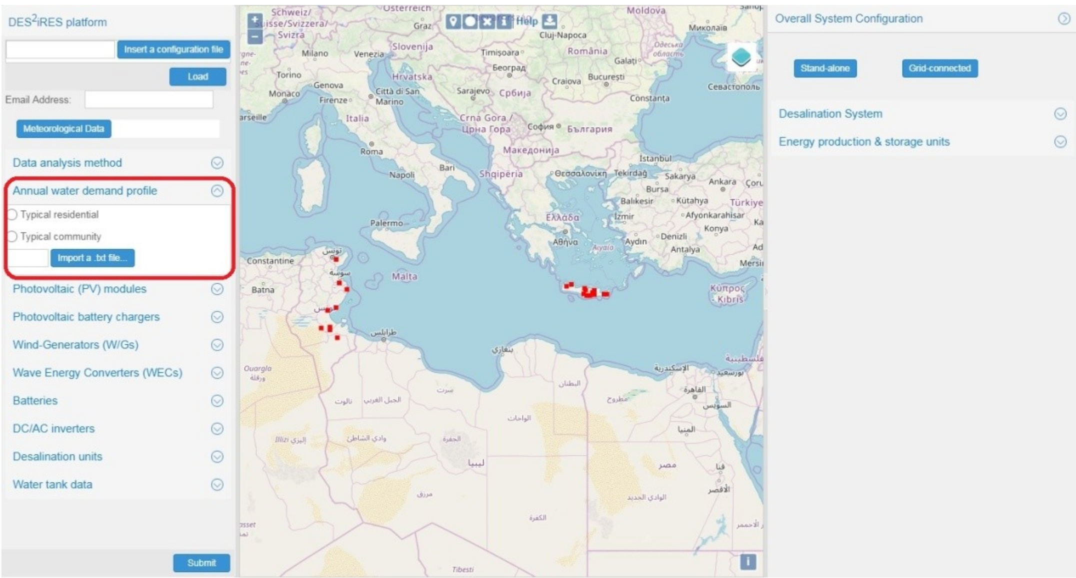
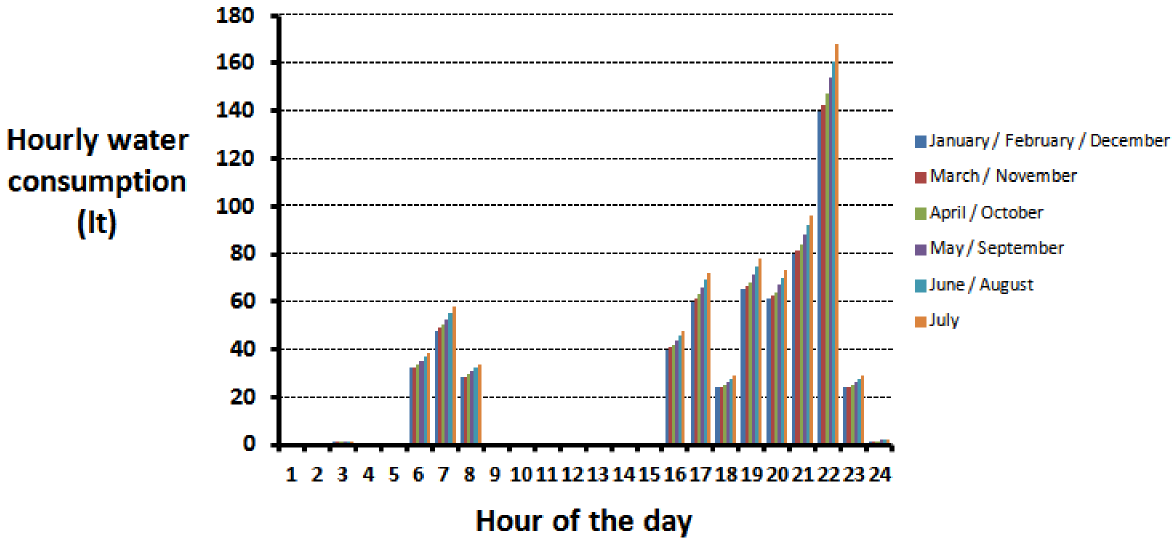
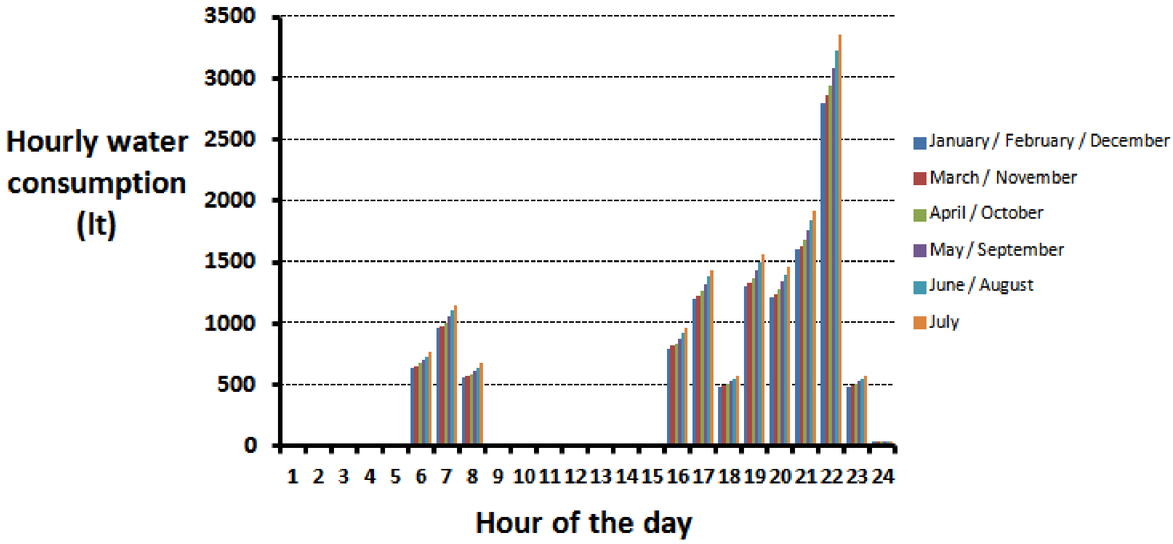


Fig. 4.The form for defining the water demand to be covered by the RES-based desalination system under design.



(a)



(b)

Fig. 5. Diagrams of the predefined water consumption profiles: (a) single household and (b) community of houses.

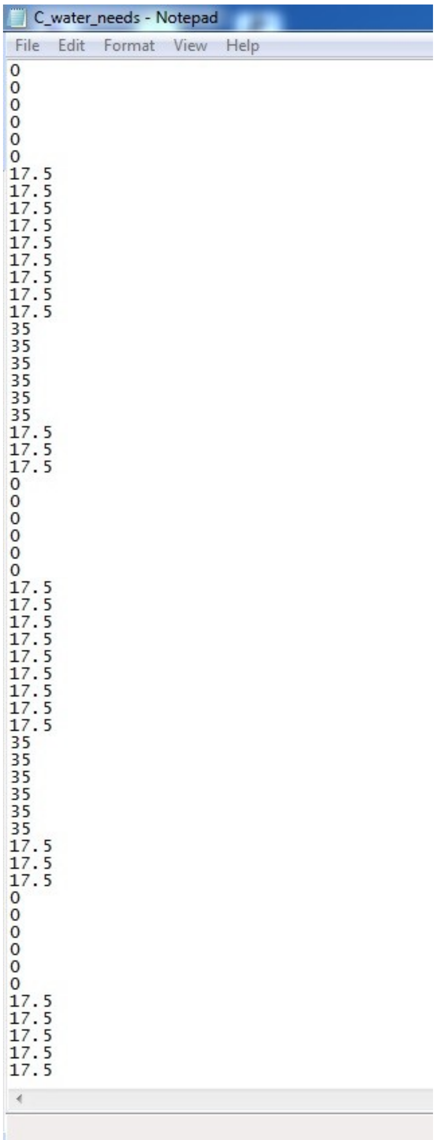


Fig. 6. An example of the water consumption input file provided by the user.

3. Specifying the configuration of the RES-based desalination system

The desalination units and the RES/battery units can be considered to be installed either at the same location or at different locations, as described next. The WECs are installed at the 5th (offshore) point defined by the user through the web-GIS interface of the DES^{2}iRES platform, as also described in the following.

The structure of the RES-based desalination system may take one of the following forms, which can be defined by the user through the web-GIS interface:

1. In terms of the desalination system:
    a. Desalination of brackish water by selecting a desalination unit type which is suitable for brackish water or

b. Desalination of seawater by selecting a desalination unit type which is suitable for seawater.

2. In terms of the energy production/storage units:
   a. Only with PVs
   b. Only with W/Gs
   c. Only with Wave Energy Converters
   d. Hybrid system comprising more than one of the above RES types
   e. Configurations (a)-(d) with or without a battery bank
   f. Configurations (a)-(e) with or without connection to the electric grid for buying additional energy or selling the excess energy
   g. Without any RES source and battery bank, but only a connection to the electric grid for buying additional energy or selling the excess energy.

The categories of the devices comprising the RES-based desalination system are the following:

(i) Renewable Energy Sources:
- PV modules
- PV battery chargers
- Wind-Generators with integrated battery chargers
- Wave Energy Converters with integrated battery chargers

(ii) Balance of System devices:
- Batteries
- DC/AC inverters

(iii) Water production devices
- Desalination units
- Water Tank

As shown in Figs. 7 and 8, the user may select to design a desalination plant which is power-supplied by either a stand-alone RES system (i.e. without any interconnection with the electric grid), or by a grid-connected RES system which is interconnected with the electric grid for selling any excess energy produced by the RES sources, or buying additional electric energy. In both of these cases, the values of the following parameters should be provided:

(i) desalination plant lifetime (in number of years),

(ii) inflation rate (in %),

(iii) interest rate (in %),

(iv) the cost of connecting the desalination plant water production to the general water distribution network per liter of water transferred hourly (c_{wnet}, in €/l),

(v) the cost per Watt of the electric network which transfers the RES-generated energy to the desalination units (c_{enet}, in €/W),

(vi) the installation cost of the water transportation system per meter of horizontal distance and per m^3 of daily nominal water production of the desalination unit selected (c_H, in $\frac{€}{m \cdot m^3}$),

(vii) the installation cost of the water transportation system per meter of elevation and per m^3 of daily nominal water production of the desalination unit selected (c_E, in $\frac{€}{m \cdot m^3}$),

(viii) the power of the water pumping system per meter of horizontal distance and per m^3 of daily nominal water production of the desalination unit selected (P_H, in $\frac{Watt}{m \cdot m^3}$),

(ix) the power of the water pumping system per meter of elevation and per m^3 of daily nominal water production of the desalination unit selected (P_E, in $\frac{Watt}{m \cdot m^3}$) and

(x) the cost per meter and per Watt of nominal power of the electrical line used to transfer the power produced by the Wave Energy Converters to the desalination unit ($C_{w/l}$, in $\frac{€}{W \cdot m}$).

The values of c_{wnet} and c_{enet} should be defined by the designer taking into account the distances of the desalination plant and installation point of the RES generators from the water distribution network and the electric grid, respectively.

In case that the RES system is interconnected with the electric grid, the values of the following parameters should additionally be provided:

(i) present value of the price of electric energy sold to the electric grid (c_c, in € / kWh) and

(ii) present value of the buying price of electric energy from the electric grid (c_p, in € / kWh).

If the value of any of the above parameters is not provided by the user, then its value is considered to be equal to zero.

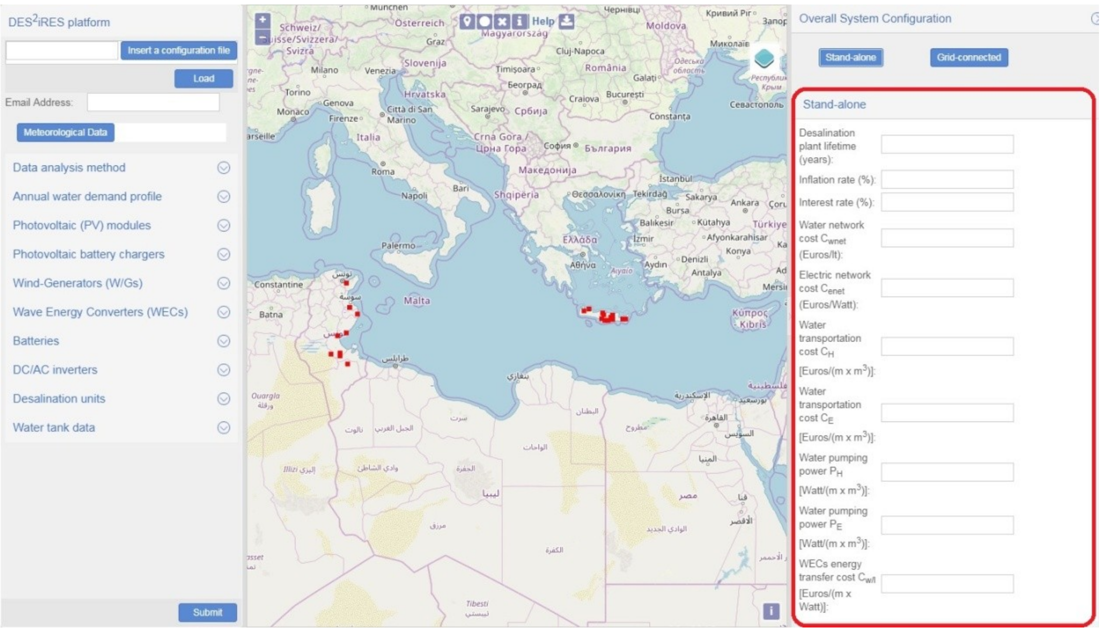


Fig. 7. The form for providing the required data for a desalination plant power-supplied by a stand-alone RES-based system.

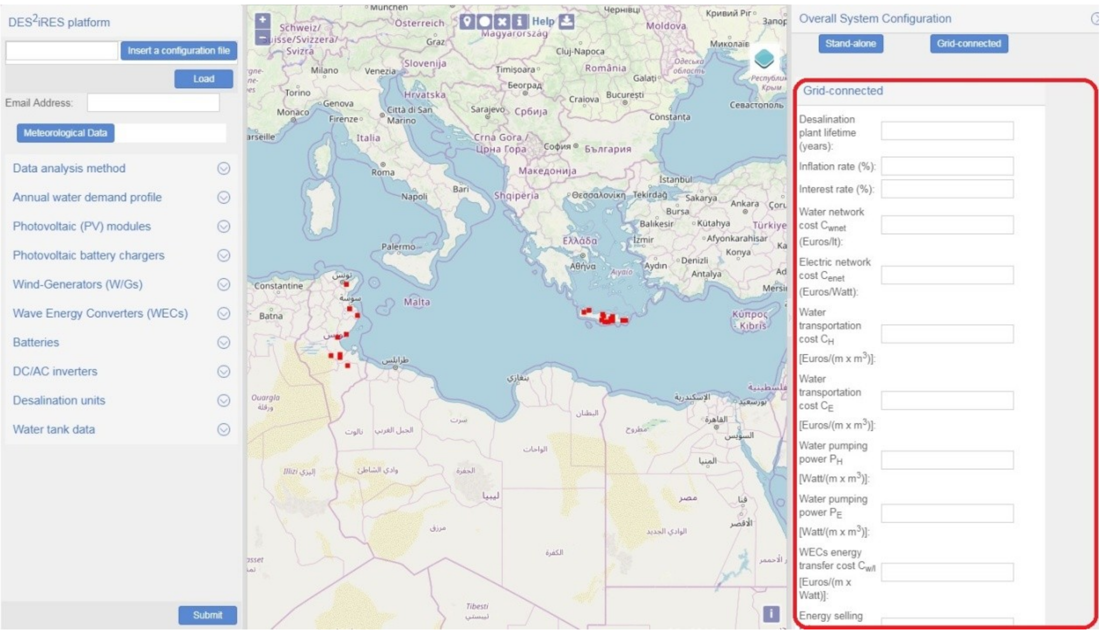


Fig. 8. The form for providing the required data for a desalination plant power-supplied by a grid-connected RES-based system.

Next, as shown in Fig. 9, the user can select if the desalination process will be performed for brackish water or seawater, respectively. The model of desalination plant selected must be suitable for operation with the selected type of water, else an error message is displayed by the DES^{2}iRES interface.

Also, the configuration of the power-supply system of the desalination plant can be selected among the following alternatives: 1) only PVs and batteries, 2) only WGs and batteries, 3) only

WECs and batteries, 4) hybrid RES system with PVs, WGs and batteries, 5) hybrid RES system with PVs, WECs and batteries, 6) hybrid RES system with W/Gs, WECs and batteries, 7) hybrid RES system with PVs, WGs, WECs and batteries, 8) only PVs without batteries, 9) only W/Gs without batteries, 10) only WECs without batteries, 11) hybrid RES system with PVs and WGs and without batteries, 12) hybrid RES system with PVs and WGs and without batteries, 13) hybrid RES system with PVs and WGs and without batteries, 14) hybrid RES system with PVs, W/Gs and WECs and without batteries, 15) without any RES or battery and only with connection with the electric grid. Configuration no. 15 can be used as a reference in order to compare the desalination cost of RES-based desalination systems with conventional configurations.

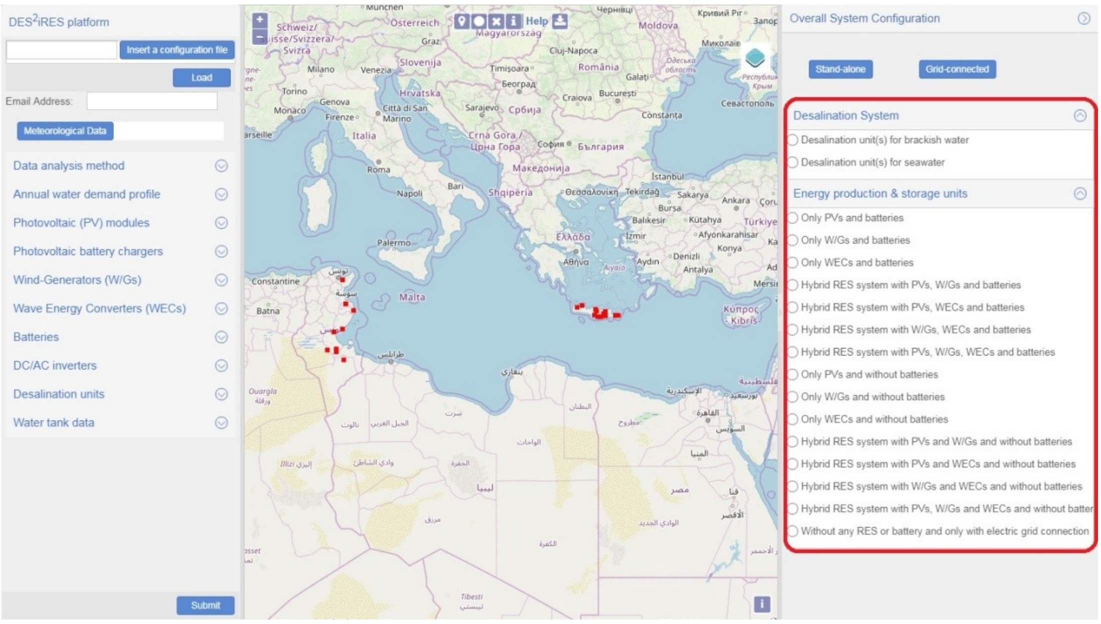
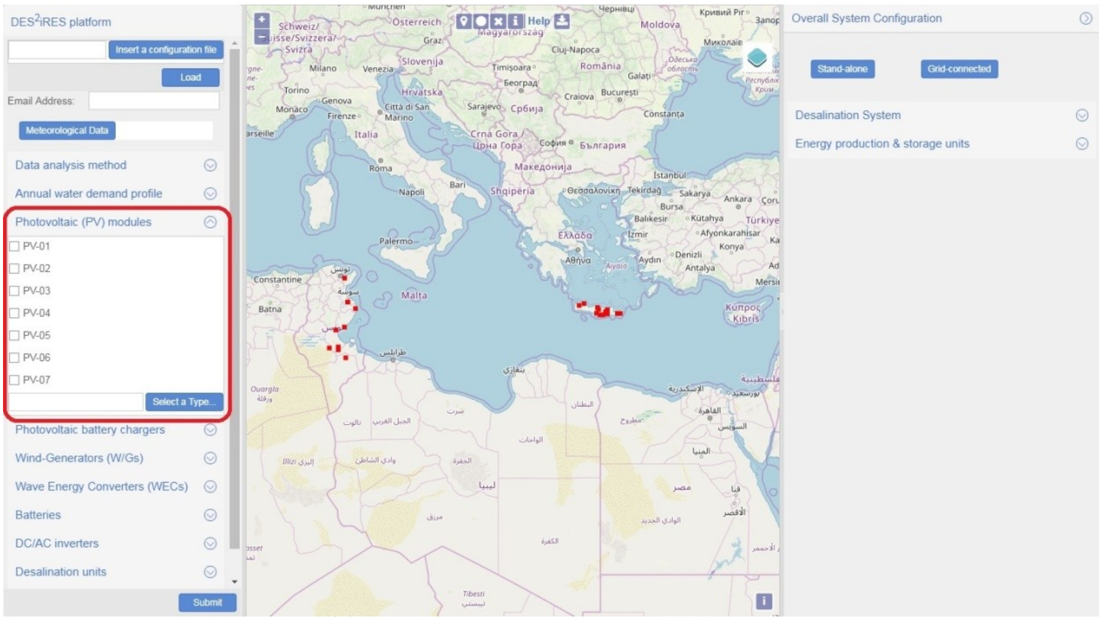


Fig. 9. The forms where the type of feed-in water and the RES-based system configuration are selected.

