European Commission

Clean energy for EU islands: Strategic plan for the island of Chios

Greece

Strategic plan for the port of the island of Chios, Greece

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Summary

The present project has been developed for the island of Chios (Greece) in order to evaluate the renewable energy potential on the island with the final goal of assessing the current and future role of desalination for the energy transition of Chios towards a circular economy framework. Therefore, several tasks have been performed.

Two scenarios have been defined, based on the number of desalination plants to be decarbonized:

- Phase I: considering the existing plants RO Linari and RO Dei (close to the airport) which will be provided with energy by on-site solar energy plants and a reduced number of small horizontal axis wind turbines at Merovigli,
- Phase II: considering the existing plants RO Linari, RO Dei and, in addition, the potential plant of RO Kontari (in the vicinity of the airport) which will be provided with energy by on-site solar energy plants and a higher number of small horizontal axis wind turbines at Merovigli

The aforementioned locations and desalination plants are shown in Figure 1

Figure 1: Location of RO Linari, RO Dei, RO Kontari and Merovigli, in the central-west side of Chios.

For the analysis of the wind potential, the terrain of the whole island has been modelled in detail, including elevation, roughness and obstacles to the wind flow. A wind atlas has been created using the software WindPro at different, relevant heights above ground level (AGL). Subsequently, the most significant locations for the exploitation of wind energy have been traced, taking also into account the presence of nature reserves, archaeological areas and the proximity to airports. One configuration of a small-scale wind turbine has been conceived for each of the two scenarios under study. The Vergnet MP-R at 32 m with nominal power of 275 kW has been selected for this specific project, with a configuration including 8 turbines for the scenario “Phase I” and a configuration including 14 turbines for the scenario “Phase II”. This study indicates that these wind turbine configurations could produce 5,481 MWh/year and of electricity for the scenario “Phase I” and 9,286 MWh/year of electricity for the scenario “Phase II” over a project lifespan of 20 years, based on a P50 probability.

For the analysis of the solar potential, an assessment of solar irradiance on the entire island was performed based on the Solar Global Atlas. Subsequently, the average yearly irradiation was estimated and converted to PV output. Solar plants were conceived to fulfill the energy requests of RO Linari, RO Dei and RO Kontari, according to the previously defined scenarios.

For the analysis of the Circular Desalination value chains, calculations were made based on the circular value of desalination brines for a specific case. Consultation with the local stakeholders resulted in the selection of the most desirable secondary raw materials that can be recovered. This part of the study continues also after the project completion.

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Glossary

AGL / ASL Above Ground Level / Above Sea Level

CAPEX Capital Expenditure

Corine Land Cover The Corine Land Cover database is an inventory of land cover in 44 classes. It was initiated in 1985 by the European Union and has been taken over by the EEA. 3E associates roughness information to each class in order to create roughness maps that are used in the wind flow models.

LCOH Levelised Cost of Heat

NPC Net Present Cost

WACC Weighted Average Cost of Capital

WAsP WAsP (Wind Atlas Analysis and Application Program) is a software package that simulates wind flows for predicting wind climates, wind resources, and power productions from wind turbines and wind farms. WAsP is developed and distributed by DTU Wind Energy, Denmark. It has become the wind power industry-standard PC-software for wind resource assessment.

WindPRO WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

Introduction

Chios is a Greek island located situated in the northern Aegean Sea (Figure 2). With an area of about 842.3 km^2, Chios is the fifth largest Greek island. It has a permanent population of approximately 54,030 inhabitants with high peaks in the summer season.

Chios would like to assess the island's renewable energy potential to evaluate how renewable energy could contribute to decarbonizing and powering innovative desalination plants on the island.

The technical assistance from the Islands secretariat (presented in this report) includes the following:

1. Island's renewable energy potential.
   The renewable energy resources of the island have been investigated, with a focus on solar and wind potential. This has led to the development of wind and solar resource maps, necessary to identify strategic areas on the island for renewable energy exploitation.

2. Estimation of the desalination plants energy baseline
   The secretariat has estimated, in a conservative fashion, the required electricity consumption of the different desalination plants under study, taking into account two scenarios:
   - Phase I: considering the existing plants RO Linari and RO Dei
   - Phase II: considering the existing plants RO Linari, RO Dei and the potential plant of RO Kontari

3. Conception of solar and wind plants
   The conception and dimensioning of renewable energy plants, in strategic locations of the island, considering both the local resources, the constraints related to reserved/protected areas and the vicinity to the plants.

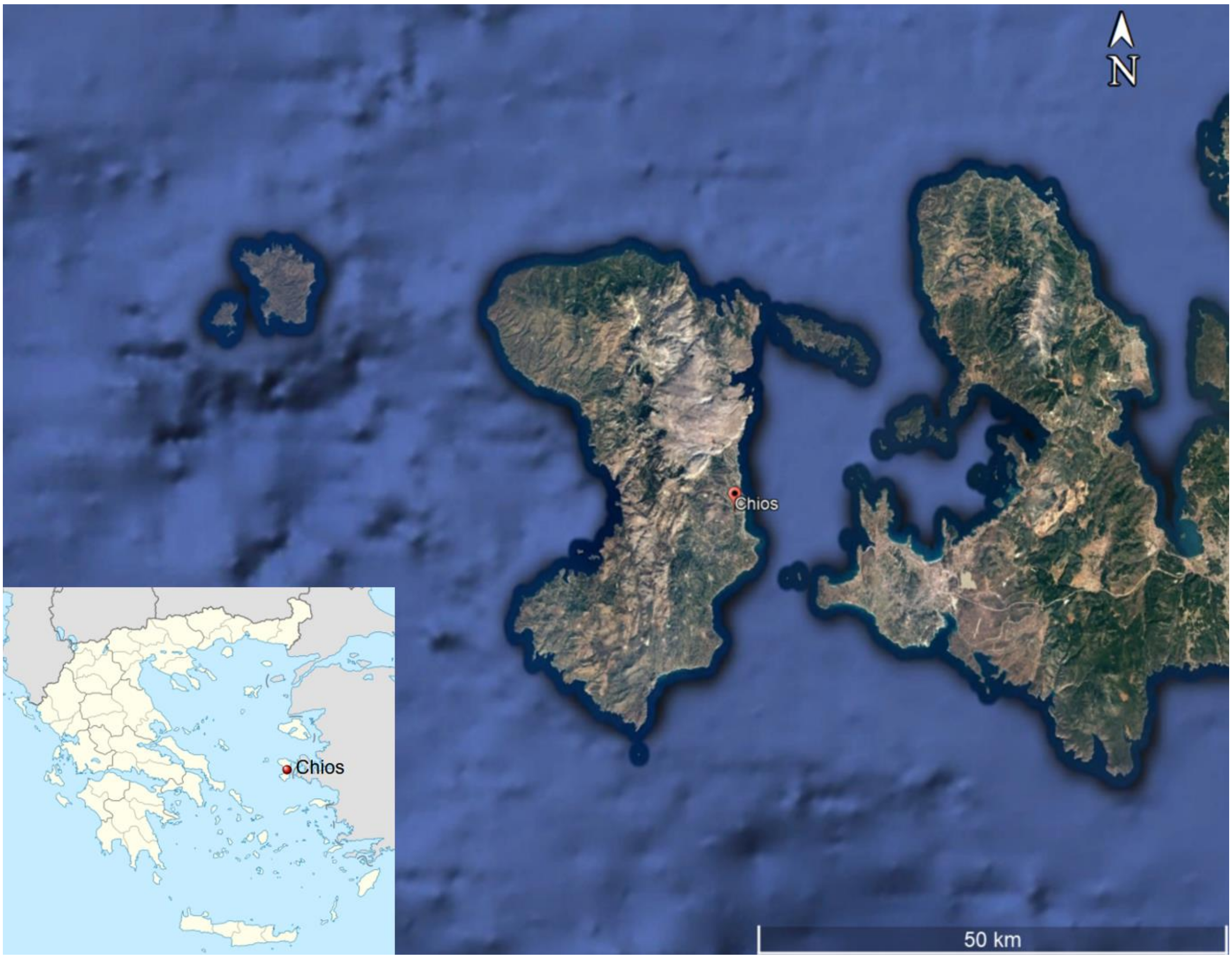


Figure 2: Site location

Task 1 Solar PV assessment

Three different sites were considered for rooftop and/or ground mounted PV installations: Linari, Dei, and Kontari. The details of all three sites are provided in Table 1.