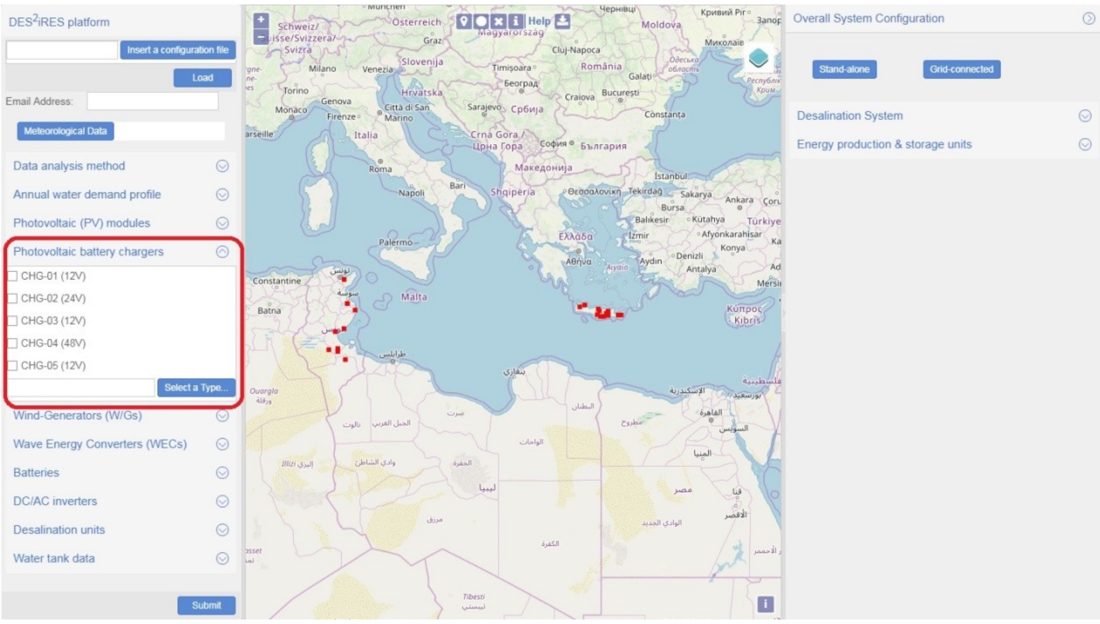
4. Selecting the desired types of RES and desalination devices and importing new device types

In order to perform the design optimization of the RES-based desalination system, a database has been formed, containing the operational characteristics and cost of commercially-available devices (i.e. PV modules, W/Gs, desalination units etc.), which can be used to synthesize a RES-based desalination plant. Multiple alternative devices by different manufacturers, with different operational characteristics (e.g. power rating, voltage range etc.) have been included in the database of each device category, such that the most suitable device type (model) of each category can be derived during the design optimization process (Fig. 10). The operational characteristics and cost of these devices are presented in the Appendix. Through the web-GIS interface of the DES^{2}iRES platform, the user is able to select one or more different devices types of each category to be considered in the design optimization process. Then, the optimization algorithm calculates the optimal models of devices among the alternative device types selected by the user. Before using the operational characteristics of the devices selected by the user to be considered in the optimization process, it is checked that:

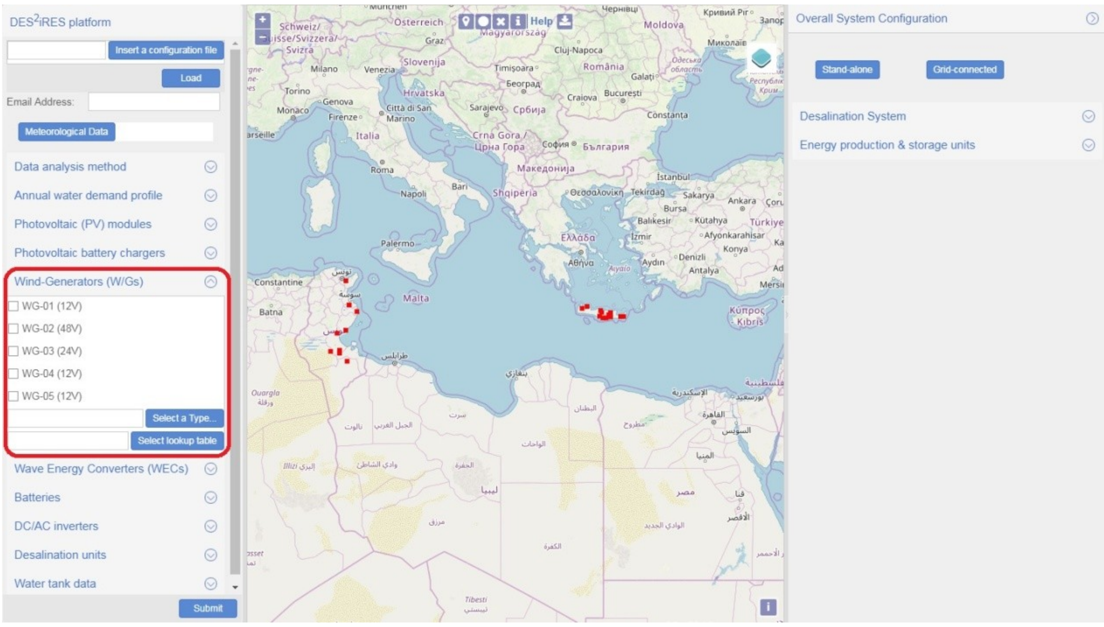
- The nominal operating output voltage of the PV battery charger, which is also equal to the nominal voltage of the DC-bus in Fig. 1, is within the operating DC input voltage range of the DC/AC inverter.
- The output voltage and frequency of the DC/AC inverter(s) is compatible with the corresponding operational characteristics of the desalination units which are power-supplied by the DC/AC inverter(s).



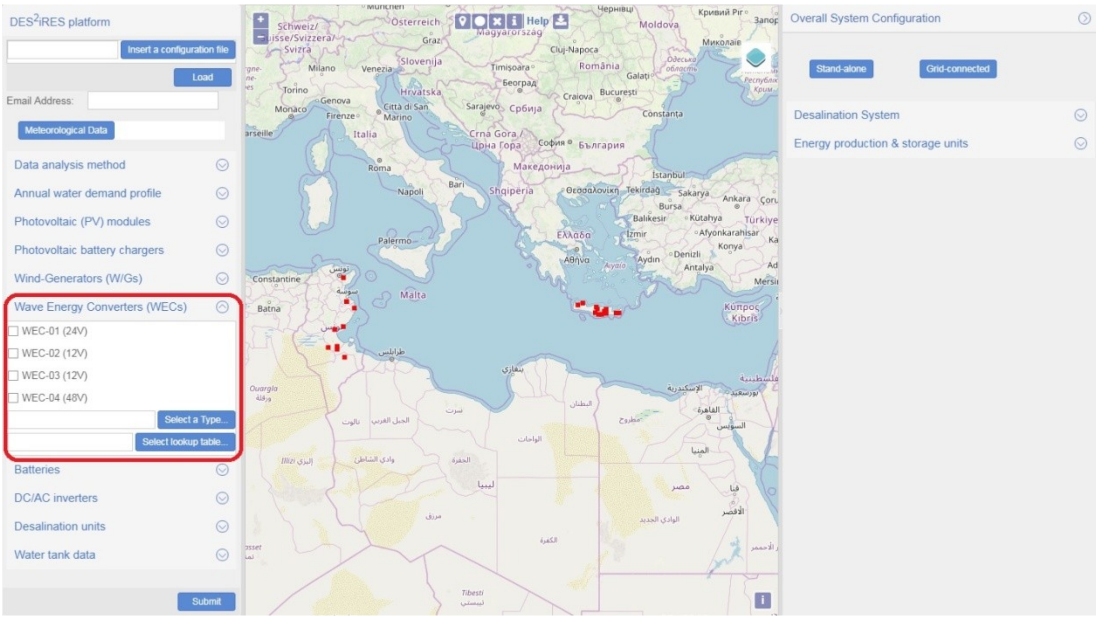
(a)


DES²iRES platform
Insert a configuration file
Load
Email Address:
Meteorological Data
Data analysis method
Annual water demand profile
Photovoltaic (PV) modules
Photovoltaic battery chargers
CHG-01 (12V)
CHG-02 (24V)
CHG-03 (12V)
CHG-04 (48V)
CHG-05 (12V)
Select a Type...
Wind-Generators (W/Gs)
Wave Energy Converters (WECs)
Batteries
DC/AC inverters
Desalination units
Water tank data
Submit
Help
Overall System Configuration
Stand-alone
Grid-connected
Desalination System
Energy production & storage units

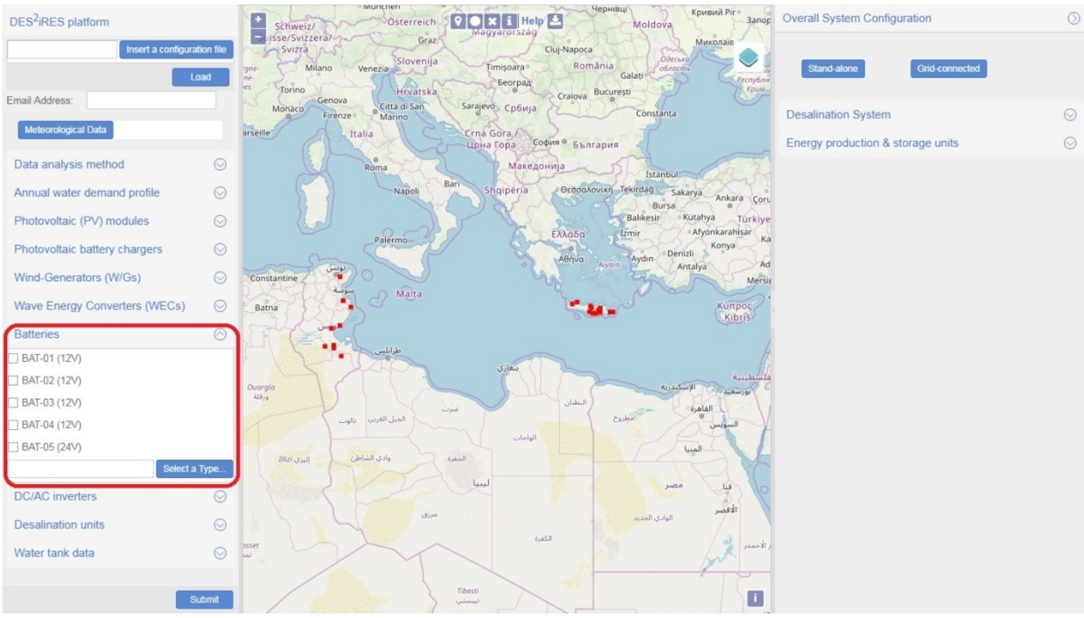
(b)


DES²iRES platform
Insert a configuration file
Load
Email Address:
Meteorological Data
Data analysis method
Annual water demand profile
Photovoltaic (PV) modules
Photovoltaic battery chargers
Wind-Generators (W/Gs)
WG-01 (12V)
WG-02 (48V)
WG-03 (24V)
WG-04 (12V)
WG-05 (12V)
Select a Type...
Select lookup table
Wave Energy Converters (WECs)
Batteries
DC/AC inverters
Desalination units
Water tank data
Submit
Help
Overall System Configuration
Stand-alone
Grid-connected
Desalination System
Energy production & storage units

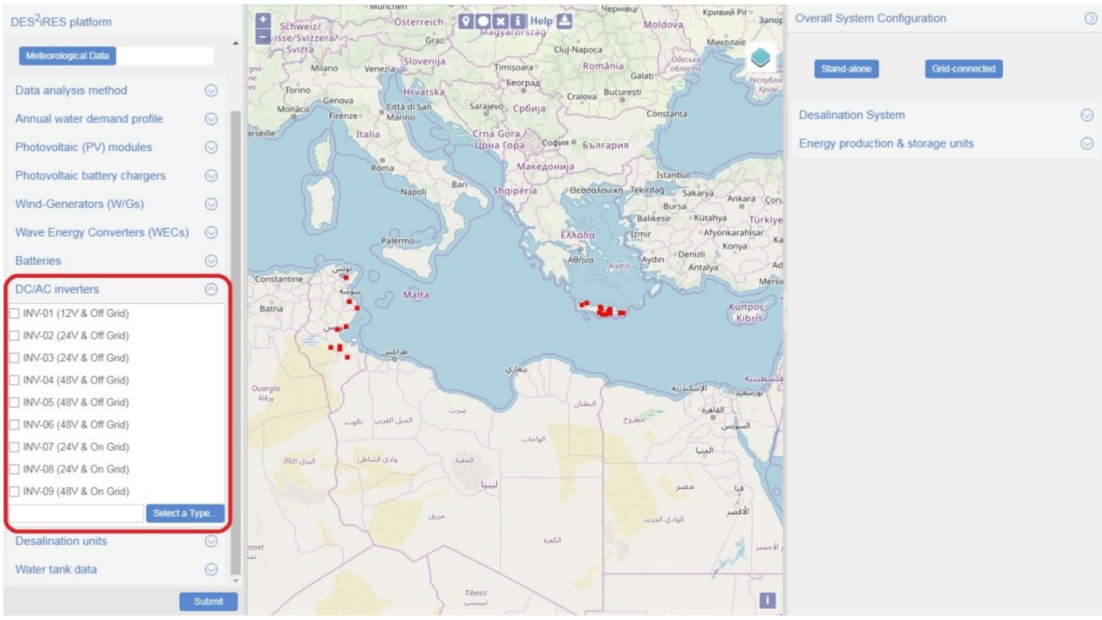
(c)


DES2iRES platform
Insert a configuration file
Load
Email Address:
Meteorological Data
Data analysis method
Annual water demand profile
Photovoltaic (PV) modules
Photovoltaic battery chargers
Wind-Generators (W/Gs)
Wave Energy Converters (WECs)
WEC-01 (24V)
WEC-02 (12V)
WEC-03 (12V)
WEC-04 (48V)
Select a Type...
Select lookup table...
Batteries
DC/AC inverters
Desalination units
Water tank data
Submit
Help
Overall System Configuration
Stand-alone
Grid-connected
Desalination System
Energy production & storage units

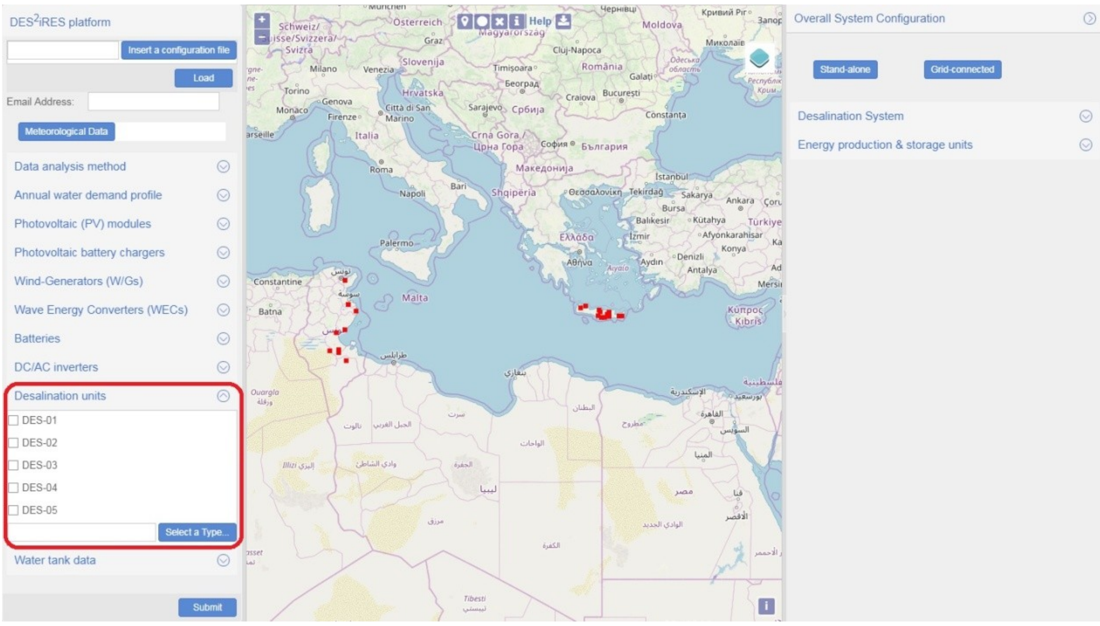
(d)


DES2iRES platform
Insert a configuration file
Load
Email Address:
Meteorological Data
Data analysis method
Annual water demand profile
Photovoltaic (PV) modules
Photovoltaic battery chargers
Wind-Generators (W/Gs)
Wave Energy Converters (WECs)
Batteries
BAT-01 (12V)
BAT-02 (12V)
BAT-03 (12V)
BAT-04 (12V)
BAT-05 (24V)
Select a Type...
DC/AC inverters
Desalination units
Water tank data
Submit
Help
Overall System Configuration
Stand-alone
Grid-connected
Desalination System
Energy production & storage units

(e)



(f)



(g)

Fig. 10. The selection of the desired models of devices in the DES²iRES interface among the available types: (a) Photovoltaic modules, (b) Photovoltaic battery chargers, (c) Wind-Generators, (d) Wave Energy Converters, (e) Batteries, (f) DC/AC inverters and (g) Desalination units.

As shown in Fig. 11, the data required for the water tank are the manufacturing cost in € per liter and the annual maintenance cost in € per liter.

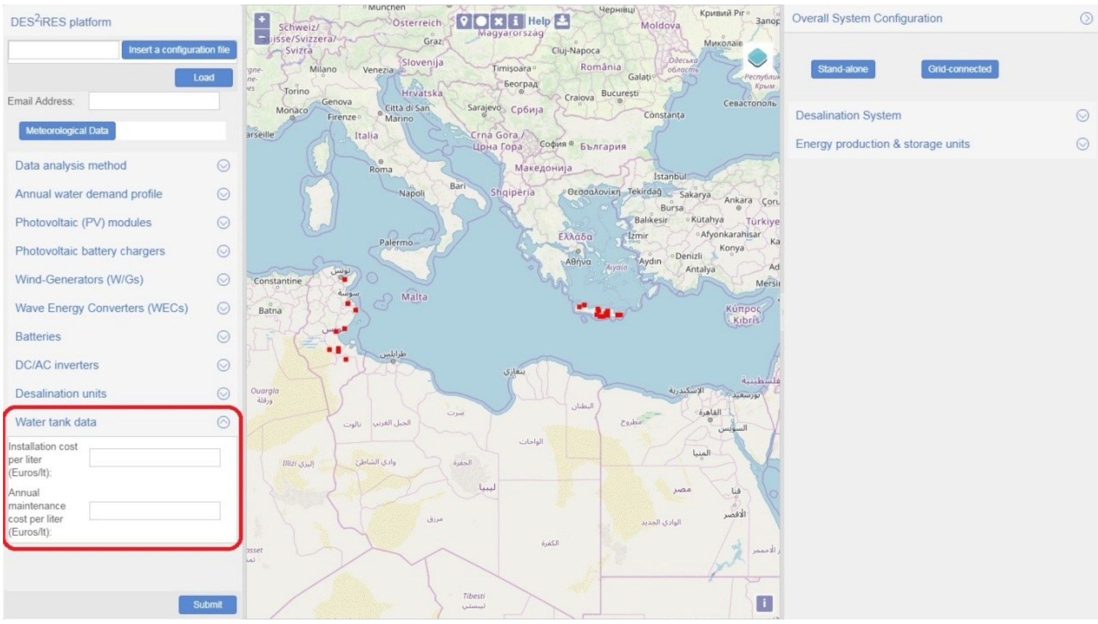


Fig. 11. The form for providing the data required for the water tank.