The following subsections present first the solar potential maps for the Chios Island, the equipment recommended for PV installations, followed by the preliminary design (including equipment sizing and electrical configuration).

Table 1: Site geographical details, coordinate system: Geo [deg]-WGS84

Sites	Latitude	Longitude	Altitude (m)
Linari	38.339029	26.142657	3
Dei	38.329908	26.154032	8
Kontari	38.332984	26.148057	0

Solar potential

Methodology

At this preliminary stage of the project, in the absence of onsite measurements, a first assessment of the solar irradiance on Chios was performed by referring to Global Horizontal Irradiance (GHI) and Global Tilted Irradiance (GTI) maps. These maps are obtained from the "Global Solar Atlas 2.0", a free, web-based application developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, using Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). The first index represents the total solar radiation incident on a horizontal surface while the second one represents irradiation that falls on a tilted surface. As opposed to wind, solar irradiance remains quite high and consistent on the entire island, with higher values in the central and southern areas not in the proximity of terrain elevation features (mountains, hills, e.g.). The two indexes are show in Figure 3 and Figure 4.

The average solar irradiance has also been converted into solar PV power output, based on the same source. Also, for the solar PV power output it is possible to observe a trend similar to the one observed for the GHI and GTI, with higher production values located in the central and southern regions of the island (Figure 5).

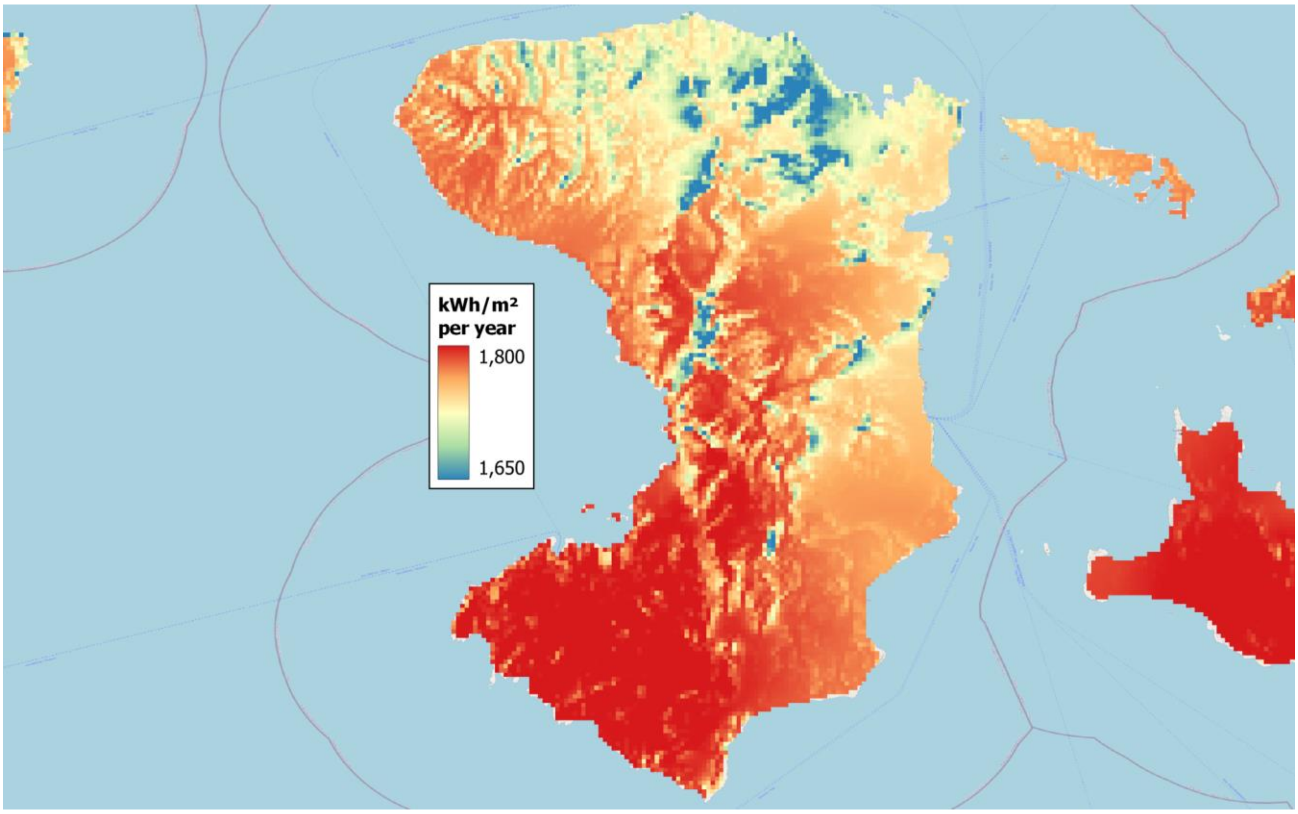


Figure 3: Global Horizontal Irradiance (GHI) map of Chios

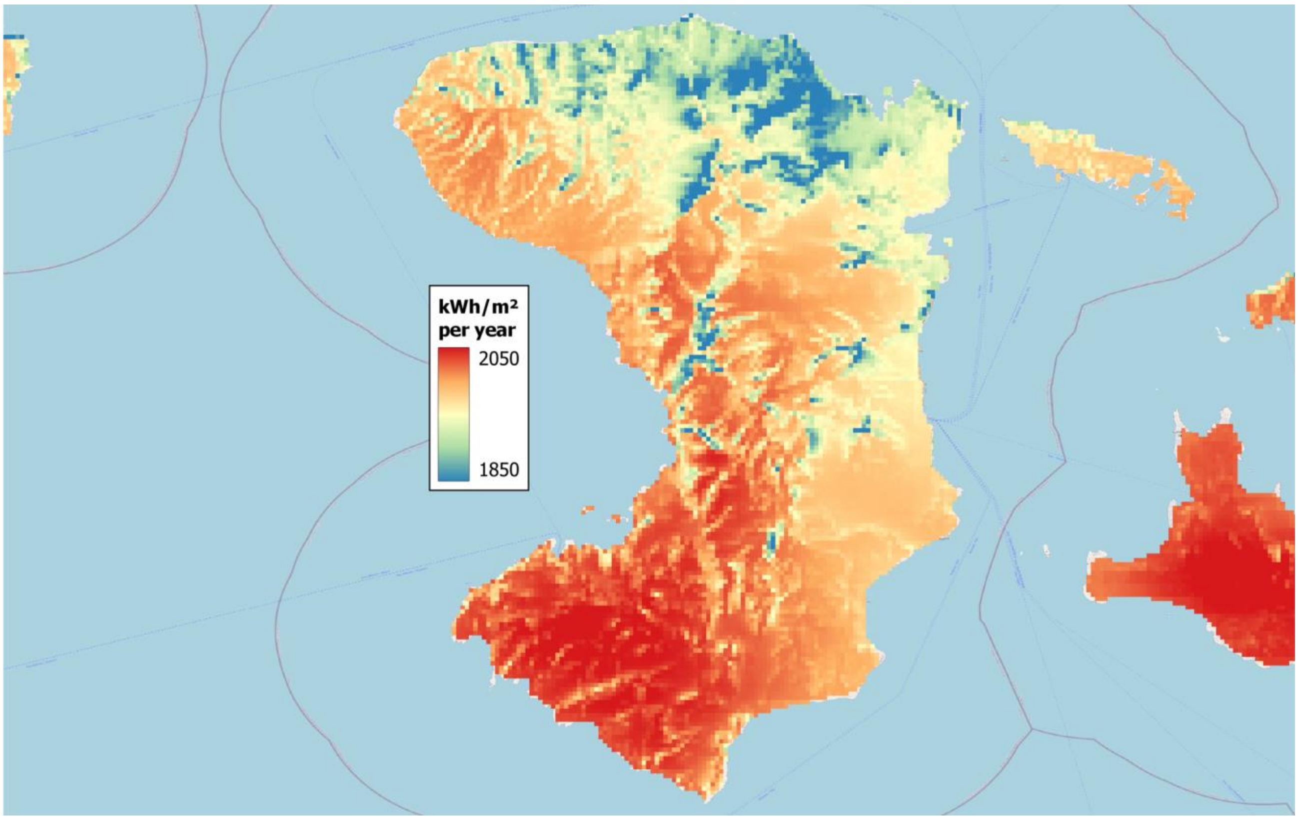


Figure 4: Global Tilted Irradiance (GTI) map of Chios

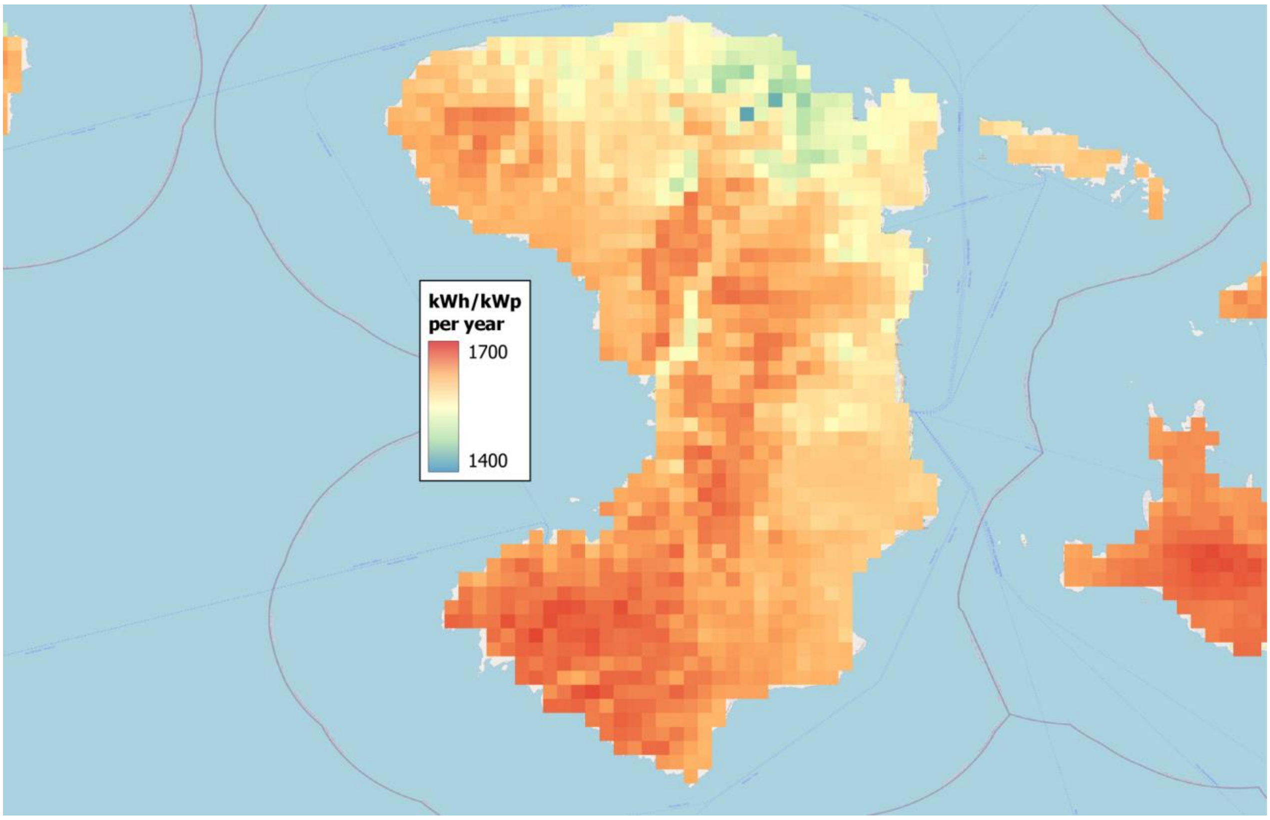


Figure 5: PV output map of Chios

Equipment Overview

PV modules[1]

PV modules can be grouped into three categories: thin film modules, mono crystalline modules, and poly crystalline modules.

Although thin film modules are relatively less expensive, they are manufactured using heavy metals such as Cadmium and Telluride, which therefore may require extra precautions for handling and disposal. In addition, they require more roof space for installation.

Poly crystalline and mono crystalline modules are more widely used in solar PV installations and are made of silicon substrate. While mono crystalline modules are more expensive, they offer a higher efficiency than other types of modules. Hence, mono crystalline modules are recommended for this study.

There are several established mono crystalline module manufacturers. Among these, Trina Solar, with headquarters in China and representations in Europe, offers modules which are

[1] Evaluation of PV modules is supported by a guide published by Arup for rooftop installations: "Five_min_guide_to_solar_Arup.pdf"

specifically designed for small scale residential/industrial installations. The new product Vertex S TSM DE09C.05 – 405W is of a relatively smaller frame size to optimise the use of rooftop space while maximising power output at an efficiency as high as 21.1% and offers a longer product warranty of 25 years. Hence, this module (Trina Solar Vertex S TSM DE09C.05 – 405W) has been selected for the purpose of this study.

Inverters

For small scale industrial and residential solar PV installations, string inverters are typically used in the industry due to their small size. Huawei is an established manufacturer of string inverters, which have been selected for the purpose of the current study. The different inverter sizes selected for each site are shown in Table 2. Detailed information on equipment configuration is provided in the Equipment sizing section.

Table 2: Inverter selection

Sites	Inverter selection	Power rating	Output voltage
Linari	Huawei SUN2000-8KTL-M1 Huawei SUN2000-5KTL-M1	8 kW and 5 kW	400 V_{AC}
Dei	Huawei SUN2000-8KTL-M1 Huawei SUN2000-10KTL-M1	8 kW and 10 kW	400 V_{AC}
Kontari	Huawei SUN2000-100KTL-M1	100 kW	400 V_{AC}

Preliminary Design Configuration

General approach and assumptions

Site dimensions

Site dimensions were obtained/calculated from the drawings provided. Refer to Annex B for more details.

Azimuth

The azimuth angle for each roof section was first estimated qualitatively (South, North, East, West or Northeast etc.) by visual observations of satellite images. This estimate was further refined within the PVsyst simulation software by importing 2-dimensional satellite ground images for each site. Once the PV tables were defined according to the visual azimuth orientation of the ground image, a more accurate azimuth angle was automatically calculated by PVsyst and used in the final simulation.

PV modules inclination/tilt

PV module inclinations were obtained/calculated from the drawings provided. For the ground mounted section of the Dei installation, as well as Kontari, the near optimum tilt of 30° was used as confirmed with the orientation tool in PVsyst.

PV modules quantity

The dimensions of the PV module selected for the study are provided below:

- Length: 175.4 cm

- Width: 109.6 cm.

In the absence of editable AutoCAD drawings for each site, the above PV module dimensions were used to estimate the number of PV modules which can fit within the dimensions (along the length, and along the width) of the available roof and ground sections, assuming an arrangement of PV modules in portrait. The final adjusted estimate accounts for roof edge clearance of at least 10 cm, and PV module spacing of 2 cm.

In the specific case of Kontari, site coordinates were provided with no boundary specifications and site drawings. Therefore, a site boundary was assumed as shown in ANNEX B: Solar PV site dimensions. Then the PVsyst 3D shading tool was used along with the ground image of the site to fit as many modules as possible within the assumed site boundary, while leaving some space (green boundary) for the planned installation of the RO plant. The authors recommend that the assumed site boundary is ascertained at a later stage.

Type of usage
This study assumes an industrial usage of the power produced from the PV system, at low voltage. As such no transformer system has been considered. Furthermore, an inverter output voltage of 400 V_{AC} has been considered as the applicable three-phase voltage in Greece[2].

Inverters quantity
The power rating and the number of inverters for each site was determined in such a way to maximise the AC output of the PV system.