Also, the user is able to define new types of system devices, which are not included in the devices database (these devices are referred to as "user-defined" in the design results displayed to the user by the DES²iRES platform as described in § 7). In such a case, the desired operational characteristics of the system devices can be input in the form of .txt files according to the following format:

4.1 PV module data

An example of the input file for the PV modules is shown in Fig. 12. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €), open-circuit voltage under Standard Test Conditions (in Volt), short-circuit current under Standard Test Conditions (in Ampere), Maximum Power Point (MPP) voltage under Standard Test Conditions (in Volt), MPP current under Standard Test Conditions (in Ampere), MPP power under Standard Test Conditions (in Watt) , NCOT (in ^oC), open-circuit voltage temperature coefficient (in $\mathrm{Volt} / {}^\circ\mathrm{C}$), short-circuit current temperature coefficient (in $\mathrm{Ampere} / {}^\circ\mathrm{C}$), number of solar cells in series per PV module, number of solar cell strings in parallel per PV module.

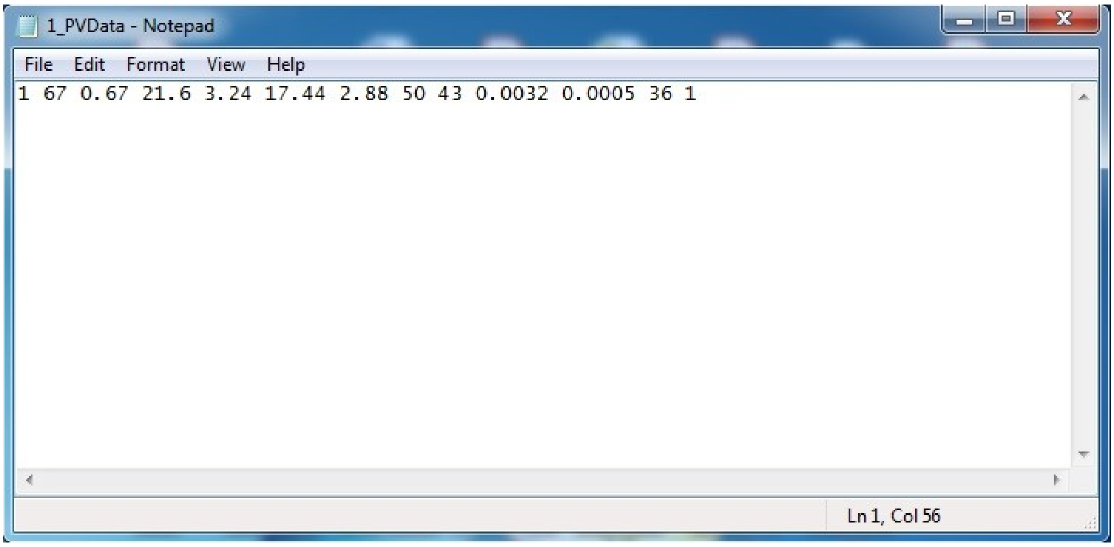


Fig. 12. An example of the data inside the file for the PV modules.

4.2 PV battery charger data

An example of the PV battery charger input file is shown in Fig. 13. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €), charger power conversion efficiency (in %), efficiency of the Maximum Power Point Tracking (MPPT) process (in %), nominal power rating of the charger (in Watt), Mean Time Between Failures (in hours), nominal output voltage of the battery charger, which is also equal to the nominal DC-bus voltage (in Volt), minimum MPP voltage of the PV array that the charger can operate with (in Volt), maximum MPP voltage of the PV array that the charger can operate with (in Volt). If the PV battery charger does not include an MPPT function, then the value of MPPT efficiency is set equal to 70 %.

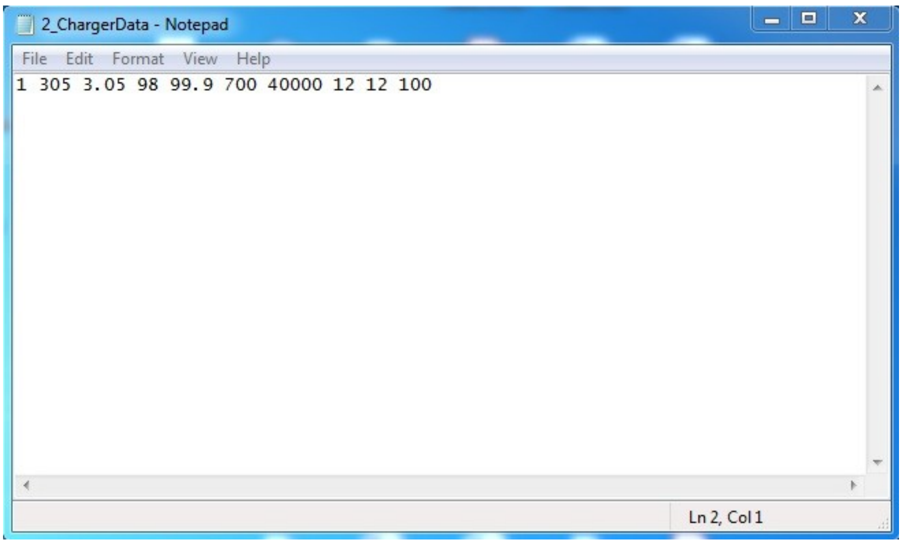


Fig. 13. An example of the data inside the file for the PV battery chargers.

In case that the MPP voltage (under Standard Test Conditions) of the PV modules selected by the designer is higher than the upper limit of the PV battery charger MPP voltage range, then the optimization process is not executed and an error message is displayed to the user.

4.3 Wind-Generator Data

An example of the W/G input file is shown in Fig. 14. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €), installation cost of the W/G tower per meter height (in €/m), maintenance cost of the W/G tower per meter height and per year (in €/m/year), nominal output power at the W/G battery charger output (in Watt) and nominal DC output voltage of the W/G battery charger (in Volt). The battery charger is incorporated in the Wind-Generator structure.

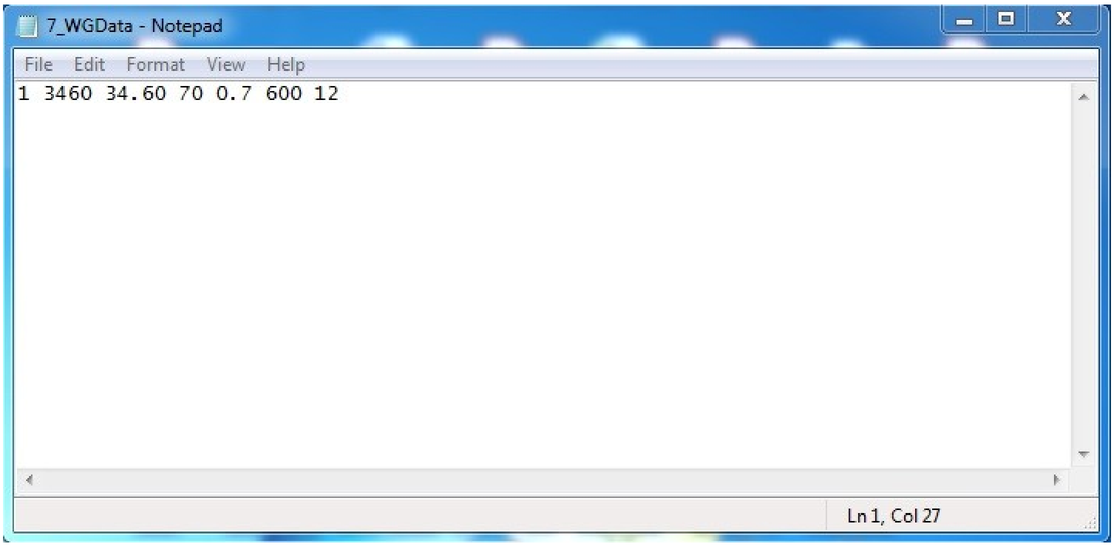
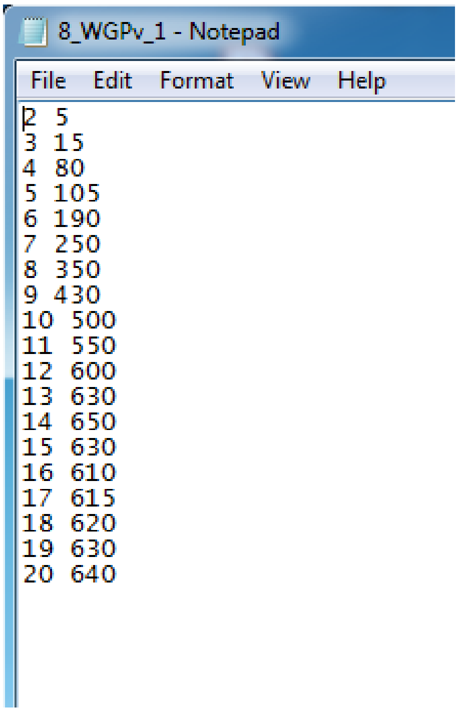


Fig. 14. An example of the data inside the file for the Wind-Generator.

4.4 Wind–Generator output power vs. wind speed look-up table

An example of the W/G output power vs. wind speed look-up table input file is shown in Fig. 15. There are two columns in the file: the first corresponds to the wind speed (in m/sec) and the second one to the power that will be produced (in Watt) at that wind speed. The battery charger is incorporated in the W/G structure, thus the output power provided by the look-up table is the power provided by the W/G to the DC bus of the desalination system (see Fig. 1).


8_WGPv_1 - Notepad

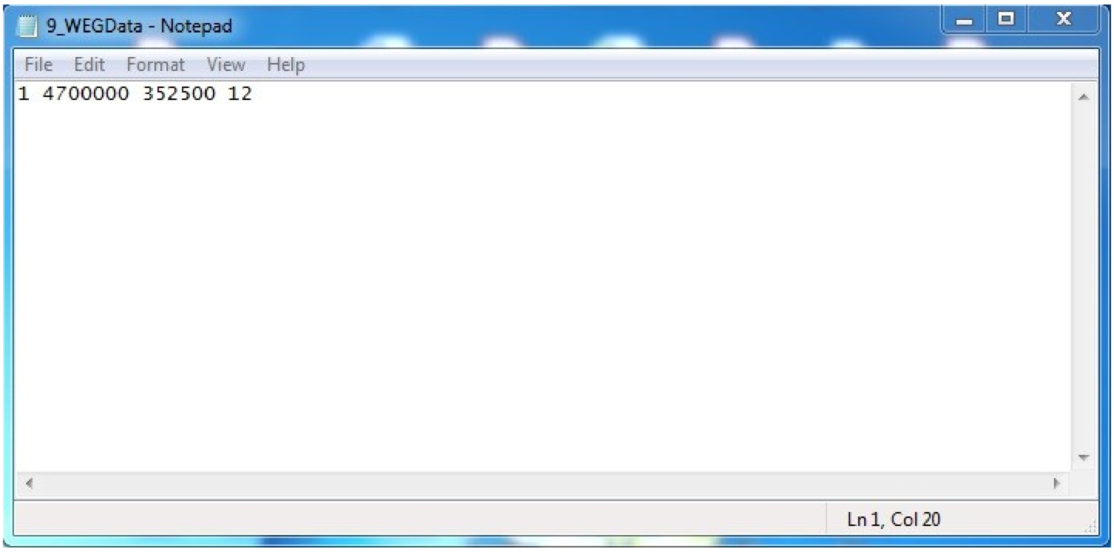
File Edit Format View Help

2 5
3 15
4 80
5 105
6 190
7 250
8 350
9 430
10 500
11 550
12 600
13 630
14 650
15 630
16 610
17 615
18 620
19 630
20 640

Fig. 15. An example of the data inside the file for the Wind-Generator output power vs. wind speed look-up table.

4.5 Wave Energy Converter data

An example of the WEC data input file is shown in Fig. 16. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €) and the nominal DC output voltage of the WEC battery charger (in Volt). Similarly to the W/Gs, a battery charger is incorporated in each WEC.


9_WEGData - Notepad

File Edit Format View Help

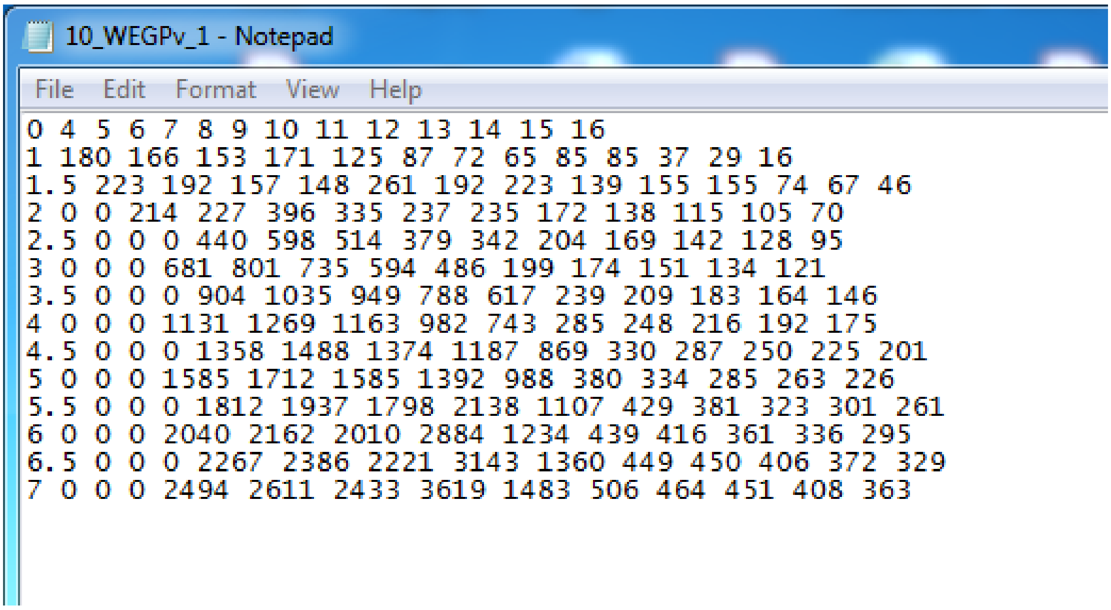
1 4700000 352500 12

Ln 1, Col 20

Fig. 16. An example of the data inside the file for the Wave Energy Converter.

4.6 Wave Energy Converter output power look-up table

An example of the file for the WEC output power look-up table is shown in Fig. 17. The first line in the file corresponds to the wave period values (in seconds) and the first column corresponds to the wave height values (in meters). The battery charger is incorporated in the WEC structure, thus the output power provided by the look-up table is the power provided by the WEC to the DC bus of the desalination system (Fig. 1).




```
0 4 5 6 7 8 9 10 11 12 13 14 15 16
1 180 166 153 171 125 87 72 65 85 85 37 29 16
1.5 223 192 157 148 261 192 223 139 155 155 74 67 46
2 0 0 214 227 396 335 237 235 172 138 115 105 70
2.5 0 0 0 440 598 514 379 342 204 169 142 128 95
3 0 0 0 681 801 735 594 486 199 174 151 134 121
3.5 0 0 0 904 1035 949 788 617 239 209 183 164 146
4 0 0 0 1131 1269 1163 982 743 285 248 216 192 175
4.5 0 0 0 1358 1488 1374 1187 869 330 287 250 225 201
5 0 0 0 1585 1712 1585 1392 988 380 334 285 263 226
5.5 0 0 0 1812 1937 1798 2138 1107 429 381 323 301 261
6 0 0 0 2040 2162 2010 2884 1234 439 416 361 336 295
6.5 0 0 0 2267 2386 2221 3143 1360 449 450 406 372 329
7 0 0 0 2494 2611 2433 3619 1483 506 464 451 408 363
```

Fig. 17. An example of the data inside the file for the Wave Energy Converter output power look-up table.

4.7 Battery data

An example of the battery input file is shown in Fig. 18. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €), battery nominal capacity (in Ah), battery nominal operating voltage (in Volt), maximum Depth of Discharge permitted (in %), number of lifetime charging/discharging cycles with the permitted % DOD.

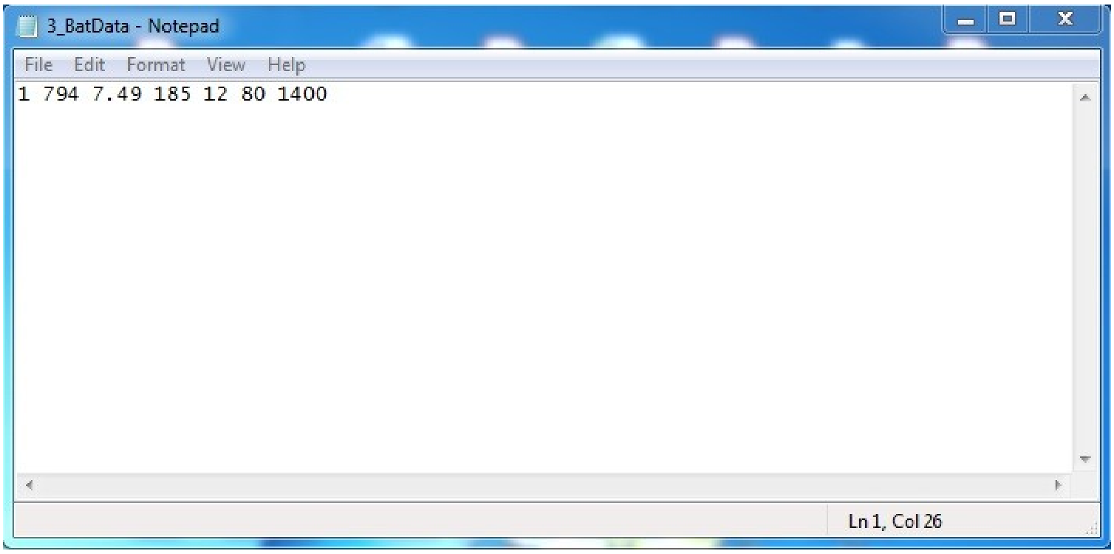


Fig. 18. An example of the data inside the file for the batteries.

4.8 DC/AC inverter data

An example of the DC/AC inverter input file is shown in Fig. 19. The data contained in this file in order of appearance are the following: serial number, installation cost (in €), maintenance cost per year (in €), efficiency of the inverter (in %), AC power rating of the DC/AC inverter (in Watt), Mean Time Between Failures (in hours), minimum permissible DC input voltage of the DC/AC inverter (in Volt) and maximum permissible DC input voltage of the DC/AC inverter (in Volt), Root-Mean-Square (RMS) value of the nominal AC output voltage (in Volt) and nominal output voltage frequency (in Hz). For three-phase DC/AC inverters, the nominal AC output voltage parameter corresponds to the line-to-line voltage, while for single-phase DC/AC inverters it corresponds to the line-to-neutral voltage.

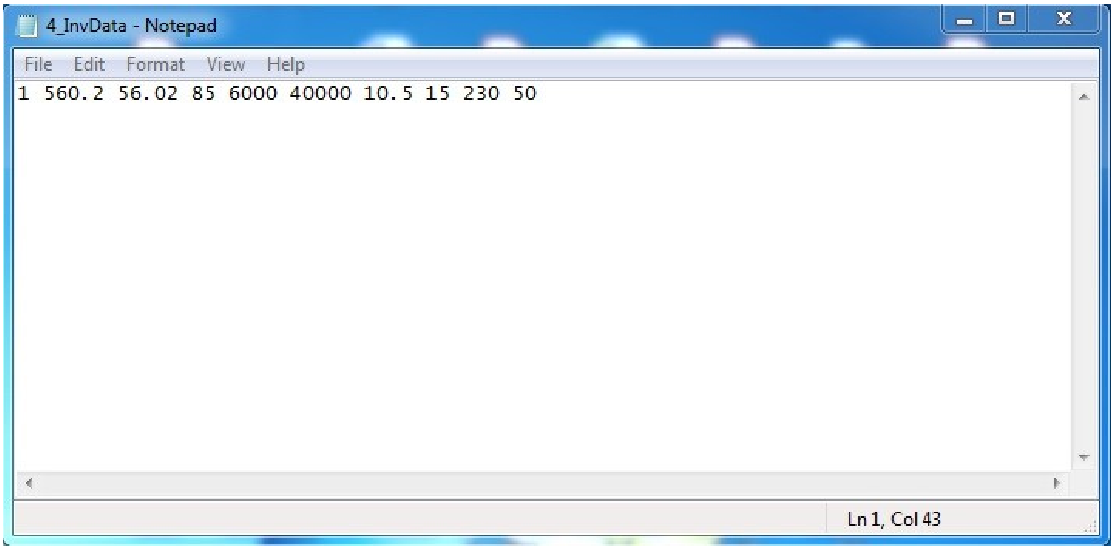


Fig. 19. An example of the data inside the file for the DC/AC inverters.