Equipment sizing

Linari
Table 3: Equipment sizing for Linari

Roof sections	Dimensions (m)	Azimuth	Tilt	PV modules quantity	Inverters quantity
1	6.74 x 17.2	0° (~ South)	12.8°	3 x 14 = 42	2 (8 kW)
2	6.74 x 17.2	180° (~ North)	12.8°	3 x 14 = 42	2 (8 kW)
3	7.50 x 19.59	0° (~ South)	12.8°	2 x 16 = 32	2 (5 kW)
			Total	**116**	**6**
			DC power	**46.98 kWp**	
			AC power		**42 kW_{AC}**

Dei
Table 4: Equipment sizing for Dei

Roof/ground sections	Dimensions (m)	Azimuth	Tilt	PV modules quantity	Inverters quantity
1 (rooftop)	6.74 x 17.2	45° (~ Southwest)	12.8°	3 x 14 = 42	2 (8 kW)

[2] List of Voltages & Frequencies (Hz) Around the World. Available at: https://www.generatorsource.com/Voltages_and_Hz_by_Country.aspx .

Roof/ground sections	Dimensions (m)	Azimuth	Tilt	PV modules quantity	Inverters quantity
2 (rooftop)	6.74 x 17.2	-135° (~ Northeast)	12.8°	3 x 14 = 42	2 (8 kW)
3 (ground)	5 x (7.04 x 17.20)	0° (South)	30°	4 x (2 x 15) = 120	4 (10 kW)
			Total	**204**	**8**
			DC power	**82.62 kWp**	
			AC power		**72 kW_{AC}**

Kontari

Table 5: Equipment sizing for Kontari

Ground sections	Dimensions (m)	Azimuth	Tilt	PV modules quantity	Inverters quantity
1		0° (South)	30°	3600	12 (100 kW)
Total				**3 600**	**12**
DC power				**1 458 kWp**	
AC power					**1 200 kW_{AC}**

Electrical configuration

Table 6: Electrical configuration for all four sites

Sites	Electrical configuration[3]
Linari	2 INV X 1 STR X 21 MOD (South)
	2 INV X 1 STR X 21 MOD (North)
	2 INV X 1 STR X 16 MOD (South)
Dei	2 INV X 1 STR X 21 MOD (Southwest)
	2 INV X 1 STR X 21 MOD (Northeast)
	4 INV X 2 STR X 15 MOD (South)
Kontari	12 INV X 20 STR X 15 MOD

Yield Assessment

Meteorological data

The authors considered different meteorological data sources for calculating the yield of the PV installations presented in this study. These sources are listed in Table 7, which provides a comparison of horizontal irradiation results.

Table 7: Global irradiation on the horizontal plane (kWh/m²/yr)

Source	Number of years	Linari	Dei	Kontari
Meteonorm	20	1 789	1,791	1,790
Soda-HelioClim	17	1,823	1,808	1,823

[3] INV: Inverters; STR: Strings in parallel per inverter; MOD: Modules in series per string.

3E Solar Data	17	1,795	1,795	1,795
PVGIS-SARAH2	16	1,832	1,843	1,832
SolarGIS	26	1,753	1,755	1,753

The horizontal irradiation source was used to calculate the yield before combining the results by using a statistical weighting function. This function considers the specific characteristics of the data, such as the number of years available and the uncertainty of resource quantification according to the authors' own experience. Table 8 shows the weighted horizontal irradiation as well as the in-plane irradiation. These weighted values are given as an indication only, as they are not directly used in the calculations. The transposition factor is obtained from the irradiation data of 3E Solar Data and the Perez transposition model within the PVsyst simulation software. The transposition factor is the ratio of in-plane irradiation to the horizontal irradiation and gives an indication of the effective solar irradiation based on the PV system's orientation and inclination. The ambient temperature used in the simulations is also presented. It comes from the 3E Solar Data database.

Table 8: Weighted irradiation, transposition factor and temperature

Parameter	Linari	Dei	Kontari
Weighted horizontal irradiation (kWh/m²/yr)	1 790	1 790	1 790
Transposition factor (%)	1.4	7.3	13.4
In-plane irradiation (kWh/m²/yr)	1 815	1 921	2 031
Ambient temperature (°C)	18.2	18.2	18.2

The monthly breakdown of meteorological data for each site is presented in Table 9, Table 10, and Table 11.

Table 9: Monthly breakdown of the meteorological data – Linari

Month	Global Horizontal Irradiation – GHI (kWh/m²)	Global In-plane Irradiation – GII (kWh/m²)	Ambient temperature (°C)
January	62	66	10.6
February	76	79	11.8
March	130	133	13.9
April	173	174	15.3
May	219	218	18.6
June	238	236	24.7
July	250	248	25.6
August	222	223	26.0
September	170	174	22.8
October	121	127	18.3
November	74	79	16.7
December	55	58	14.0
Year	**1 790**	**1 815**	**18.2**

Table 10: Monthly breakdown of the meteo data – Dei

Month	Horizontal irradiation (kWh/m²)	In-plane irradiation (kWh/m²)	Ambient temperature (°C)
January	62	82	10.6
February	76	91	11.8
March	130	146	13.9
April	173	181	15.3
May	219	217	18.6
June	238	229	24.7
July	250	243	25.6
August	222	228	26.0
September	170	190	22.8
October	121	148	18.3
November	74	96	16.7
December	55	72	14.0
Year	**1 790**	**1 921**	**18.2**

Table 11: Monthly breakdown of the meteo data – Kontari

Month	Horizontal irradiation (kWh/m²)	In-plane irradiation (kWh/m²)	Ambient temperature (°C)
January	62	97	10.6
February	76	103	11.8
March	130	159	13.9
April	173	188	15.3
May	219	217	18.6
June	238	224	24.7
July	250	241	25.6
August	222	234	26.0
September	170	204	22.8
October	121	167	18.3
November	74	112	16.7
December	55	84	14.0

Year	**1 790**	**2 031**	**18.2**

System modelling

The 3D visual illustrations of the PV systems are presented in Figure 6, Figure 7, and Figure 8. These allow to visualise the roof/ground sections and orientations, and the surrounding obstacles (trees, buildings etc., shown as black structures) which were considered in the modelling of the near shading loss.

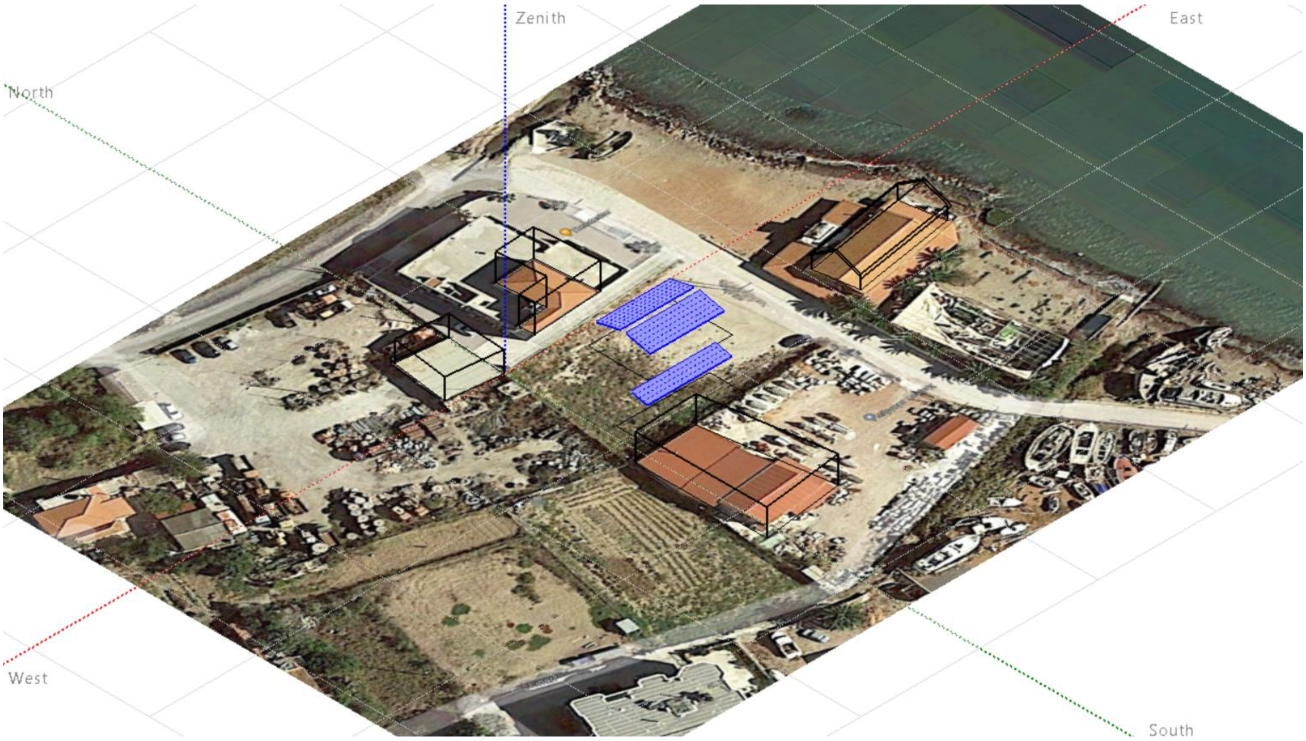


Figure 6: Linari – PVsyst 3D model for near shading losses

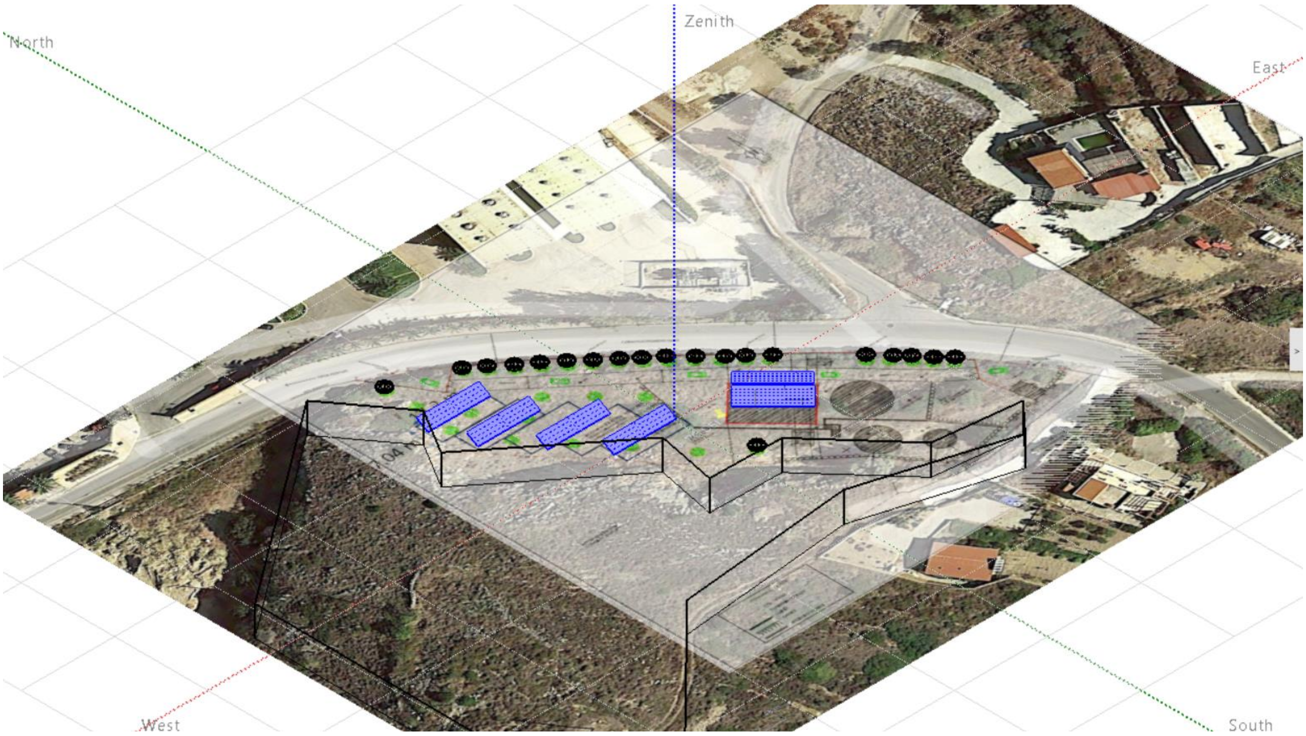


Figure 7: Dei – PVsyst 3D model for near shading losses

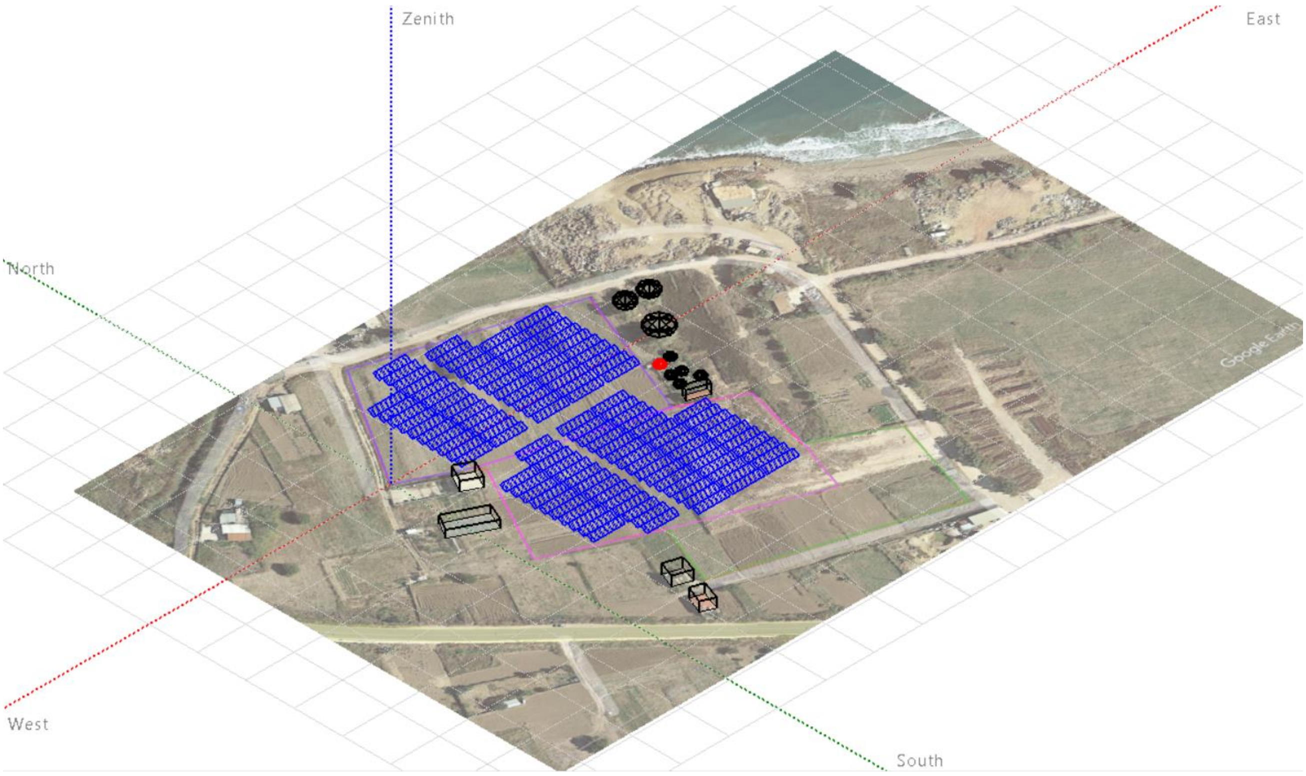


Figure 8: Kontari – PVsyst 3D model for near shading losses

Detailed performance losses

The Performance Ratio (PR) presented in Table 12, is equivalent to the PV system's efficiency and allows to compare the actual performance of the system relative to the maximum theoretical performance. It includes all losses occurring in the PV system, from the solar irradiation hitting the PV module to the final energy output at the point of energy delivery.