4.9 Desalination unit data

An example of the desalination unit input file is shown in Fig. 20. The data contained in this file in order of appearance are the following: serial number, installation cost (C_{DU}, in €), maintenance cost per year (in €), volume of water produced per day (in liters/day), power needed during operation (P_U, in Watt), volume of water needed for the flushing process of reverse-osmosis desalination units (in liters), power needed for the flushing process of reverse-osmosis desalination units (in Watt), feed water type ("1" for seawater and "0" brackish water), RMS value of the nominal AC operating input voltage (in Volt) and nominal operating input voltage frequency (in Hz). For three-phase desalination units, the nominal AC operating input voltage parameter corresponds to the line-to-line voltage, while for single-phase desalination units it corresponds to the line-to-neutral voltage. The value of P_U includes the power required for pumping seawater to the desalination system installation point and brine disposal back to the sea when the desalination system is installed next to the sea. The value of C_{DU} also includes:

(i) the costs of internal constructions related to the desalination units, such as the seawater filters, the holding tanks for water pre- and post-treatment, equipment for water and solids handling, instrumentation equipment etc. and

(ii) the total cost of the pipelines (running in parallel) transporting seawater to the desalination system installation point and brine disposal back to the sea (brine outfall pipeline), when the desalination system is installed next to the sea.

In case that a flushing process is not required for a desalination unit under consideration, then the corresponding fields of power and water required for flushing should be set equal to zero.

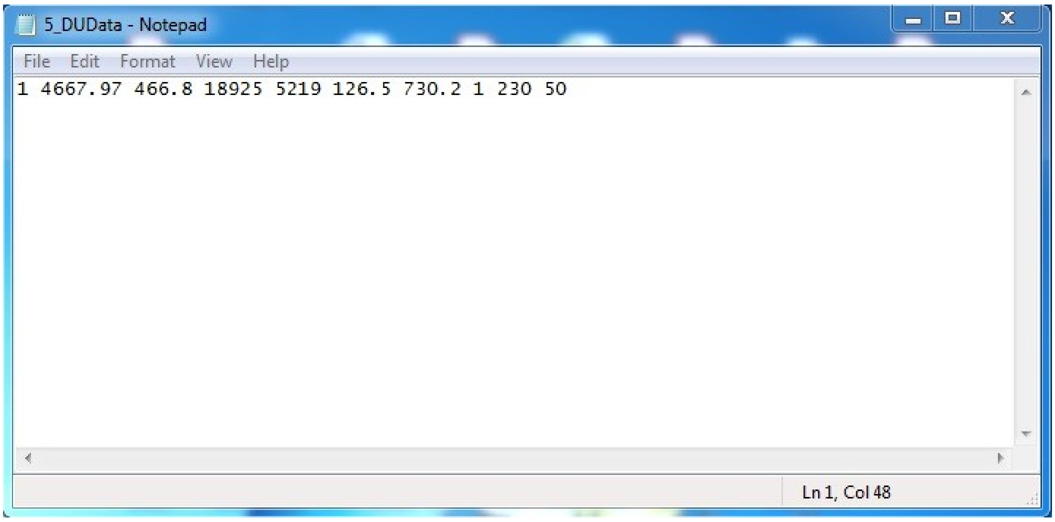


Fig. 20. An example of the data inside the file for the desalination units.

In case that multiple lines are provided in the .txt. input files described in § 4.1-4.9, only the first line (i.e. device) is considered in the optimization process. Even if a new device type is imported as described above, the user is also able to select additional devices from those already available in the DES²iRES platform and the optimal type among them will finally be recommended to the user in the design results.

5. Meteorological data

In order to perform the design optimization of the RES-based desalination system, meteorological data for various parameters are used. These parameters for every location chosen include ambient temperature (in °C), wind speed (in m/s), solar irradiance on horizontal plane (in Watt/m^2), significant wave height (in meters), and the corresponding wave period (in seconds), and their combinations for hybrid scenarios. Thus, a database has been formed, based on ground stations (shown with the red dots on the GIS map of Figs. 2 and 21) and reanalysis data. That database is used in combination with geostatistical algorithms (which also perform spatial interpolation) when the user does not supply data for the desired locations. Additionally, as shown in Fig. 21, the user is able to import new meteorological data for 1 to 4 different stations through the web-GIS interface of the DES²iRES platform, which correspond to ambient temperature, wind speed, and solar irradiance, plus (if desired) significant wave height and wave period data for 1 offshore location. The data imported must follow the predefined specifications (see § 5.1 – 5.7), else an error message will be sent to the user by the DES²iRES platform as described next.

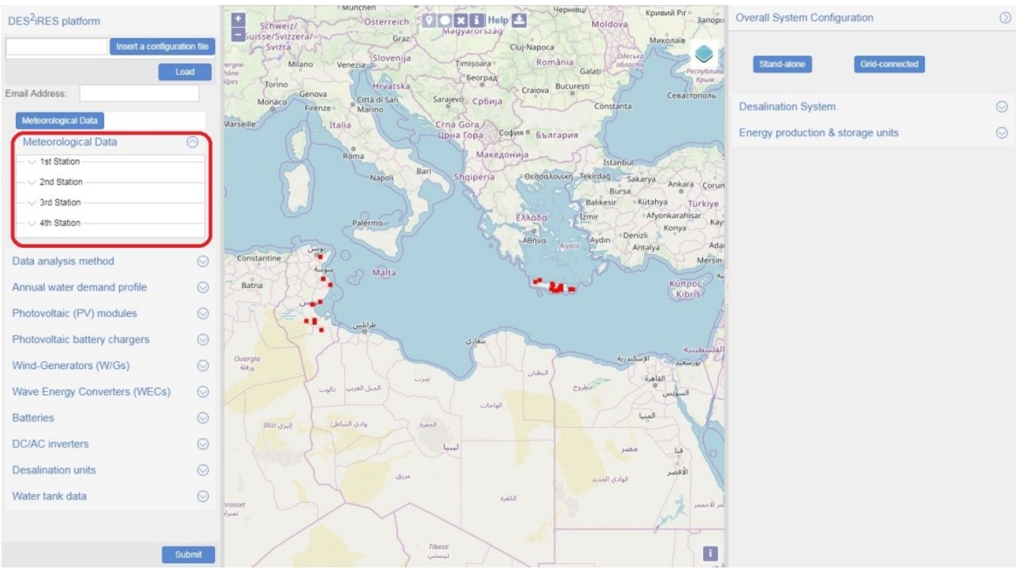


Fig. 21. The form for providing the user-defined meteorological data.

Next, as shown in Fig. 22, the user can select if the data analysis will be performed with the more complex, but more robust Stochastic Local Interaction (SLI) algorithm, which is more time demanding, or if the analysis will be performed with the linear interpolation algorithm. Linear interpolation based on neighboring stations is the default algorithm for the estimation of either missing values (time instants) at a single location, or for the generation of an entire time-series at one or multiple locations based on the database data. Linear interpolation estimates the value at each time from the available data on the same time slice. The more robust SLI interpolation method is based on the stochastic local interaction model, which uses kernel functions to estimate the neighborhood that is required for the estimation of the missing values. The SLI method is only used to estimate missing values at a single location. If a data analysis method is not selected by the user, then the default setting "Typical" is used by the DES²iRES platform during the design optimization process.

Fig. 22. The form for providing the desired method used for the data analysis (optional).

The user defined meteorological data should be separate .txt files, which should follow the format described below:

5.1 Location data

An example of the input file for the location data is shown in Fig. 23. The input file should be a .txt file, with comma separated values. The first line in the file defines the names of the geographic coordinates as "longitude,latitude", while the second line includes the corresponding values measured in degrees. The data contained in this file in order of appearance are the following: longitude (degrees), latitude (degrees).

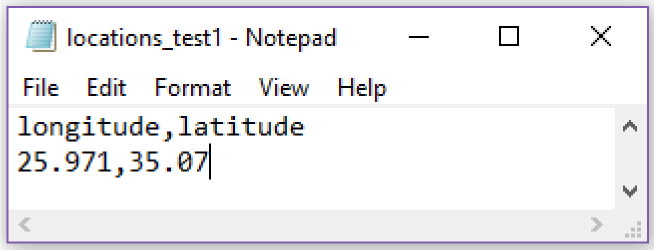


Fig. 23. An example of the data inside the file for the station location.

5.2 Time period data

An example of the input file for the time-period data is shown in Fig. 24. The input file should be a .txt file, with values comma separated. The first line in the file defines the starting date and the starting time referring to the provided data (dd/mm/yyyy, HH:MM:SS), while the second line defines the ending date, as well as the ending time (with the aforementioned format).

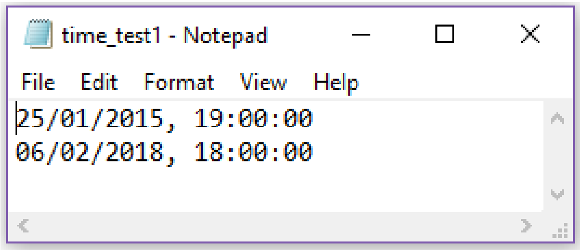


Fig. 24. An example of the data inside the file for the time period of the imported data.

5.3 Ambient temperature data

An example of the input file for the temperature data is shown in Fig. 25. The input file should be a .txt file with hourly values of temperature measured in °C, for as many years as desired, with the first line giving the name of the variable "Temperature". Every hourly value corresponds to a different line. The minimum entries should be 8760, which translates to a whole calendar year of hourly values (from 01/01/YYYY - 31/12/YYYY, calendar year). Note that the length of the data should meet the length of the hours that are included into the time period defined. In case of missing values add "NaN" as shown in Fig. 25, although the missing values should not be more than 5% of the total data, and the missing contiguous values should not be longer than 2 weeks (i.e. 336 hours). Temperature values lower than -40 °C and greater than 60 °C will be removed automatically from the dataset, since they are considered as measurement errors.

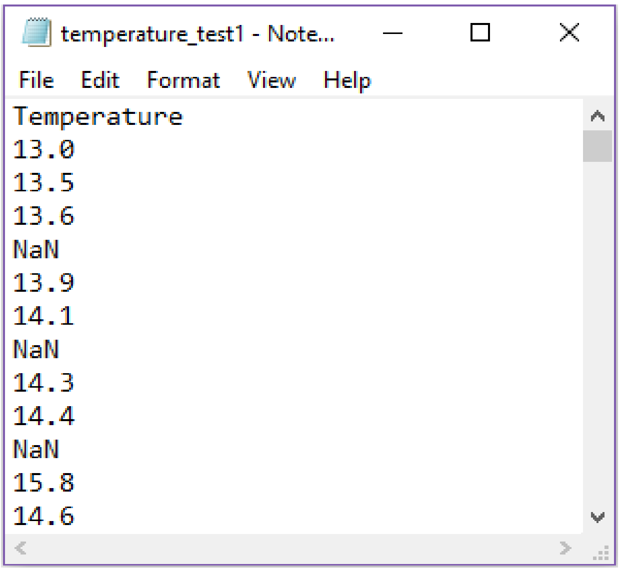


Fig. 25. An example of the data inside the file for the temperature data.

5.4 Wind speed data

An example of the input file for the wind speed data is shown in Fig. 26. The input file should be a .txt file with the hourly mean values of wind speed (measured in meters/second) at a height of 10 meters above ground level, for as many years as desired, with the first line giving the name of the variable "Wind". The data constraints are the same as in the temperature dataset, except of the limits for the lower (0 meters/second) and higher (50 meters/second) acceptable values. Wind speed values outside the range of acceptable measurements are automatically replaced with "NaN" values in the dataset, since they are considered as errors.

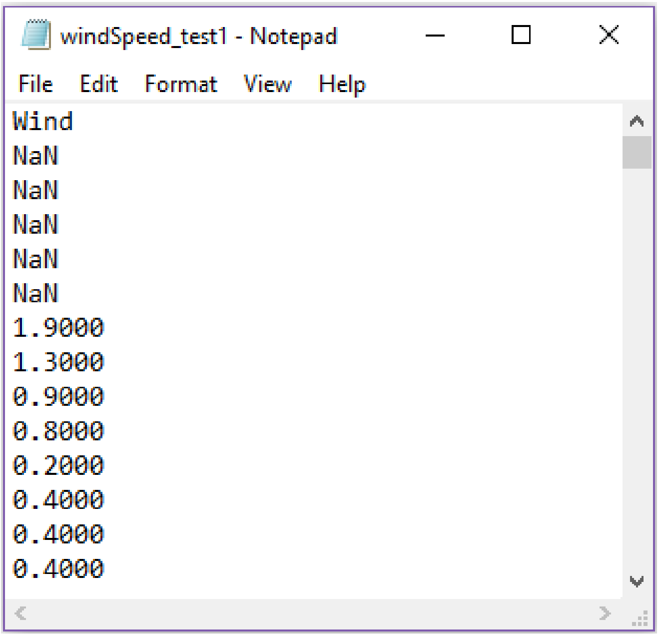


Fig. 26. An example of the data inside the file for the wind speed.

5.5 Solar irradiance data

An example of the input file for the global solar irradiance on horizontal plane data is shown in Fig. 27. The input file should be a .txt file with hourly values of global solar irradiance on horizontal plane measured in Watt/m^2, for as many years as desired, with the first line giving the name of the variable "Solar". The data constraints are the same as in the temperature dataset, except of the boundaries for the lower (0 Watt/m^2) and higher (1500 Watt/m^2) values. Solar irradiance values outside the range of acceptable measurements are automatically replaced with "NaN" values in the dataset, since they are considered as errors.

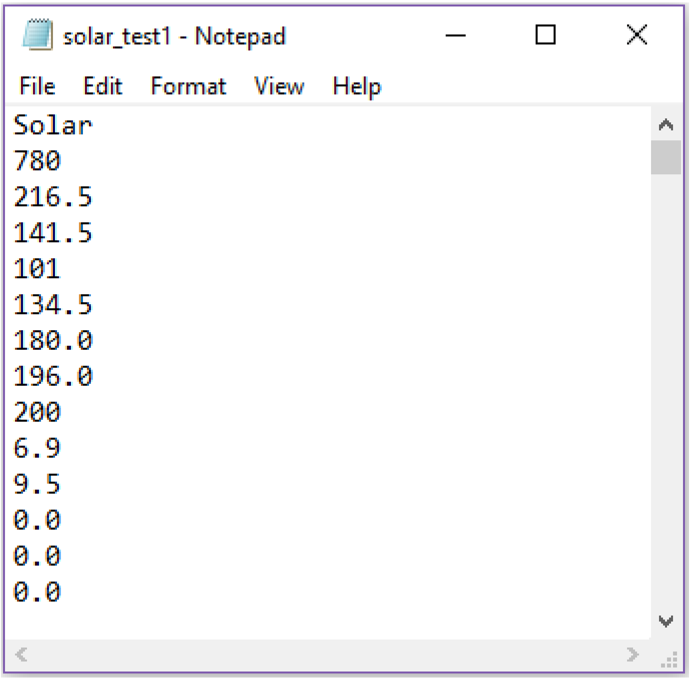
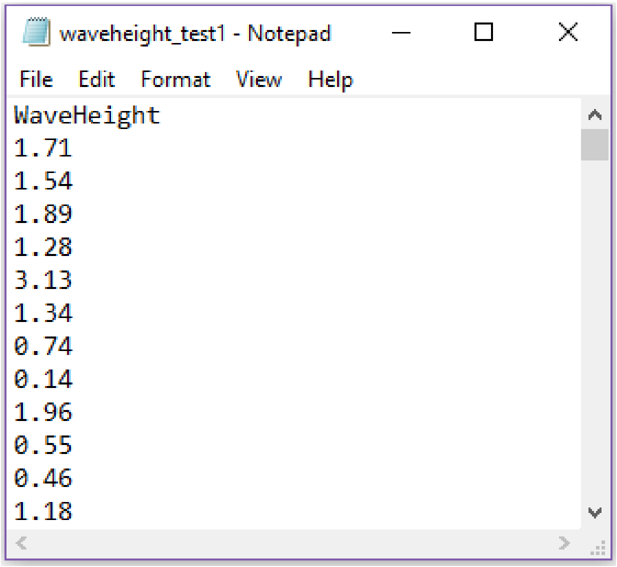


Fig. 27. An example of the data inside the file for the global solar irradiance on horizontal plane.

5.6 Wave height data

An example of the input file for the significant wave height data is shown in Fig. 28. The input file should be a .txt file with hourly values of wave height measured in meters, for as many years as desired, with the first line giving the name of the variable "WaveHeight". The data constraints are the same as in the temperature dataset, except of the boundaries for the lower (0 meters) and higher (10 meters) values. Wave height values outside the range of acceptable measurements are automatically replaced with "NaN" values in the dataset, since they are considered as errors.

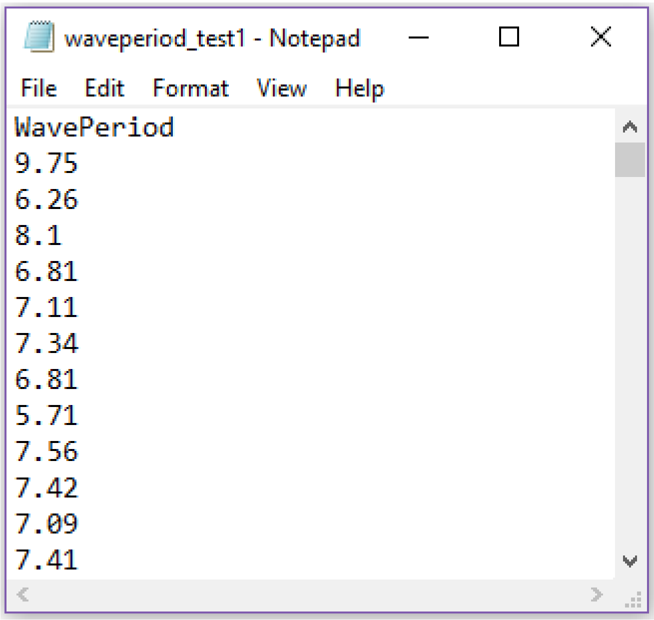

waveheight_test1 - Notepad
File Edit Format View Help

WaveHeight
1.71
1.54
1.89
1.28
3.13
1.34
0.74
0.14
1.96
0.55
0.46
1.18

Fig. 28. An example of the data inside the file for the wave height.

5.7 Wave period data

An example of the input file for the wave period data is shown in Fig. 29. The input file should be a .txt file with hourly values of wave period measured in seconds, for as many years as desired, with the first line giving the name of the variable "WavePeriod". The data constraints are the same as in temperature data, except of the boundaries for the lower (0 seconds) and higher (20 second) values. Wave period values outside the range of acceptable measurements are automatically replaced with "NaN" values in the dataset, since they are considered as errors.


waveperiod_test1 - Notepad
File Edit Format View Help

WavePeriod
9.75
6.26
8.1
6.81
7.11
7.34
6.81
5.71
7.56
7.42
7.09
7.41

Fig. 29. An example of the data inside the file for the wave period.

All the meteorological parameters described in § 5.3-5.7 should be accompanied with the location and the time period. Also for each location, all the variables should have the same length which corresponds to the start and end date/time with a one-hour sampling frequency (i.e. time-step). After the submission of the design query, an internal validation process will evaluate the compliance of the files imported with the guidelines given. If any inconsistencies are present, the platform will send error messages via e-mail to the user.

6. Selection of the installation points

The user is able to select on the map of the DES²iRES interface, up to 4 alternative installation points of the desalination plant which should be located on the land, as well as an additional (i.e. 5th) point in the sea where the Wave Energy Converters will be installed (Figs. 30 and 31). The DES²iRES platform will calculate which of the (up to) 4 points selected by the user on the land is the optimal one, in terms of lifetime system cost, for installing the RES-based desalination system. The installation points selected by the user do not need to coincide with the locations of the meteorological stations of the DES²iRES database (shown with the red dots on the GIS map of Fig. 2), since the geostatistical analysis algorithms, which have been built-in the DES²iRES platform, calculate (offline) the meteorological data required for the design of the RES-based desalination system at any point selected by the user away from the meteorological stations available. In case of desalination plants comprising WECs, the user should select one point located in the sea and at least one point located on the land (for installing the desalination units, DC/AC inverters etc.).