Table 12: Initial Performance Ratio breakdown

	Loss/ Gain		
Losses breakdown	**Linari**	**Dei**	**Kontari**
In-plane conversion	**1.4%**	**7.3%**	**13.4%**
Horizon shading	**-0.2%**	**-0.5%**	**-0.9%**
Optical	**-4.7%**	**-9.4%**	**-8.9%**
- Near shading: irr. loss	-0.2%	-4.7%	-4.4%
- Reflection	-2.5%	-2.0%	-1.8%
- Dirt and soiling	-2.0%	-3.0%	-3.0%
- Snow	0.0%	0.0%	0.0%
			0.0%
Module	**-9.0%**	**-8.3%**	**-8.8%**
- Irradiance dependencies	-0.7%	-0.7%	-0.6%
- Temperature dependencies	-6.9%	-4.4%	-4.5%
- Spectral dependencies	0.0%	0.0%	0.0%
- Near shading: acc. to strings	0.0%	-1.9%	-2.5%
- Power tolerance of modules	0.3%	0.3%	0.3%
- Light induced degradation (LID)	-1.3%	-1.3%	-1.3%
- Mismatching	-0.5%	-0.5%	-0.5%
Electrical	**-3.8%**	**-3.8%**	**-3.2%**
- DC cabling	-1.0%	-1.0%	-1.0%
- Inverter	-2.3%	-2.1%	-1.6%
- Auxiliaries	0.0%	0.0%	0.0%
- AC cabling (LV, MV & HV)	-0.5%	-0.8%	-0.6%
- Transformer (MV & HV)	0.0%	0.0%	0.0%
- Curtailment	0.0%	0.0%	0.0%
Total	**-16.7%**	**-20.5%**	**-20.4%**
Performance ratio at project start-up	**83.3%**	**79.5%**	**79.6%**

The Performance Ratio of all sites, approximately 80%, is relatively good.

Monthly yield breakdown

The monthly energy yield figures for all fours sites are presented in Table 13, Table 14, and Table 15.

Table 13: Monthly PR and system yield at year 1 – Linari

Month	Performance ratio (PR) year 1	System yield (P50) year 1 (MWh)	System yield (P90 lifetime) year 1 (MWh)
January	84.6%	2.6	2.5
February	85.3%	3.2	3.0
March	85.0%	5.3	5.0
April	84.2%	6.9	6.5
May	82.8%	8.5	7.9
June	80.6%	8.9	8.4
July	80.2%	9.3	8.7
August	80.3%	8.4	7.9
September	81.7%	6.7	6.3
October	83.4%	5.0	4.6
November	83.5%	3.1	2.9
December	83.6%	2.3	2.1
Year	**82.2%**	**70.2**	**65.7**

Table 14: Monthly PR and system yield at year 1 – Dei

Month	Performance ratio (PR) year 1	System yield (P50) year 1 (MWh)	System yield (P90 lifetime) year 1 (MWh)
January	72.8%	4.9	4.6
February	77.5%	5.8	5.4
March	80.3%	9.7	9.0
April	81.7%	12.2	11.3
May	81.7%	14.6	13.6
June	80.0%	15.1	14.0
July	79.5%	16.0	14.8
August	78.8%	14.8	13.8
September	78.2%	12.2	11.4
October	76.5%	9.3	8.7
November	73.8%	5.9	5.5
December	71.7%	4.3	4.0
Year	**78.5%**	**124.9**	**116.1**

Table 15: Monthly PR and system yield at year 1 – Kontari

Month	Performance ratio (PR) year 1	System yield (P50) year 1 (MWh)	System yield (P90 lifetime) year 1 (MWh)
January	66.4%	93.6	87.1
February	73.4%	110.1	102.4
March	83.3%	193.3	179.8
April	84.2%	231.0	214.9
May	83.1%	262.9	244.6
June	81.1%	265.4	246.9
July	80.9%	283.8	264.1
August	81.1%	276.8	257.5

September	82.0%	244.4	227.4
October	75.4%	183.5	170.7
November	67.9%	111.2	103.4
December	65.4%	80.3	74.8
Year	**78.6%**	**2 336.2**	**2 173.8**

Based on the P50 year-1 annual yields and the system DC capacities, the specific yields can be estimated as 1 494 kWh/kWp, 1 512 kWh/kWp and 1 602 kWh/kWp for Linari, Dei and Kontari respectively. These figures fall in the middle of the range, according to the World Bank's estimates of solar PV power potential for countries globally[4], which shows that with the proposed installations, the solar PV potential of the sites is relatively good.

Uncertainties affecting yield estimates

The expected yield is affected by several uncertainties of different types. The uncertainty due to the climate variability is stochastic and its effect is levelled out when calculating long-term averages. Most other uncertainties, e.g. those related to the modelling, the site or the system, are systematic and their effect is not levelled out when calculating long-term averages. Stochastic uncertainties vary year by year whereas systematic uncertainties are constant assuming a system properly working as per design.

The uncertainties affecting the yield estimates are summarised in Table 16. All uncertainty values are standard deviations and apply to well-functioning systems. Negative outliers in performance due to bad installation, low-quality components or extreme local conditions (e.g. heavy soiling or unidentified shading) are not taken into account in these uncertainties. The uncertainty values have been determined by 3E based on an extensive literature study and own calculations.

Table 16: Uncertainties considered for the calculation of the probabilities (P90)

			Values	
Uncertainty	**Variable**	**Linari**	**Dei**	**Kontari**
Due to the yearly variation	Climate variability	1.4%	1.4%	1.4%
Affecting the resource estimation	Resource quantification	3.5%	3.5%	3.5%
	In-plane conversion	2.0%	2.0%	2.0%
Affecting the system performance	Optical	1.4%	3.0%	2.9%
	Module	2.0%	1.7%	1.8%
	Electrical	1.3%	1.2%	1.0%
	Degradation	0.3%	0.3%	0.3%

[4] Suri, Marcel; Betak, Juraj; Rosina, Konstantin; Chrkavy, Daniel; Suriova, Nada; Cebecauer, Tomas; Caltik, Marek; Erdelyi, Branislav. Global Photovoltaic Power Potential by Country (English). Energy Sector Management Assistance Program (ESMAP) Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/466331592817725242/Global-Photovoltaic-Power-Potential-by-Country

Project Cost Estimate

Average country cost information for residential and commercial solar PV installations, for the year 2020, was obtained from the International Renewable Energy Agency (IRENA) database and used along with the system installed capacity to estimate the total project Capital Expenditure (CAPEX). Based on their sizes, Linari and Dei were considered as residential while Kontari was considered as commercial, for costing purposes. The equivalent cost in EUR is based on USD/EUR exchange rate for the year 2020.

Table 17: Project cost estimate

Sites	DC Capacity [kWp]	CAPEX[5] [USD/kWp]	CAPEX [USD]	CAPEX[6] [EUR]
Linari	46.98	1 609	75 590	52 244
Dei	82.62	1 609	132 935	91 877
Kontari	1 458.00	1 136	1 656 288	1 144 732

Conclusion on solar PV assessment

In terms of solar PV, this preliminary study showed that solar PV capacities of 42 kW_{AC}, 72 KW_{AC}, and 1 200 kW_{AC} can be installed at Linari, Dei and Kontari respectively, and the performance ratio (PR) of all sites (approximately 80%) is acceptable. Furthermore, based on the P50 year-1 annual yields and the system DC capacities, the specific yields were estimated as 1 494 kWh/kWp, 1 512 kWh/kWp and 1 602 kWh/kWp for Linari, Dei and Kontari respectively. These figures fall in the middle of the range, according to the World Bank's estimates of solar PV power potential for countries globally. This shows that with the proposed installations, the solar PV potential of the sites is relatively good.

[5] As included in: IRENA_Power_Generation_Costs_2020.pdf – Table 3.1.
Cost in the year 2020, with Germany used as reference country.
[6] Based on USD/EUR exchange rate of 0.691143, for the year 2020. Available at: https://www.ofx.com/en-au/forex-news/historical-exchange-rates/yearly-average-rates/

Task 2: Wind power assessment

This section details the wind energy potential on the island of Chios, followed by the proposition of a suitable wind farm configuration, accounting for wind resources, local constraints and energy needs.

Wind potential

The wind potential in Chios has been studied by elaborating a wind resource map suitable for wind turbines at two different heights: 50.0 m and 75.0 m. This map has been used to assess the wind potential across the island and to identify the most suitable locations for wind exploitation. The wind resource map covers the entire surface of the island of Chios and is representative also for slightly lower or higher hub heights.

Methodology

At this preliminary stage of the project, in the absence of measurements on site, a grid of equally spaced libraries from the Global Wind Atlas [2] was used as the wind resource, as shown in Figure 9. The wind flow model WAsP was employed to extrapolate the wind regime vertically and horizontally. Terrain elevation is modelled within a radius of 15 km (in line with WAsP recommendations [3]) based on EU-DEM data (25 m grid). Height contour lines were then generated with an elevation difference of 5 m between two successive lines. Given that roughness length is closely related to land use, terrain roughness was modelled using a land-use database. The Corine Land Cover (2018) database was used and roughness length values specific to each land use were applied according to 3E's methodology [3]. Following WAsP recommendations, the terrain roughness has been modelled within a radius of 20 km.