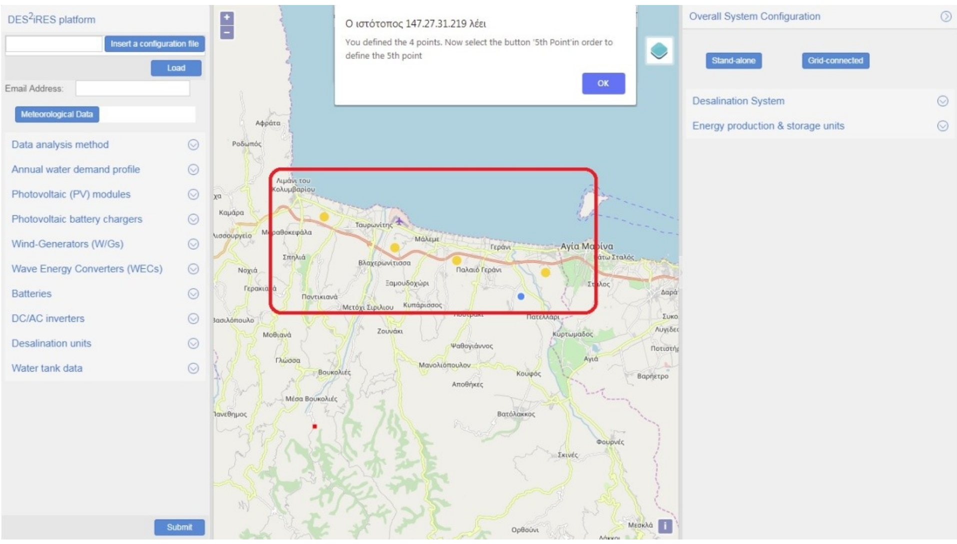


Fig. 30. An example of definition in the GIS map of alternative installation points of the desalination plant on the land.

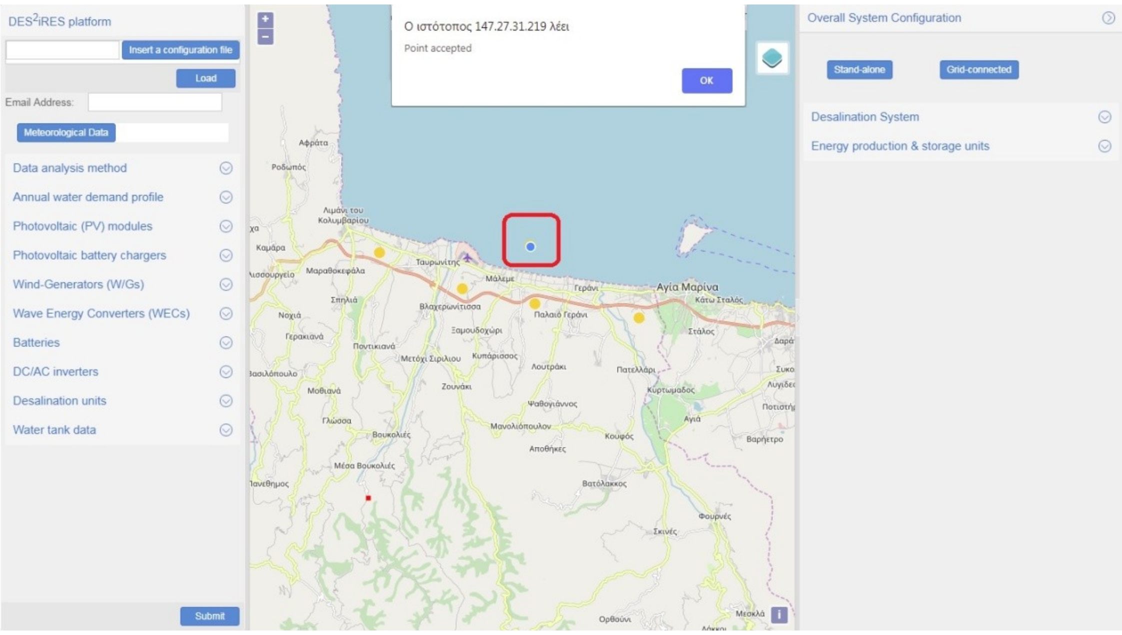


Fig. 31. An example of definition in the GIS map of the WEC installation point in the sea.

The mapping tools and the layers panel (Figs. 32-49) are responsible for the interaction between the user and the back-end software of the platform before the submission of the design query. The mapping tools are the following:

Point tool: With the "Point" tool the user is able to insert four locations on the map. Every time that the user selects a location, the coordinates of each point are automatically processed by the DES^{2}iRES platform in order to disallow the location if it doesn't conform with anyone of the following three constraints:

- The location must be in a terrestrial area of Crete (Greece) or Tunisia,
- A location with ground surface slope higher than 70 % cannot be selected in the area of Crete (Greece),
- A location in shade zone (i.e. near in areas with ground surface slope above 70 %) cannot be selected in the area of Crete (Greece).

Marine tool*:* With the "Marine" tool, the user is able to select one location for the installation of the Wave Energy Converters. When the user selects a location on the map, its coordinates are automatically processed by the DES^{2}iRES platform in order to disallow the location if it doesn't conform with anyone of the following two constraints:

- The selected location must be in the sea area,
- A location further than 5 km from the coastline of Crete (Greece) or Tunisia cannot be selected.

Remove tool: With the "Remove" tool the user can remove all the points that have been selected on the map before the submission of the design query.

Get info tool: With the "Get info" tool the user is able to retrieve information for the "Meteorological Stations" layer by the GIS server. To succeed that, the user has to activate the tool (with the "On" button) and click a feature (Meteorological station) from the "Meteorological stations" layer. After that, the system displays a pop-up window with the related information.

Help tab: With the "Help" tab the user is directed to the webpage of the DES²iRES user's guide.

Download a file: With the "Download a file" button the user can download a file with all the parameters that have been inserted in the web-GIS interface. The user is able to upload the downloaded file when the platform will be used again in order to avoid re-defining in the web-GIS interface the values of all operational parameters of the RES-based desalination system when a new design is desired. To succeed that, the user has to upload the file from the corresponding form of the web-GIS interface and select the "load" button, as shown in Fig. 32.

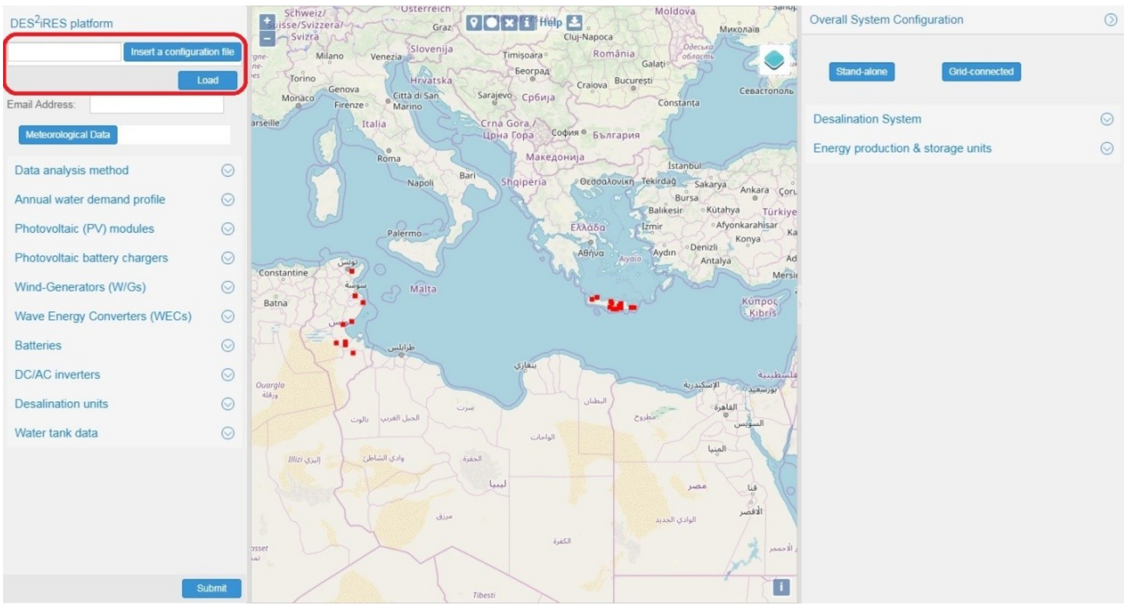


Fig. 32. The form that the user is able to upload a previously downloaded file with the desired input parameters.

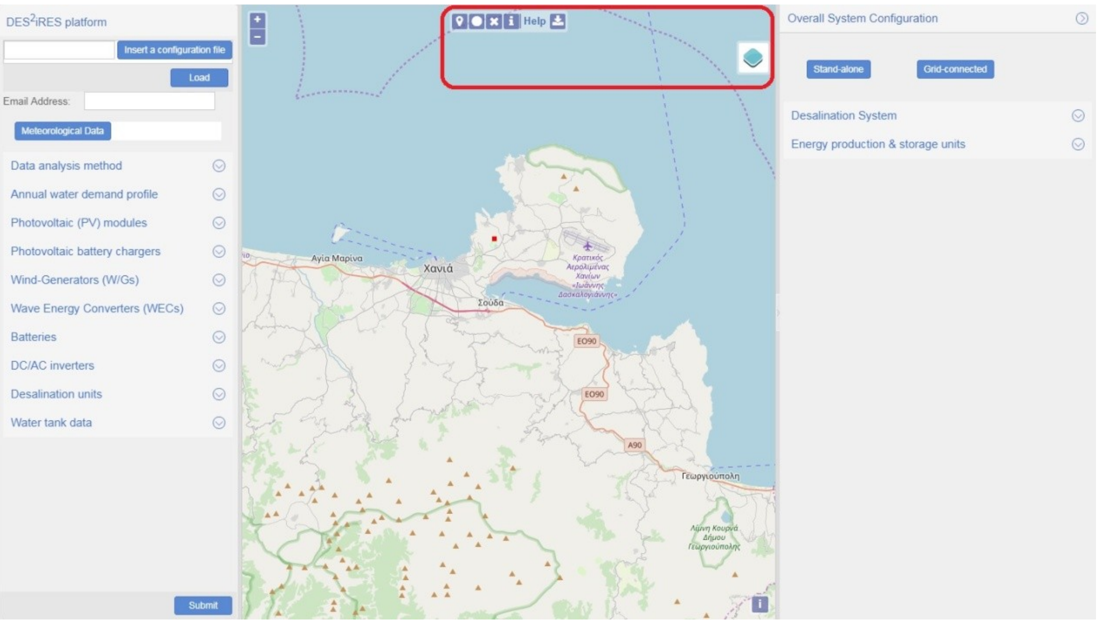


Fig. 33. The mapping tools (at the top of the map) and the layers panel button (at the right side of the map) through which the user is able to expand a form for the activation of layers.

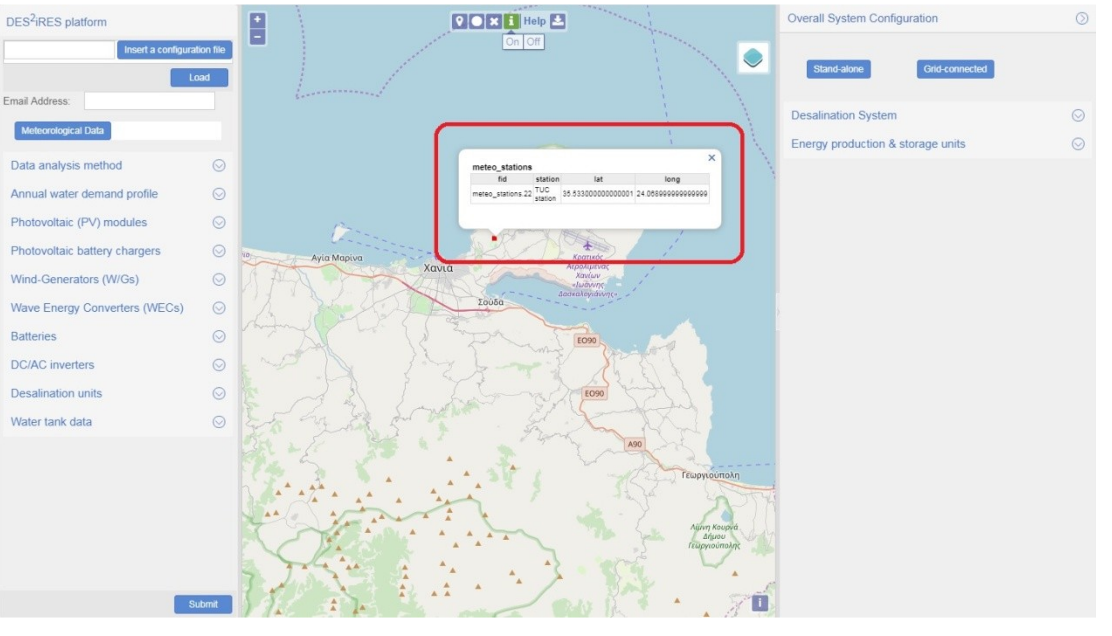


Fig. 34. Information from the "Meteorological Stations" layer with a click on features.

With the "layers panel" the user is able to activate or deactivate the following layers:

"Tunisia: Desalination plants": *This layer presents the locations of desalination plants for the region of Tunisia.*

"Tunisia: BRW stations": *This layer depicts the locations of BRW stations for the region of Tunisia.*

"Tunisia: Electric lines": This layer presents the electric lines for the area of Tunisia.

"Tunisia: Substations": This layer contains the locations of electrical grid substations for the area of Tunisia.

"Tunisia: Towns": This layer depicts the towns of Tunisia.

"Meteo Stations": This layer presents the available meteorological stations for the regions of Crete and Tunisia, respectively.

"Crete: Villages": This layer displays the villages of Crete.

"Crete: Airports": The "Crete Airports" layer presents the airports for the region of Crete.

"Crete: Natura2000": The "Natura 2000" layer depicts the areas which have been characterized as "Natura" regions for the region of Crete.

"Crete: Renewable Energy Zones (REZ)": the "REZ zones" layer presents the geographical areas recommended by the Region of Crete administration to host large-scale RES systems investments.

"Tunisia: Hillshade map": Hill-shading is a technique used to visualize terrain as shaded relief, illuminating it with a hypothetical light source. This layer covers the region of Tunisia.

"Crete: Hillshade map": The same as above, for the region of Crete.

"**Tunisia: Slope map**": This layer is a slope map for the region of Tunisia, which depicts the ground surface slope in shades of gray (grayscale). The areas with a color closer to white have high slope, while the areas with a color closer to black have low slope.

"Crete: Slope map (binary)": Slope map (binary) is a binary map for the region of Crete. The areas with a ground surface slope less than 70% are presented with white color, while the areas with a ground surface slope higher than 70% are shown in black.

"***Crete: Slope map***": This layer is a slope map for the region of Crete, which depicts the ground surface slope in shades of gray (grayscale). The areas with a color closer to white have high slope, while the areas with a color closer to black have low slope.

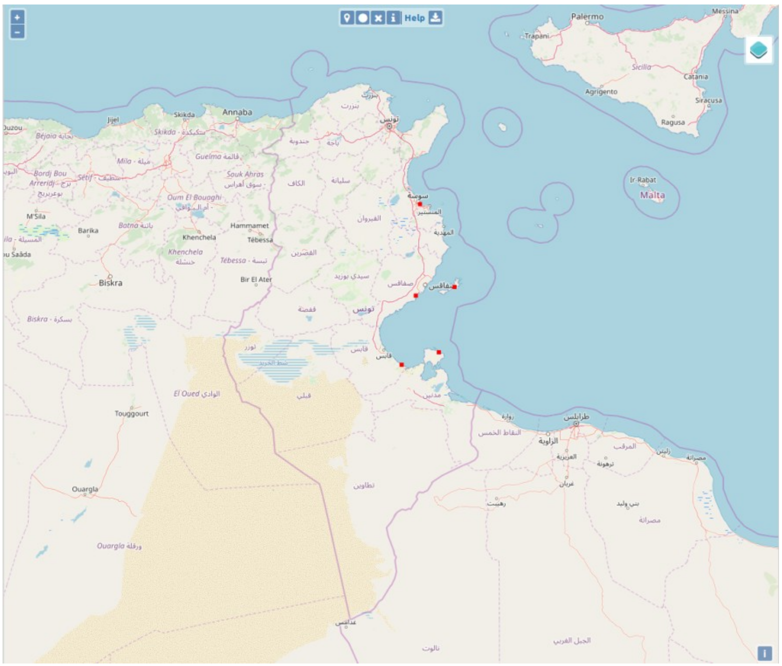


Fig. 35. Tunisia: Desalination plants layer.

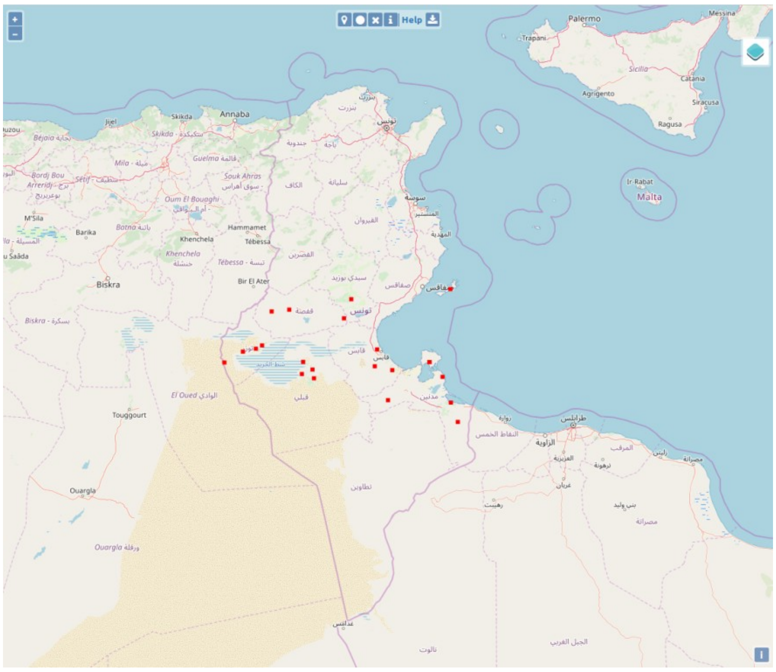


Fig. 36. BRW stations layer.

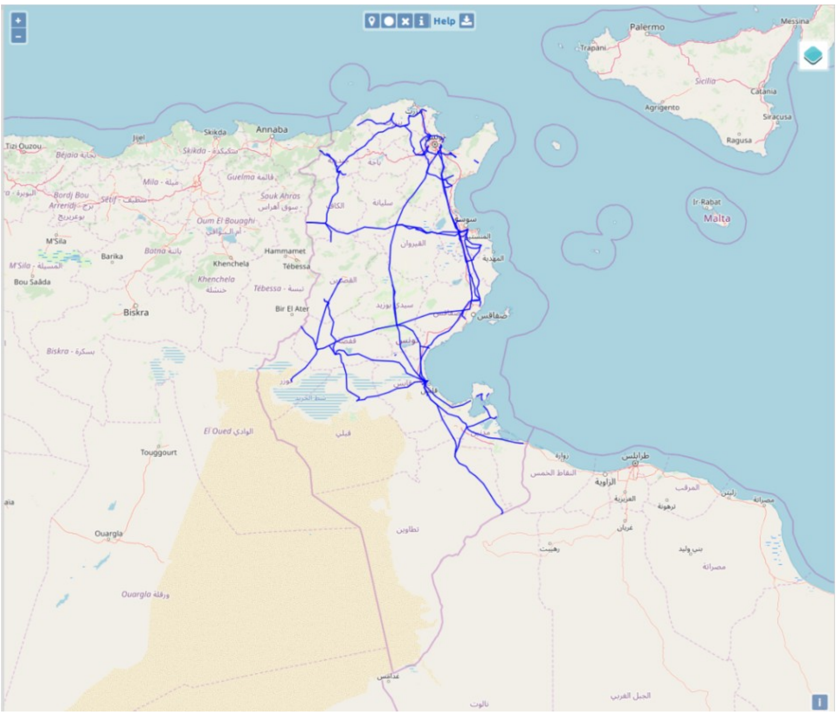


Fig. 37. Tunisia: Electric lines layer.

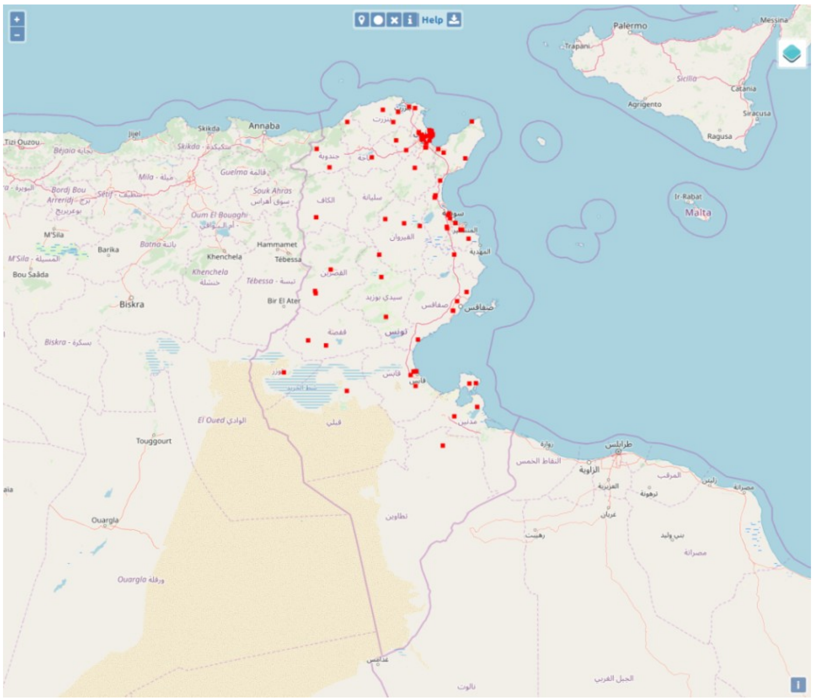


Fig. 38. Tunisia: Substations layer.

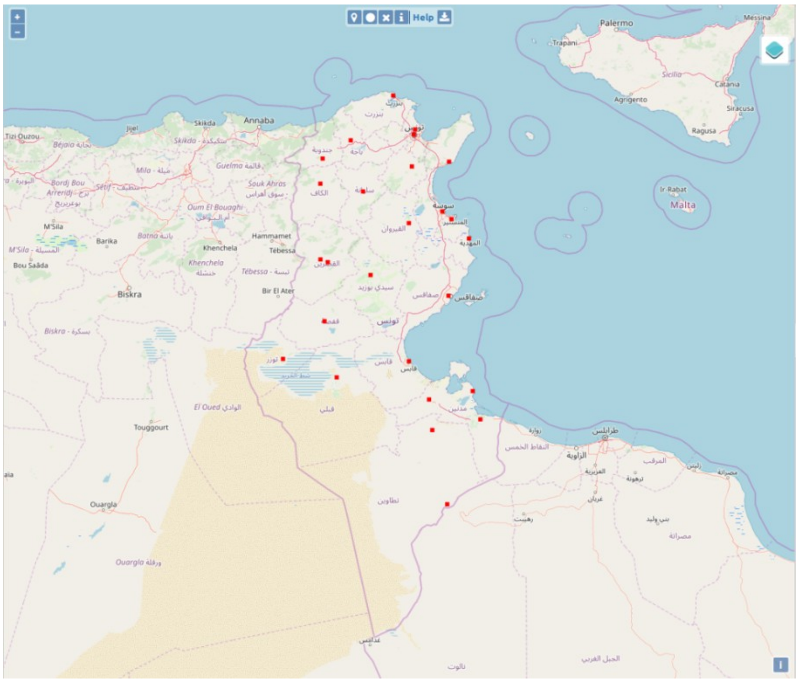


Fig. 39. Tunisia: Towns layer.

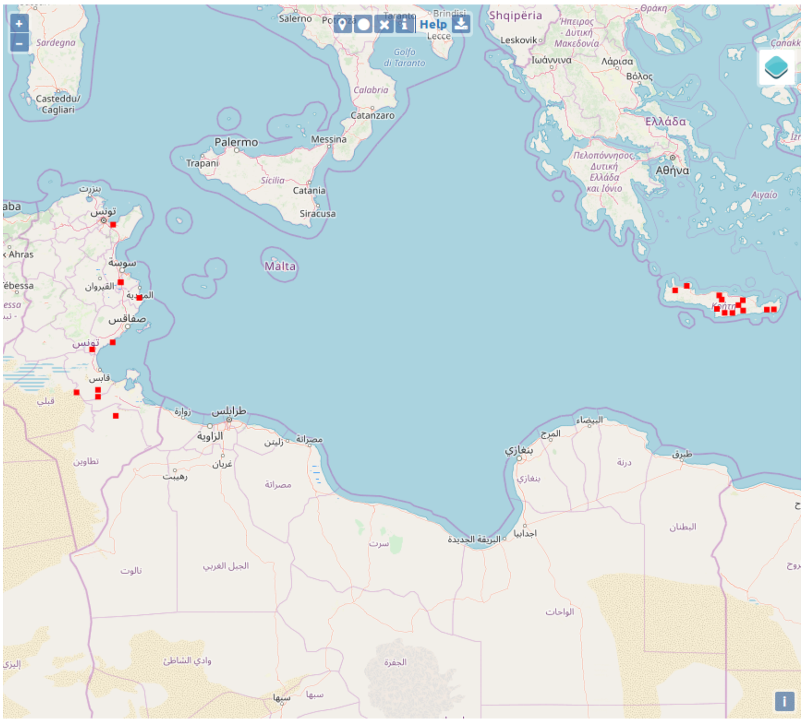


Fig. 40. Meteorological stations layer.

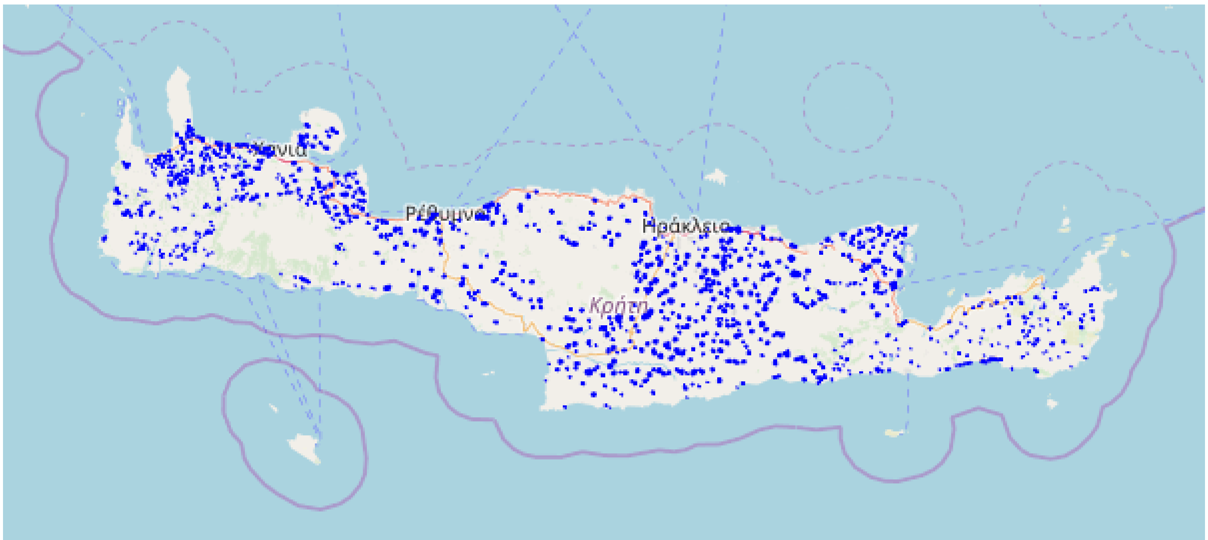


Fig. 41. Crete: Villages layer.

Fig. 42. Crete: Airports layer.

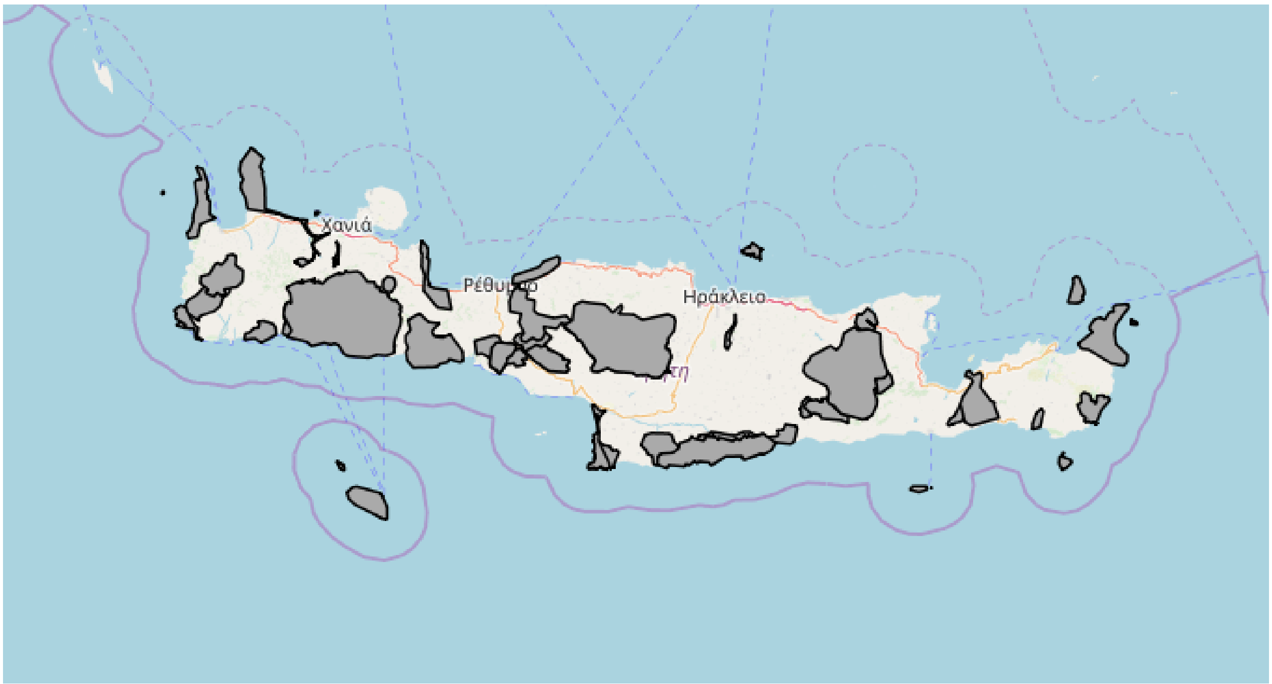


Fig. 43. Crete: Natura 2000 layer.

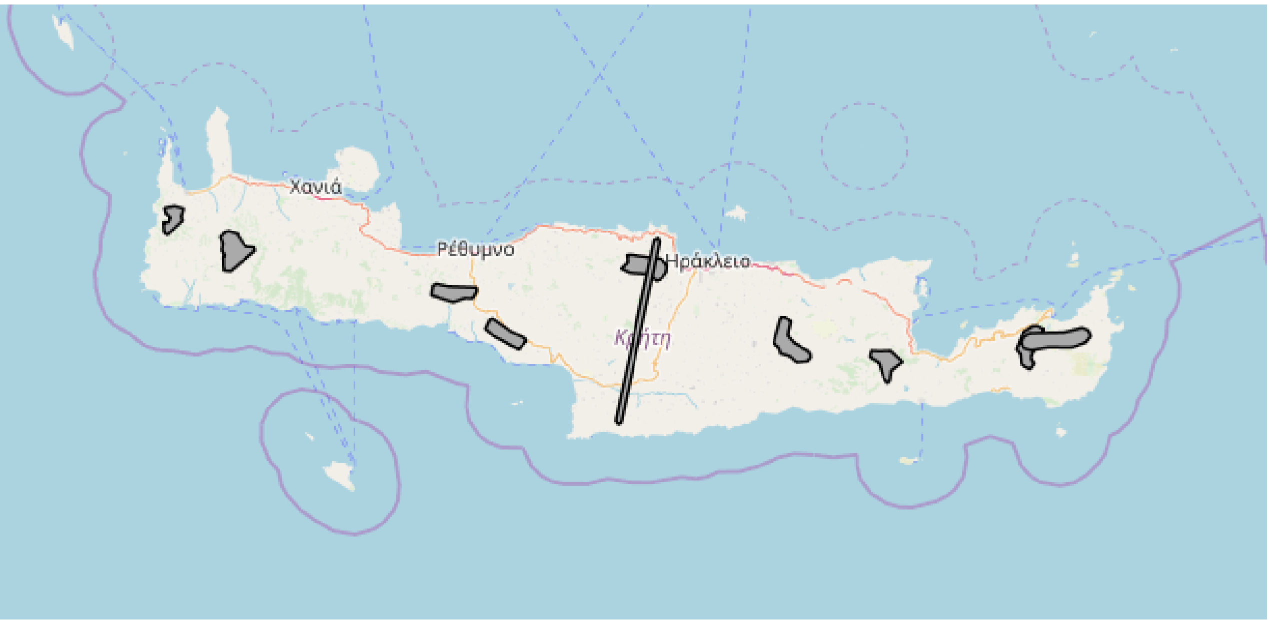


Fig. 44. Crete: Renewable Energy Zones layer.

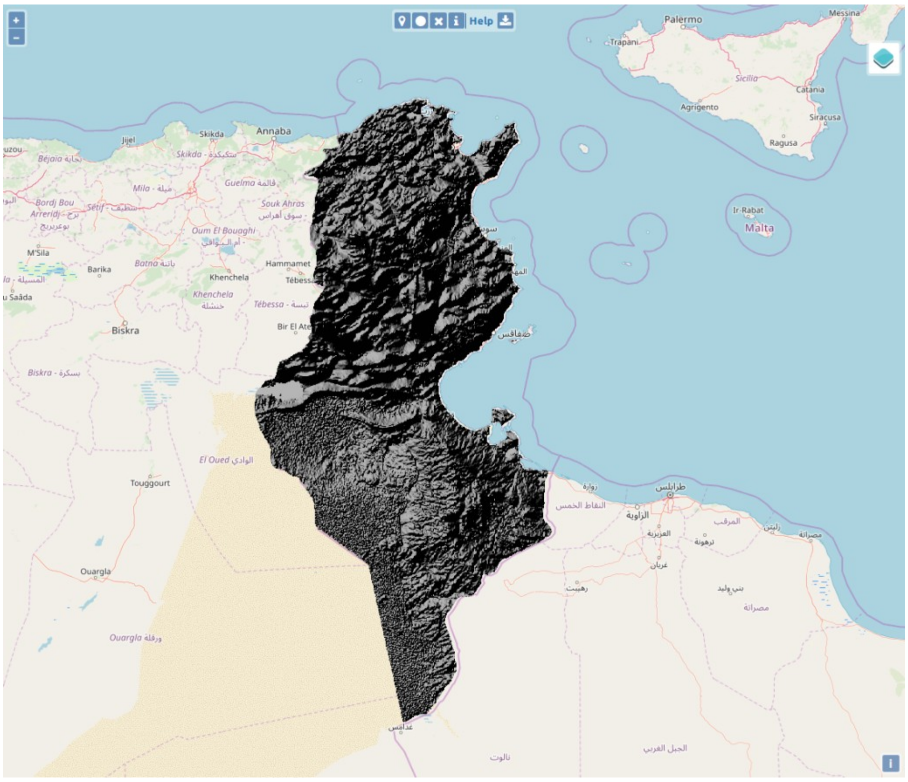


Fig. 45. Tunisia: Hillshade map.

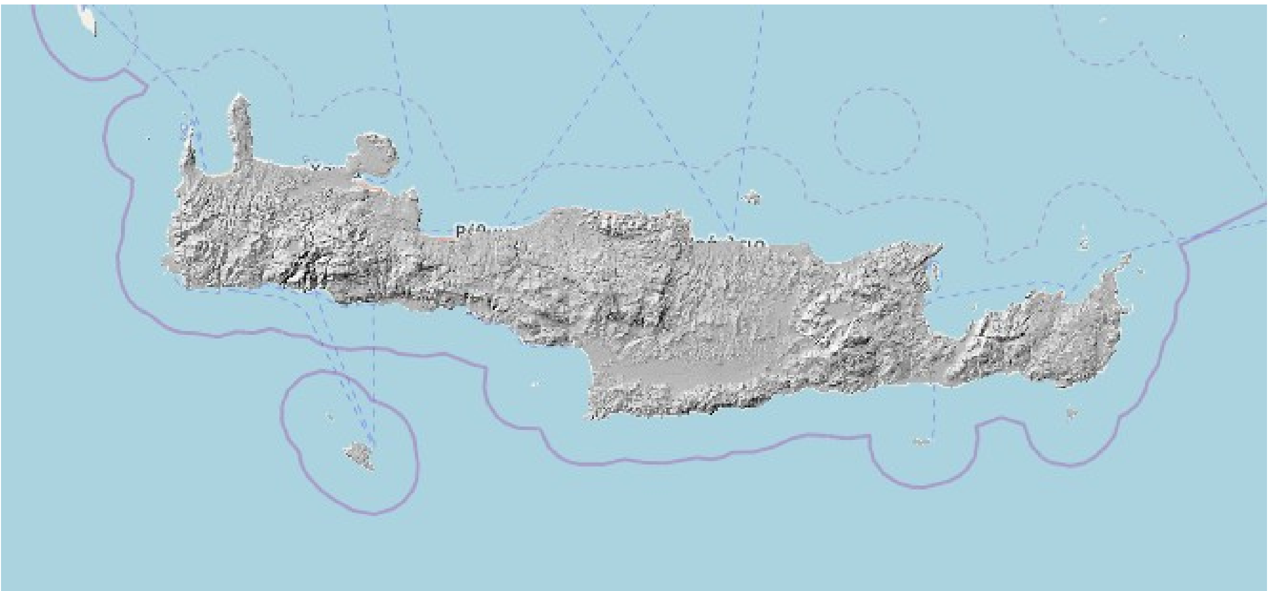


Fig. 46. Crete: Hillshade map.

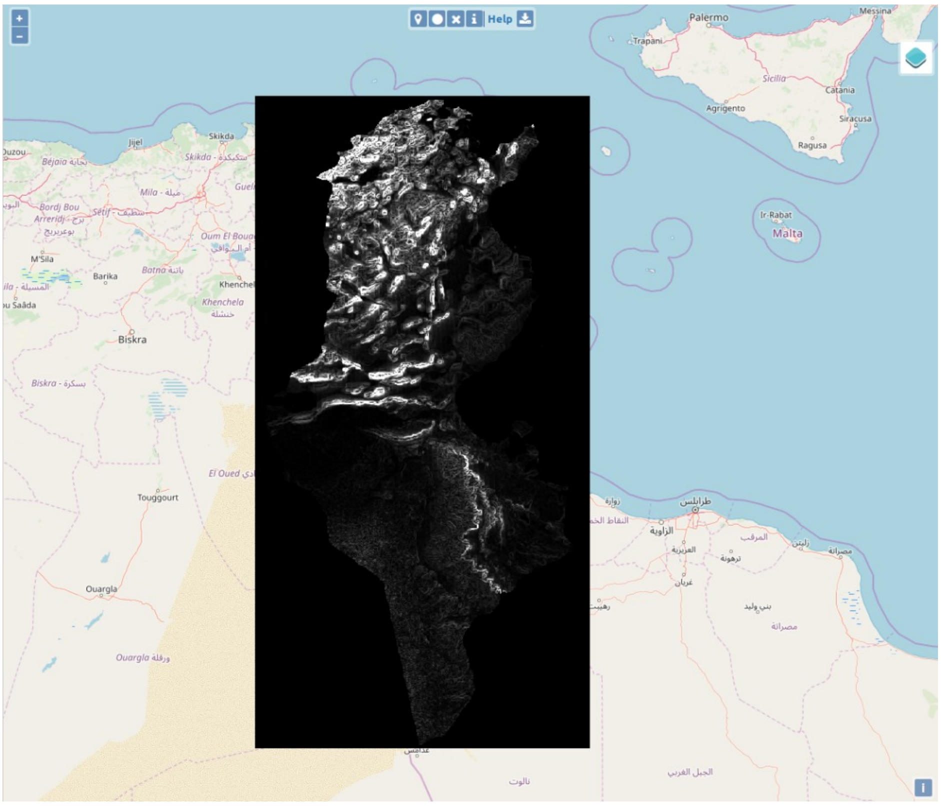


Fig. 47. Tunisia: Slope map.

Fig. 48. Crete: Slope map (binary).