Figure 9: Grid of libraries from the Global Wind Atlas

Wind Resource Maps

For the whole island, a wind atlas has been created using the software WindPro[7]. The Wind Climate from the Global Wind Atlas [2] has been employed to generate wind resource maps at two different heights above ground level: 50.0 m and 75.0 m. These heights are in the range or envelope potential hub heights for relevant wind turbine types which can be considered for the island.

The wind on the island of Chios predominantly blows from the north (N) and north-northeast (NNE) sectors. The wind energy rose depicts that most of the energy production comes from the same sectors (Figure 10).

[7] WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

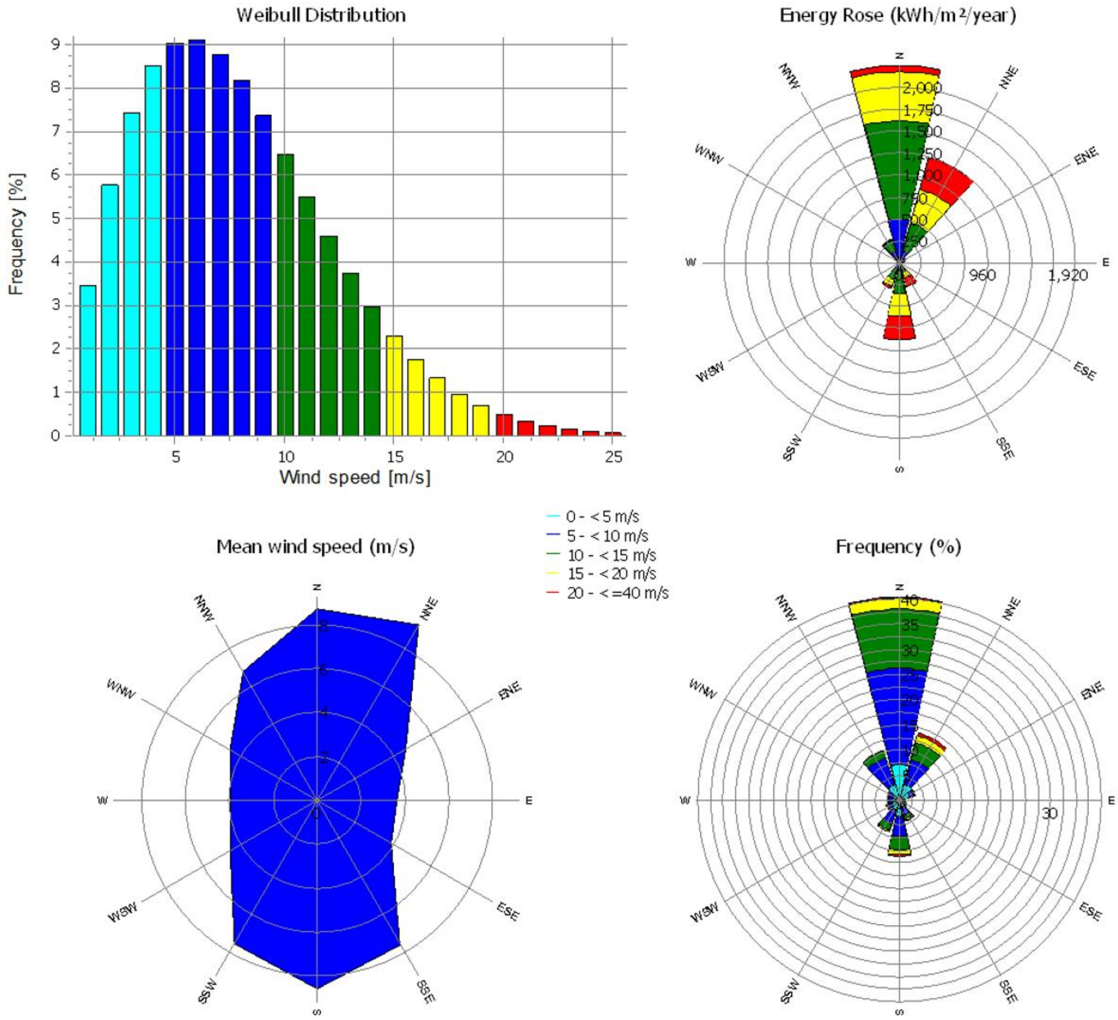


Figure 10: Wind distribution on the most wind-efficient location of the Island at 50 m of height. (Exact location: 38.31N and 26.15E)

The different wind resource maps are presented in the figures below. The mean wind speed on site ranges between 1.5 m/s and 12.0 m/s at 50.0 m and between 2.5 m/s and 12.1 m/s at 75.0 m depending on the location on the island, as shown in the resource maps from Figure 11 to Figure 12.

The highest wind speeds can be found in those locations characterized by the highest altitudes. As a general observation, northern, central, central-western and south-eastern locations of the island show higher wind speeds, especially in correspondence of mountainous and hilly reliefs. This trend is observed both at 50m and 75m and is indicative also for slightly lower or higher altitudes.