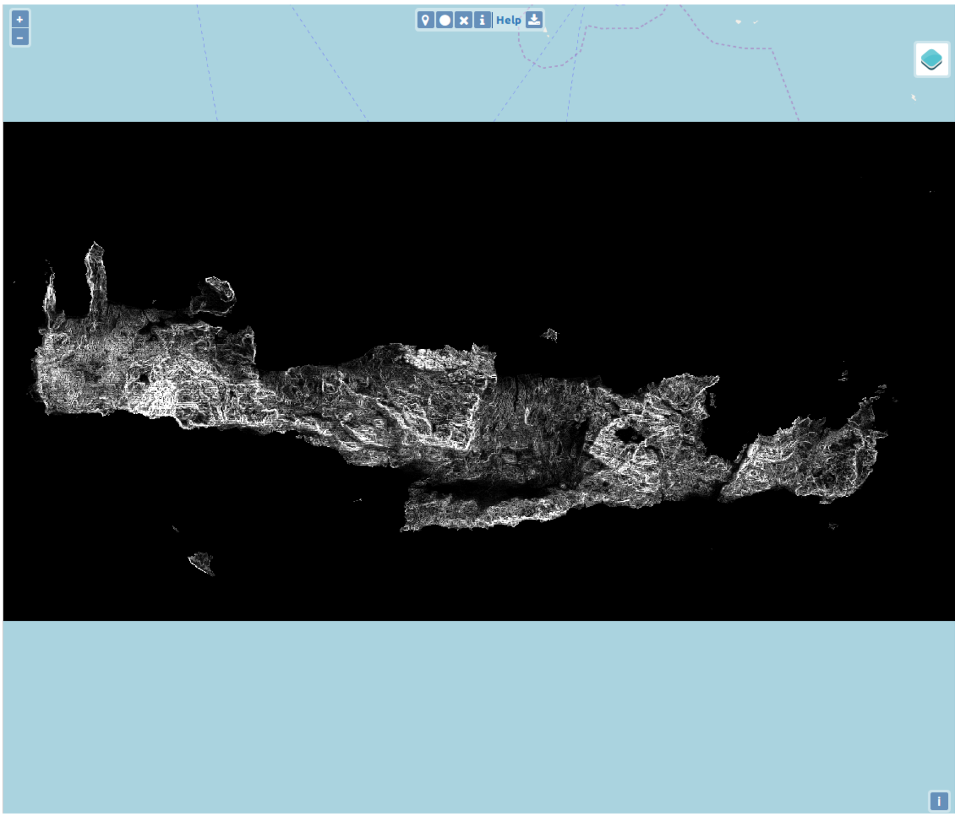


Fig. 49. Crete: Slope map.

7. Final submission of the design query to the DES^{2}iRES platform and output of the design optimization results

After the required values of all parameters have been input by the user in the corresponding fields of the DES^{2}iRES platform interface, the optimal design process of the RES-based desalination plant will be initiated by selecting the "Submit" button (Fig. 50).

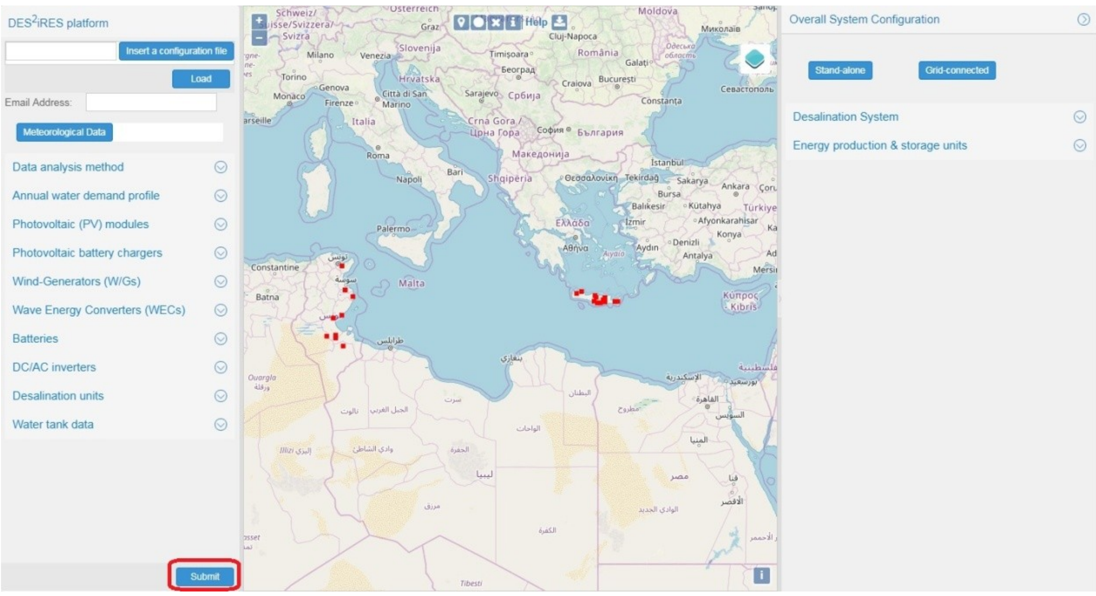


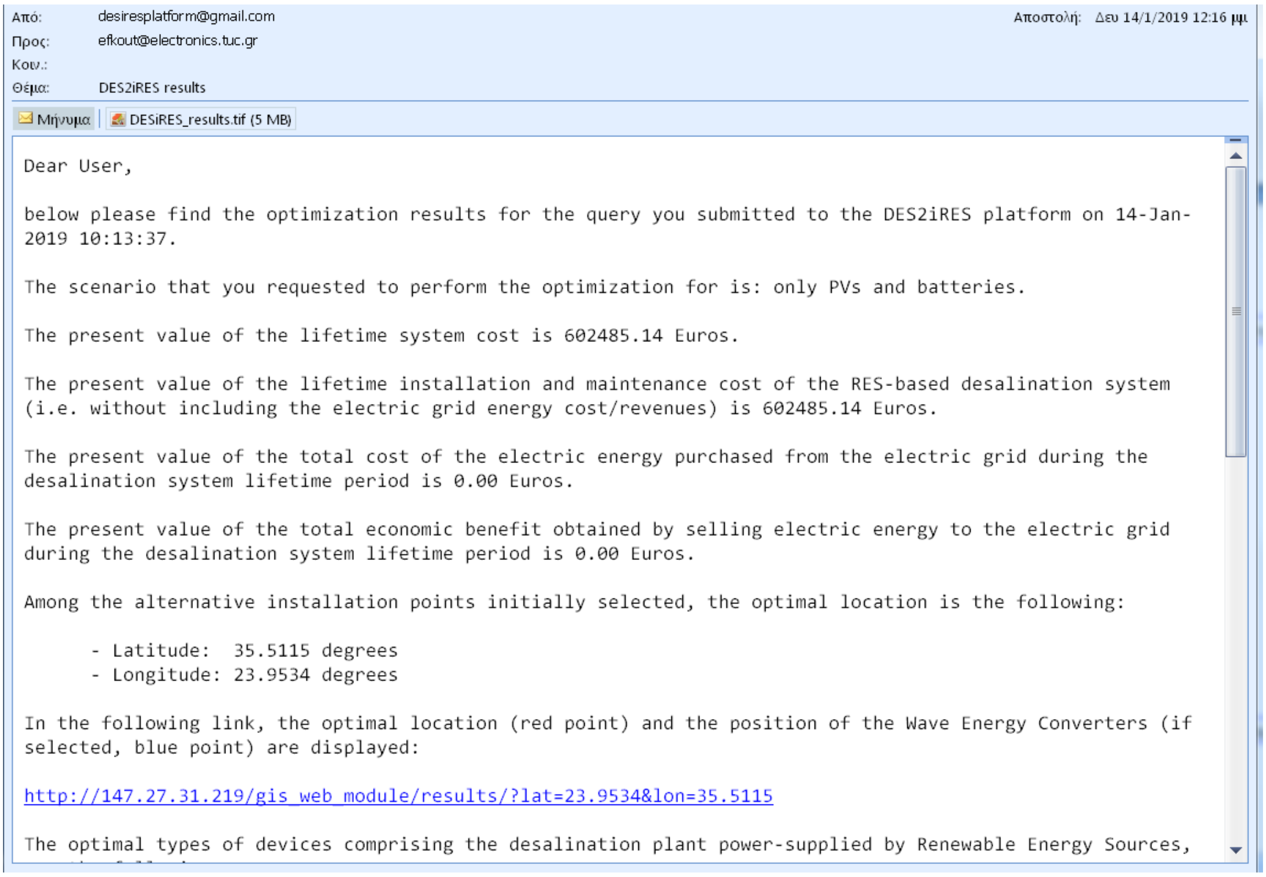
Fig. 50. The button for submitting the design optimization query to the DES^{2}iRES platform.

If the input data of the user have been provided successfully, then the optimization process is executed and the following message is displayed to the user:

"*Your selections are now processed by the DES2iRES platform. The design results will be sent to the email address that you have provided when ready (typically within a few hours, depending on the number of users requests)*", else the optimization process is not executed and the following message is displayed to the user:

"*Your request will not be processed since the required fields have not been filled properly.*"

When the design optimization process is finished, an email is sent to the email address provided by the user in the Web-GIS interface, which contains the design optimization results. An example of such an email is depicted in Fig. 51, while the photo attached in this email is shown in Fig. 52. By the following link included in the email, the optimal location (red point) and the position of the Wave Energy Converters (if selected, blue point) are displayed on a map of the Web-GIS interface.



Από: desiresplatform@gmail.com
Αποστολή: Δευ 14/1/2019 12:16 μμ
Προς: efkout@electronics.tuc.gr
Κοιν.:
Θέμα: DES2iRES results

Μήνυμα | DESiRES_results.tif (5 MB)

Dear User,

below please find the optimization results for the query you submitted to the DES2iRES platform on 14-Jan-2019 10:13:37.

The scenario that you requested to perform the optimization for is: only PVs and batteries.

The present value of the lifetime system cost is 602485.14 Euros.

The present value of the lifetime installation and maintenance cost of the RES-based desalination system (i.e. without including the electric grid energy cost/revenues) is 602485.14 Euros.

The present value of the total cost of the electric energy purchased from the electric grid during the desalination system lifetime period is 0.00 Euros.

The present value of the total economic benefit obtained by selling electric energy to the electric grid during the desalination system lifetime period is 0.00 Euros.

Among the alternative installation points initially selected, the optimal location is the following:

- Latitude: 35.5115 degrees
- Longitude: 23.9534 degrees

In the following link, the optimal location (red point) and the position of the Wave Energy Converters (if selected, blue point) are displayed:

http://147.27.31.219/gis_web_module/results/?lat=23.9534&lon=35.5115

The optimal types of devices comprising the desalination plant power-supplied by Renewable Energy Sources,

Fig. 51. An example of the email sent to the user, containing the design optimization results.

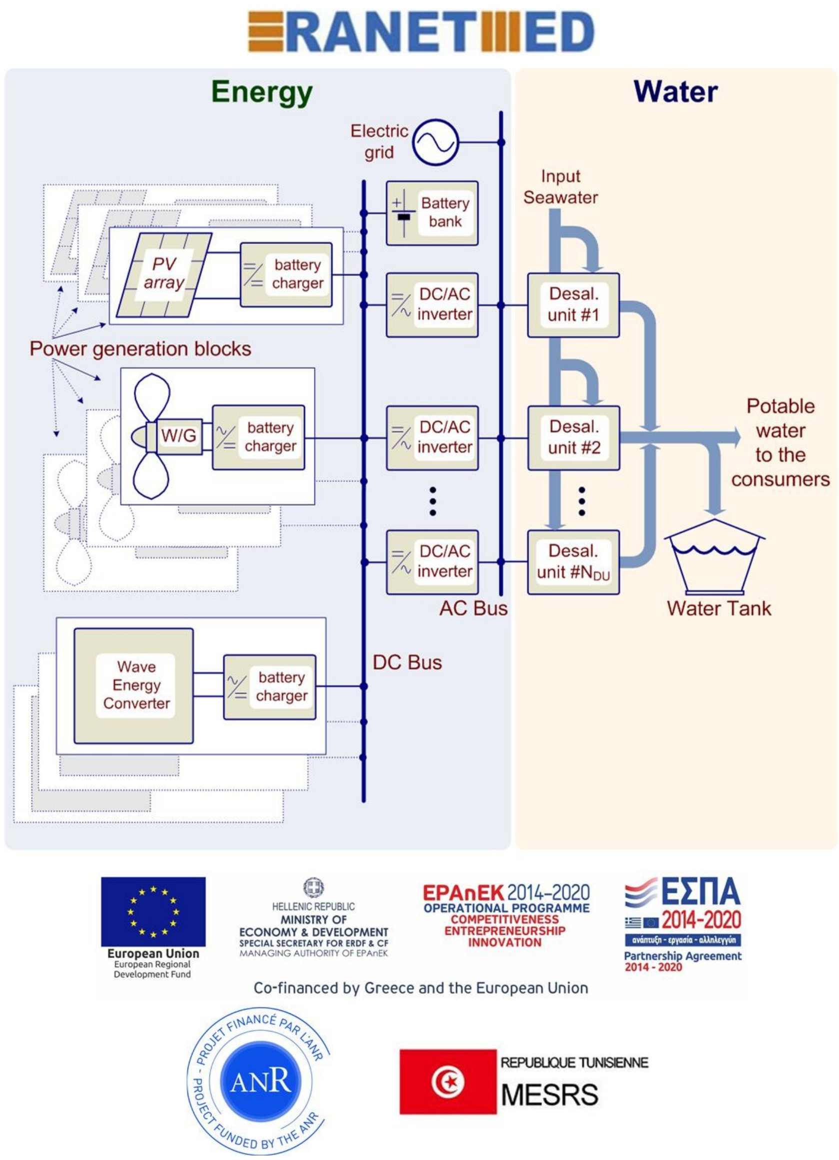


Fig. 52. The photo which is attached on the email with the design optimization results.

8. Adapting to different desalination applications

As mentioned in § 4.9, the value of P_U (defined in § 4.9) includes the power required for pumping seawater to the desalination system installation point and brine disposal back to the sea when the desalination system is installed next to the sea. Also, the value of C_{DU} (defined in § 4.9) includes the total cost of the pipelines (running in parallel) transporting seawater to the desalination system installation point and brine disposal back to the sea (together with the offshore intake water pipeline and the offshore brine outfall pipeline, both having a length of typically in the range of 0.3-2.2 km, depending on the desalination plant type), when the desalination system is installed next to the sea. In case that the desalination plant is not installed next to the sea, the total power required for pumping seawater to the desalination system installation point and brine disposal back to the sea (brine outfall pipeline) and the associated cost, are calculated separately by the optimization algorithm and added to the total lifetime system cost of the RES-based desalination plant.

The cost per Watt of the electric network which transfers the RES-generated energy to the desalination units, c_{enet} (defined in § 3), should be provided by the user considering the following parameters with respect to the configuration of the overall desalination system:

- In case that the RES-based desalination system is connected to the electric grid, then the value of c_{enet} includes the cost of connecting to the energy distribution network. Also, the utilization of the electric grid power lines for the operation of the RES-based desalination system can be compensated by including in the total cost calculation different prices of selling and buying energy to/from the electric grid.
- In case that the RES-based desalination system is not connected to an electric grid, then the value of c_{enet} corresponds to the cost of constructing a power line which transfers electric energy to the desalination units (either a new autonomous power line, or by using a part of an existing electric grid for energy transfer purposes). If the value of c_{enet} varies between the individual installation points selected by the designer through the web-GIS interface, then only installation points with the same value of c_{enet} should be selected (e.g. points having access to an existing nearby electric network), while for installation points with different values of c_{enet}, a new execution of the optimization process through the web-GIS interface should be performed exclusively for these points.

Furthermore, if the value of the cost per liter of connecting the desalination plant water production to the general water distribution network, c_{wnet} (defined in § 3), varies between the individual installation points selected by the designer through the web-GIS interface, then only installation points with the same value of c_{wnet} should be selected (e.g. points having access to an existing nearby water distribution network), while for installation points with different values of c_{wnet}, a new execution of the optimization process through the web-GIS interface should be performed for exclusively these points.

The installation points selected by the user through the web-GIS interface are constrained by geographical, land-use, topographic and environmental criteria specified through the web-GIS platform (i.e. GIS layers) which affect the values of c_{wnet}, c_{enet}, c_c and c_p (defined in § 3) which are input by the designer through the web-GIS interface, as well as the value of the total cost of the pipelines transporting seawater to the desalination system installation point and brine disposal back to the sea, which is calculated by the DES^{2}iRES platform.

In case that the surplus energy produced by the RES-based desalination system is sold to the electric grid, then the results produced by the DES^{2}iRES platform can also assist towards the optimization of the electric energy distribution network. Also, the water distribution network can be optimized by connecting the water production of the desalination system to the desired point of that network, which is reflected in the optimization process of DES^{2}iRES through the value of c_{wnet} that is input by the designer.

In case that the seawater desalination units should be installed next to the sea, while the RES units are installed at another point (e.g. with potentially significant RES potential), i.e. the desalination and RES units are installed at separate locations, then the points specified by the user through the web-GIS interface correspond to the locations of the RES units. In order to denote the installation of the desalination units next to the sea, the user should provide the values (defined in § 3) $c_H = c_E = P_H = P_E = 0$ to the optimization algorithm through the web-GIS interface. The values of c_{enet} and c_{wnet} should be selected as analyzed above.

In case of brackish water desalination, then it is assumed that the RES and desalination units are installed at the points of the brackish water wells. For such a configuration, since water and brine are not pumped and transferred from/to the sea, the user should provide the values $c_H = c_E = P_H = P_E = 0$ to the optimization algorithm through the web-GIS interface. The values of c_{enet} and c_{wnet} should be selected as analyzed above. Also, the parameters P_U and C_{DU} of the desalination units, should also include the power and pipelines installation cost, respectively, for pumping water from these wells.

9. Error messages displayed to the user

9.1. Meteorological data specifications

The user-supplied meteorological data will need to satisfy certain conditions (i.e. 1-3 below), while, in addition, the system will check the data for missing values and outliers and react accordingly (see 4-6 below):

1. Missing values should be marked as "NaN" or by an empty line in the comma separated .txt file (user-supplied data constraint).
2. Minimum variable length should equal 1 calendar year (user-supplied data constraint).

3. The user provided data should have the sizes and labels mentioned in § 4.1-4.7, and in every case the locations file must be imported (user-supplied data constraint).
4. Contiguous missing values for each variable should not extend to more than 2 weeks.
5. Every variable should not exceed the maximum percent of missing values, which is set equal to 5% of the total data.
6. If any variable takes values outside the specified limits (see § 4.3-4.7), then these values will automatically be replaced by "NaN" values by the DES^{2}iRES platform (i.e. outliers).

If any of the above cases is present, then an error message will be send by the platform to the user-provided e-mail address. The possible error messages are described in Table I.

Table I. List of possible error messages in case that the meteorological data .txt files do not conform with the required formats.

No.	Error message
1	Station: Latitude: x, Longitude: y, Error: Locations file does not have appropriate size and/or labels
2	Station: Latitude: -, Longitude: -, Error: Locations not imported
3	Station: Latitude: x, Longitude: y, Error: Short time series. The data period should be longer than a calendar year
4	Station: Latitude: x, Longitude: y, Error: Ending date should not be prior to the starting date
5	Station: Latitude: x, Longitude: y, Error: Date and time not provided
6	Station: Latitude: x, Longitude: y, Error: Wrong size of the date-time file
7	Station: Latitude: x, Longitude: y, Error: Not enough "*VariableName"* data - missing values higher than 5%. Missing equal to *"Missing%"*
8	Station: Latitude: x, Longitude: y, Error: A lot of consequent empty *"VariableName"* values
9	Station: Latitude: x, Longitude: y, Error: Different size of *"VariableName"* data and date-time
10	Station: Latitude: x, Longitude: y, Error: *"VariableName"* does not exist

In Table I, "x" and "y" are the latitude and longitude, respectively, for the particular station, "VariableName" is the name of the variable (e.g. temperature) that has the error, and "Missing%" is the percent (value) of the missing values that the imported data occupy.

9.2. Device types

An error message is sent to the user via email if the devices selected by the user have the following operational characteristics:

- The nominal operating output voltage of the battery charger is not within the operating DC input voltage range of the DC/AC inverter.
- The nominal operating output voltage of the battery charger is not equal with the nominal DC output voltage of the W/G battery charger.
- The nominal operating output voltage of the battery charger is not equal with the nominal DC output voltage of the WEC battery charger.
- The AC output voltage and frequency of the DC/AC inverters is not equal to the AC input voltage and frequency of the desalination units.
- In case of seawater desalination systems: the desalination units selected are not suitable for seawater desalination.
- In case of brackish water desalination systems: the desalination units selected are not suitable for brackish water desalination.
- In case that the MPP voltage (under STC) of the PV modules selected by the designer is higher than the upper limit of the PV battery charger MPP voltage range.
- A DC/AC inverter has been selected which is not suitable for grid-connected systems.
- A DC/AC inverter has been selected which is not suitable for stand-alone (i.e. off-grid) systems.

In case that any of the above conditions is satisfied, then the corresponding error message is sent to the user via email, as described in Table II.

Table II. List of alternative error messages due to incompatibility of device models selected by the user.

No.	Error message
1	PV charger "*model*" output voltage not compatible with the DC input voltage of the DC/AC inverter
2	Wave Energy Converter "*model*" output voltage not compatible with the DC input voltage of the DC/AC inverter
3	Desalination Unit "*model*" operating voltage or frequency not compatible with the output voltage or frequency of the DC/AC inverter

4	Wind-Generator "*model*" output voltage not compatible with the DC input voltage of the DC/AC inverter
5	Desalination unit "*model*" is not suitable for brackish water
6	Desalination unit "*model*" is not suitable for seawater
7	MPP voltage of the PV modules "*model*" not within the MPP voltage range of the PV battery charger
8	DC/AC inverter module "model" is not suitable for grid-connected systems
9	DC/AC inverter module "model" is not suitable for stand-alone systems

Also, in case that the efficiency of the PV battery charger, which is provided by the user, exceeds 100%, then the following error message is sent to the user by email (together with any other error messages): "*The efficiency of the PV battery charger "model" exceeds the maximum allowed limit which is 100%*".

The error messages sent to the user via email in case that the .txt files provided by the user for specifying the operational characteristics of the devices synthesizing RES-based desalination plant, contain negative values (except the temperature coefficient of the PV modules), are presented in Table III.

Table III. List of alternative error messages in case that the .txt files provided by the user for specifying the operational characteristics of the devices synthesizing RES-based desalination plant, do not conform to the required format.

No.	Error message
1	Wrong input device data for the DC/AC inverter
2	Wrong input device data for the PV battery charger
3	Wrong input device data for the Wind-Generator
4	Wrong input device data for the Desalination Unit
5	Wrong input device data for the Photovoltaic Module
6	Wrong input device data for the Battery
7	Wrong input device data for the Wave Energy Converter
8	Wrong input look-up table data for the Wind-Generator
9	Wrong input look-up table data for the Wave Energy Converter

In case of any error message, the optimization process is not executed by the DES^{2}iRES platform and an email containing the error messages described above is sent to the user.

9.3. Parameters input by the user

An error message will be displayed if the desalination system parameters input by the user:

- have negative values,
- the desalination plant lifetime is higher than 40 years or lower than 1,
- the inflation rate or the interest rate (both in %) is higher than 50 %.

In case that any of the above conditions is satisfied, then the optimization process is not executed and the corresponding error message is displayed to the user.

Also:

- If the desalination plant lifetime period input by the user exceeds the maximum permitted limit, then the following error message is displayed: "*The desalination plant lifetime exceeds the maximum allowed limit which is 40 years*".
- If the email field has not been filled, then the following message is displayed to the user: "This field is required".
- In case that an invalid e-mail has been inserted, the following message is displayed: "This field should be an e-mail address in the format *user@example.com*".
- If any field has been filled with a negative number, then the following message is displayed to the user: "This value cannot be negative".
- If the options "Stand-alone" and "Without any RES or battery and only grid connection" are selected, then the optimization process is not performed and the following error message is sent to the user via email: "The selections "stand-alone" and "Without any RES or battery and only grid connection" are not compatible".
- If values are provided at both the "Stand-alone" and "Grid-connection" options, or if any values are not provided at all, then the optimization process is not performed and the following error message is sent to the user via email: "The input parameters for the "Stand-alone" or "Grid-connected" option have not been defined properly".
- If the user has not selected installation points, then the design optimization process is not performed and an error message is sent to the user via email.
- In case of desalination plants comprising WECs, if the user has not selected one point located in the sea and at least one point located on the land, then the design optimization process is not performed and an error message is sent to the user via email.
- If any of the input values provided by the user is not in numerical form, or the desalination plant lifetime value has not been filled, or any required selection regarding the RES-based

desalination system configuration has not been performed in the Web-GIS interface, then the optimization process is not performed and the following error message is sent to the user via email: "The input parameters must be provided in numerical form and all configuration settings must be performed before submitting a query to the DES²iRES platform. Please refer to the DES²iRES user'guide which is available in: http://desires.tuc.gr/desires-web-gis-manual/.".

Appendix – The operational characteristics and cost of the devices contained in the database of the DES²iRES platform

A.1 PV modules

The economic and operational parameters of the PV modules contained in the database of the DES²iRES platform are the following (Table A.1): installation cost (C_{PV}, in €), maintenance cost per year (M_{PV}, in €), open-circuit voltage under Standard Test Conditions (V_{OC} in V), short-circuit current under Standard Test Conditions (I_{SC} in A), Maximum Power Point (MPP) voltage under Standard Test Conditions (V_{max} in V), MPP current under Standard Test Conditions (I_{max} in A), MPP power under Standard Test Conditions (P_{max} in W) , NCOT (in ^oC), open-circuit voltage temperature coefficient (K_V), short-circuit current temperature coefficient (K_I), number of solar cells in series per PV module (n_{cs}), number of solar cell strings in parallel per PV module (n_{cp}).

Table A.1. The operational characteristics and cost of the PV modules contained in the database of the DES²iRES platform.

Name in the DES²iRES platform	C_{PV} (€)	M_{PV} (€)	V_{OC} (V)	I_{SC} (A)	V_{max} (V)	I_{max} (A)	P_{max} (W)	$NCOT$ (^oC)	K_V ($\frac{V}{^oC}$)	K_I ($\frac{A}{^oC}$)	n_{cs}	n_{cp}
PV-01	67	0.67	21.6	3.24	17.44	2.88	50	43	-0.0032	0.0005	36	1
PV-02	166	1.66	38.9	8.85	30.2	8.45	255	44	-0.0031	0.00049	60	1
PV-03	328	3.28	37.8	8.89	31.2	8.18	255	45.7	-0.0035	0.00056	60	1
PV-04	154	1.54	38.3	9.09	31	8.39	260	45	-0.0036	0.0006	60	1
PV-05	98.4	0.98	36.45	8.59	29.86	8.1	240	46	-0.0032	0.00059	60	1
PV-06	120	1.2	46.3	9.39	37.6	8.91	335	44	-0.0032	0.0005	72	1
PV-07	98	0.98	87.2	1.75	69.4	1.59	110	45	-0.0029	0.0004	216	1

A.2 PV battery chargers

The economic and operational parameters of the PV battery chargers contained in the database of the DES²iRES platform are the following (Table A.2): installation cost (C_{CH} in €), maintenance cost per year (M_{CH} in €), charger power conversion efficiency (n_1), efficiency of the Maximum Power Point Tracking (MPPT) process (n_2), nominal power rating of the charger (P_{CH} in W), Mean Time Between Failures (in *hours*), nominal output voltage of the battery charger which is also equal to the nominal DC-bus voltage (V_{BUS} in V), minimum MPP voltage of the PV array that the charger can operate with ($V_{MPP,MIN}$ in V), maximum MPP voltage of the PV array that the charger can operate with ($V_{MPP,MAX}$ in V).

Table A.2. The operational characteristics and cost of the PV battery chargers contained in the database of the DES^{2}iRES platform.

Name in the DES^{2}iRES platform	C_{CH} (€)	M_{CH} (€)	n_1 (%)	n_2 (%)	P_{CH} (W)	$MTBF$ (hours)	V_{BUS} (V)	$V_{MPP,MIN}$ (V)	$V_{MPP,MAX}$ (V)
CHG-01 (12V)	305	3.05	98	99.9	700	40000	12	13	80
CHG-02 (24V)	308.9	3.08	98	99.9	1440	40000	24	25	80
CHG-03 (12V)	735.24	7.35	97.5	99.9	1000	40000	12	24	143.5
CHG-04 (48V)	735.24	7.35	97.5	99.9	4000	40000	48	60	143.5
CHG-05 (12V)	265.16	2.65	98	99.9	360	40000	12	15	66

A.3 Wind-Generators with integrated battery chargers

The economic and operational parameters of the Wind-Generators with integrated battery chargers contained in the database of the DES^{2}iRES platform are the following (Table A.3): installation cost (C_{WG} in €), maintenance cost per year (M_{WG} in €), installation cost of the W/G tower per meter height (C_h in €/m), maintenance cost of the W/G tower per meter height and per year (M_h in €/m/year), nominal output power at the W/G battery charger output (P_{WG} in W) and nominal DC output voltage of the W/G battery charger ($V_{o,WG}$ in V).

Table A.3. The operational characteristics and cost of the Wind-Generators with integrated battery chargers contained in the database of the DES^{2}iRES platform.

Name in the DES^{2}iRES platform	C_{WG} (€)	M_{WG} (€)	C_h (€/m)	M_h (€/m)	P_{WG} (W)	$V_{o,WG}$ (V)
WG-01 (12V)	3460	34.6	70	0.7	650	12
WG-02 (48V)	4287.73	42.87	70	0.7	1500	48
WG-03 (24V)	2336.44	23.36	60	0.6	1050	24
WG-04 (12V)	528.18	5.28	25	0.2	600	12
WG-05 (12V)	1193	11.93	15	0.1	483	12

The output power vs. wind-speed characteristics of the Wind-Generators are shown in Tables A.4-A.8. The output power shown in these Tables corresponds to the DC power injected into the DC-bus (i.e. output of the battery charger).

Table A.4. Output power vs. wind-speed of the Wind-Generator WG-01 (12V).

Wind speed (m/sec)	Output Power (W)
2	5
3	15
4	80
5	105
6	190
7	250
8	350
9	430
10	500
11	550
12	600
13	630
14	650
15	630
16	610
17	615
18	620
19	630
20	640

Table A.5. *Output power vs. wind-speed of the Wind-Generator* WG-02 (48V).

Wind speed (m/sec)	Output Power (W)
2	90
3	175
4	250
5	400
6	550
7	700
8	850
9	1000
10	1100
11	1220
12	1400
13	1480
14	1500
15	1430
16	1390
17	1400

18	1420
19	1430
20	1450

Table A.6. Output power vs. wind-speed of the Wind-Generator WG-03 (24V).

Wind speed (m/sec)	Output Power (W)
2	50
3	150
4	250
5	500
6	600
7	720
8	780
9	820
10	860
11	890
12	920
13	950
14	1000
15	1050
16	1000

Table A.7. Output power vs. wind-speed of the Wind-Generator WG-04 (12V).

Wind speed (m/sec)	Output Power (W)
4	25
5	50
6	100
7	130
8	150
9	280
10	350
11	420
12	500
13	550
14	600

Table A.8. Output power vs. wind-speed of the Wind-Generator WG-05 (12V).

Wind speed (m/sec)	Output Power (W)
3	15
4	40
5	50
6	60
7	100
8	150

9	210
10	250
11	290
12	380
13	483

A.4 Wave Energy Converters with integrated battery chargers

The economic and operational parameters of the Wave Energy Converters with integrated battery chargers contained in the database of the DES^{2}iRES platform are the following (Table A.9): installation cost (C_{WEC} in €), maintenance cost per year (M_{WEC} in €) and nominal DC output voltage of the WEC battery charger ($V_{o,WEC}$ in V).

Table A.9. The operational characteristics and cost of the Wave Energy Converters with integrated battery chargers contained in the database of the DES^{2}iRES platform.

Name in the DES^{2}iRES platform	C_{WEC} (€)	M_{WEC} (€)	$V_{o,WEC}$ (V)
WEC-01 (24V)	4700000	352500	24
WEC-02 (12V)	2437500	121250	12
WEC-03 (12V)	813000	4000	12
WEC-4 (48V)	25000000	115000	48

The output power vs. wave height and vs. wave period of each Wave Energy Converter, are shown in Tables A.10-A.13. The output power shown in these Tables corresponds to the DC power injected into the DC-bus (i.e. output of the battery charger).

Table A.10. Output power (in kWatt) vs. wave height and period of WEC-01 (24V).

		Wave period (in seconds)												
		4	5	6	7	8	9	10	11	12	13	14	15	16
Wave height (in meters)	1	180	166	153	171	125	87	72	65	85	85	37	29	16
	1.5	223	192	157	148	261	192	223	139	155	155	74	67	46
	2	0	0	214	227	396	335	237	235	172	138	115	105	70
	2.5	0	0	0	440	598	514	379	342	204	169	142	128	95
	3	0	0	0	681	801	735	594	486	199	174	151	134	121
	3.5	0	0	0	904	1035	949	788	617	239	209	183	164	146
	4	0	0	0	1131	1269	1163	982	743	285	248	216	192	175
	4.5	0	0	0	1358	1488	1374	1187	869	330	287	250	225	201
	5	0	0	0	1585	1712	1585	1392	988	380	334	285	263	226
	5.5	0	0	0	1812	1937	1798	2138	1107	429	381	323	301	261
	6	0	0	0	2040	2162	2010	2884	1234	439	416	361	336	295
	6.5	0	0	0	2267	2386	2221	3143	1360	449	450	406	372	329
	7	0	0	0	2494	2611	2433	3619	1483	506	464	451	408	363

Table A.11. Output power (in kWatt) vs. wave height and period of WEC-02 (12V).

		Wave period (in seconds)																
		5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
Wave height (in meters)	1	0	22	29	34	37	38	38	37	35	32	29	26	23	21	0	0	0
	1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
	2	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
	2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	115	103	92
	3	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
	3.5	0	270	354	415	438	440	424	404	377	362	326	292	260	230	215	203	180
	4	0	0	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
	4.5	0	0	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
	5	0	0	0	739	726	731	707	687	670	607	557	521	472	417	369	348	328
	5.5	0	0	0	750	750	750	750	750	737	667	658	586	530	496	446	395	355
	6	0	0	0	0	750	750	750	750	750	750	711	633	619	558	512	470	415
	6.5	0	0	0	0	750	750	750	750	750	750	750	743	658	621	579	512	481
	7	0	0	0	0	0	750	750	750	750	750	750	750	750	676	613	584	525
	7.5	0	0	0	0	0	0	750	750	750	750	750	750	750	750	686	622	593
	8	0	0	0	0	0	0	0	750	750	750	750	750	750	750	750	690	625

Table A.12. Output power (in kWatt) vs. wave height and period of WEC-03 (12V).

		Wave period (in seconds)												
		5	6	7	8	9	10	11	12	13	14	15	16	17
Wave height (in meters)	1	0	0	8	11	12	11	10	8	7	0	0	0	0
	1.5	0	13	17	25	27	26	23	19	15	12	12	12	7
	2	0	24	30	44	49	47	41	34	28	23	23	23	12
	2.5	0	37	47	69	77	73	64	54	43	36	36	36	19
	3	0	54	68	99	111	106	92	77	63	51	51	51	27
	3.5	0	0	93	135	152	144	126	105	86	70	70	70	38
	4	0	0	0	122	176	198	188	164	137	112	91	91	49
	4.5	0	0	0	223	250	239	208	173	142	115	115	115	62
	5	0	0	0	250	250	250	250	214	175	142	142	142	77
	5.5	0	0	0	250	250	250	250	250	211	172	172	172	92

Table A.13. Output power (in kWatt) vs. wave height and period of WEC-4 (48V).

		Wave period (in seconds)												
		5	6	7	8	9	10	11	12	13	14	15	16	17
Wave height (in meters)	1	160	250	360	360	360	360	360	360	320	280	250	220	180
	2	640	700	840	900	1190	1190	1190	1190	1070	950	830	710	590
	3	0	1450	1610	1750	2000	2620	2620	2620	2360	2100	1840	1570	1310
	4	0	0	2840	3220	3710	4200	5320	5320	4430	3930	3440	2950	2460
	5	0	0	0	4610	5320	6020	7000	7000	6790	6090	5250	3950	3300
	6	0	0	0	0	6720	7000	7000	7000	7000	7000	6860	5110	4200
	7	0	0	0	0	0	7000	7000	7000	7000	7000	7000	6650	5740

A.5 Batteries

The economic and operational parameters of the batteries contained in the database of the DES²iRES platform are the following (Table A.14): installation cost (C_{BAT} in €), maintenance cost per year (M_{BAT} in €), battery nominal capacity (C_B in Ah), battery nominal operating voltage (V_B in V), maximum Depth of Discharge permitted (*DOD* in %), number of lifetime charging/discharging cycles with the permitted % DOD (N_C).

Table A.14. The operational characteristics and cost of the batteries contained in the database of the DES²iRES platform.

Name in the DES²iRES platform	C_{BAT} (€)	M_{BAT} (€)	C_B (Ah)	V_B (V)	*DoD* (%)	N_C
BAT-01 (12V)	794	7.49	185	12	80	1400
BAT-02 (12V)	712.48	7.12	185	12	60	1200
BAT-03 (12V)	327.25	3.27	135	12	70	1250
BAT-04 (12V)	942.97	9.43	610	12	70	2400
BAT-05 (24V)	4161.72	41.61	180	24	80	3000

A.6 DC/AC inverters

The economic and operational parameters of the DC/AC inverters contained in the database of the DES²iRES platform are the following (Table A.15): installation cost (C_{INV} in €), maintenance cost per year (M_{INV} in €), efficiency of the inverter (n_i), AC power rating of the DC/AC inverter (P_{INV} in W), Mean Time Between Failures (in hours), minimum permissible DC input voltage of the DC/AC inverter ($V_{DC,min}$ in V), maximum permissible DC input voltage of the DC/AC inverter (

$V_{DC,max}$ in V), RMS value of the nominal AC output voltage (V_{AC} in V) and nominal output voltage frequency (f in Hz).

Table A.15. The operational characteristics and cost of the DC/AC inverters contained in the database of the DES^{2}iRES platform.

Name in the DES^{2}iRES platform	C_{INV} (€)	M_{INV} (€)	n_i (%)	P_{INV} (W)	$MTBF$ (hours)	$V_{DC,min}$ (V)	$V_{DC,max}$ (V)	V_{AC} (V)	f (Hz)
INV-01 (12V & Off Grid)	795	79.5	85	1000	40000	10.4	17	230	50
INV-02 (24V & Off Grid)	805	80.5	87	1000	40000	19	34	230	50
INV-03 (24V & Off Grid)	1740	174	83	800	40000	20	32	230	50
INV-04 (48V & Off Grid)	815	81.5	87	1000	40000	41.5	62	230	50
INV-05 (48V & Off Grid)	1478	147.8	90	1200	40000	40	72	230	50
INV-06 (48V & Off Grid)	1275	127.5	90	1800	40000	40.8	67.5	230	50
INV-07 (24V & On Grid)	1364	136.4	94	2200	40000	19	33	230	50
INV-08 (48V & On Grid)	1374	137.4	95	2200	40000	38	66	230	50
INV-09 (48V & On Grid)	3661.5	366.2	92.5	6000	40000	42	60	230	50

A.7 Desalination units

The economic and operational parameters of the desalination units contained in the database of the DES^{2}iRES platform are the following (Table A.15): installation cost (C_{DU} in €), maintenance cost per year (M_{DU} in €), volume of water produced per day (W_u in l/day), power needed during operation (P_U in W), volume of water needed for the flushing process of reverse-osmosis desalination units (W_{FL} in l), power needed for the flushing process of reverse-osmosis desalination units (P_{FL} in W), feed water type ("1" for seawater and "0" brackish water), RMS value of the nominal AC operating input voltage ($V_{D,in}$ in V) and nominal operating input voltage frequency (f in Hz). The value of P_U includes the power required for pumping seawater to the desalination system installation point and brine disposal back to the sea when the desalination system is installed next to the sea. Also, the value of C_{DU} includes the total cost of the pipelines (running in parallel) transporting seawater to the desalination system installation point and brine disposal back to the sea (brine outfall pipeline), when the desalination system is installed next to the sea.

Table A.16. The operational characteristics and cost of the desalination units contained in the database of the DES²iRES platform.

Name in the DES²iRES platform	C_{DU} (€)	M_{DU} (€)	W_u (l / day)	P_U (W)	W_{FL} (l)	P_{FL} (W)	$V_{D,in}$ (V)	f (Hz)
DES-01	51608	5160	18925	5219	132.5	887.2	230	50
DES-02	134800	13480	100000	29900	700	5083	380	50
DES-03	23720	2372	5675	2237	39.7	380.3	230	50
DES-04	7860	786	5760	2185	40	370	230	50
DES-05	6169	616.9	2640	966	18.5	164.2	230	50

Thank you for using the DES^{2}iRES platform!

The DES^{2}iRES team - **desires.tuc.gr**