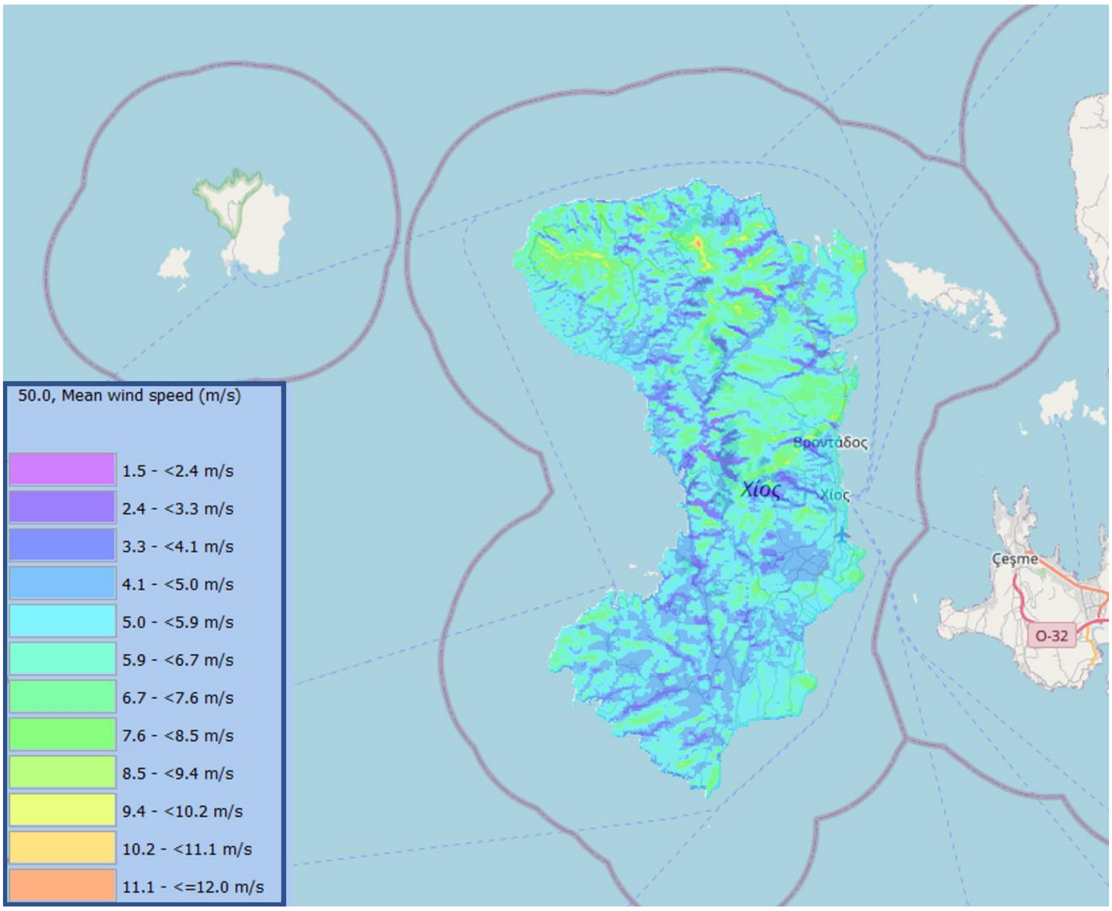


Figure 11: Mean wind speed at 50.0m AGL

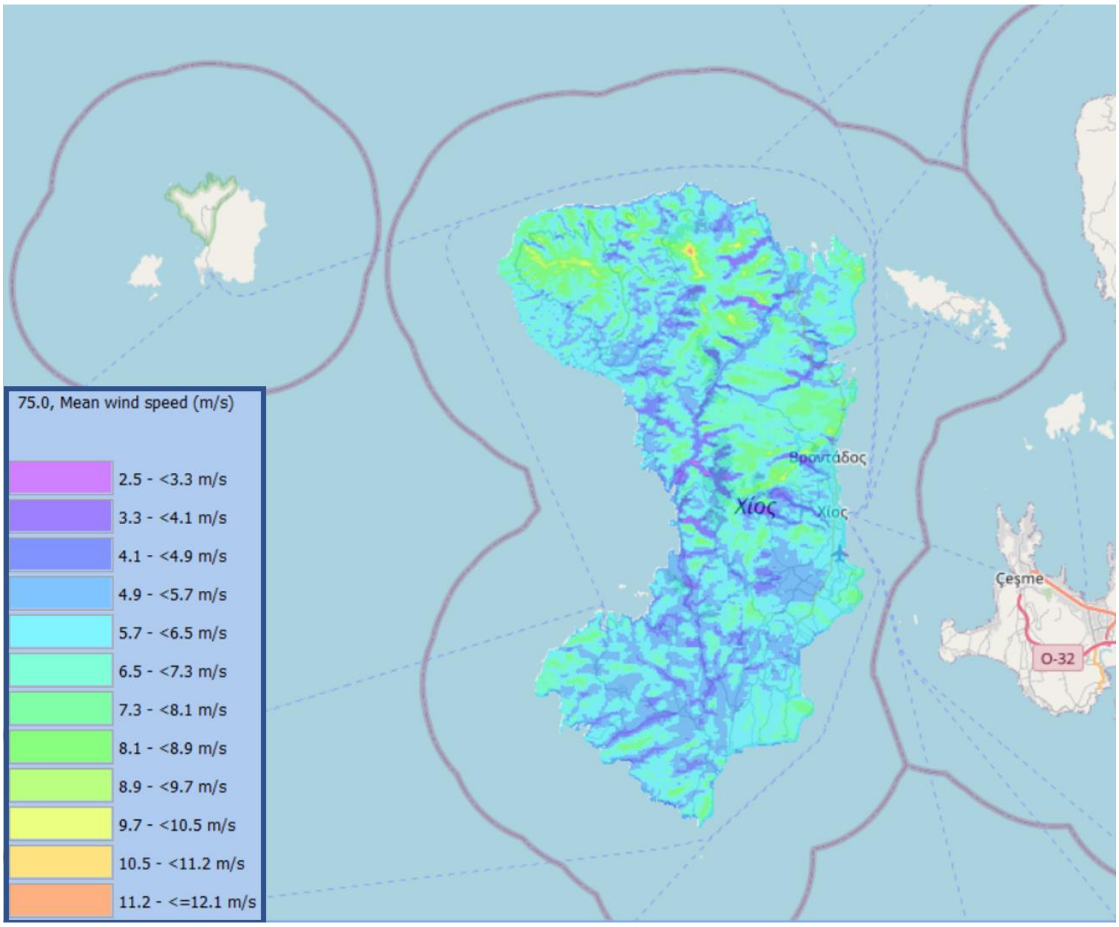


Figure 12: Mean wind speed at 75.0m AGL

A wind resource map in terms of annual production MWh/year has been generated at 50.0m and 75.0 m above ground level based the wind turbine Vergnet GEV MP R with nominal power of 275 kW. This model has been selected as an indicative choice based on the size and energy needs of the desalination plants, the turbine's relatively small dimensions and reduced visual impact, and its higher energy production compared to similarly sized vertical axis wind turbines.

The results show that the average wind potential on the island at 50.0 m ranges between 140 MWh/year and 14,408 MWh/year for the Vergnet GEV MP-R with nominal power of 275 kW. (Figure 13). At 75.0 m it ranges between 804 MWh/year and 15,115 MWh/year (Figure 14). As already observed for the wind speed, greater values are typically found at higher altitudes.

Before suggesting feasible areas for wind energy exploitation, additional criteria should be investigated such as how accessible the site is (in terms of roads, elevation), constraints related to the presence of protected areas/nature reserves, archaeological areas, and the distance from the main grid. Based on these considerations, two layouts, one for each of the different scenarios under investigation, are proposed in the following sections.

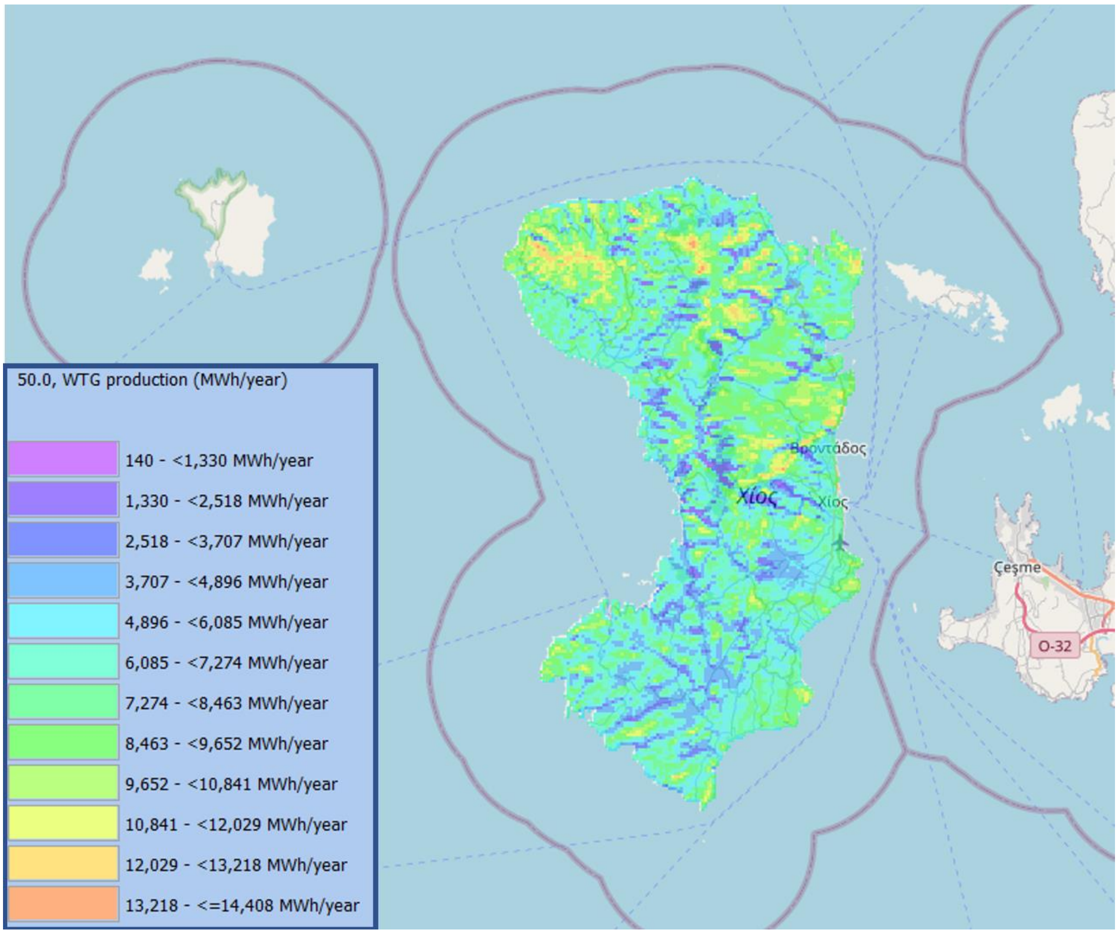


Figure 13: Annual wind production at 50.0m AGL based on the Vergnet GEV MP-R 275kW wind turbine [MWh/an]

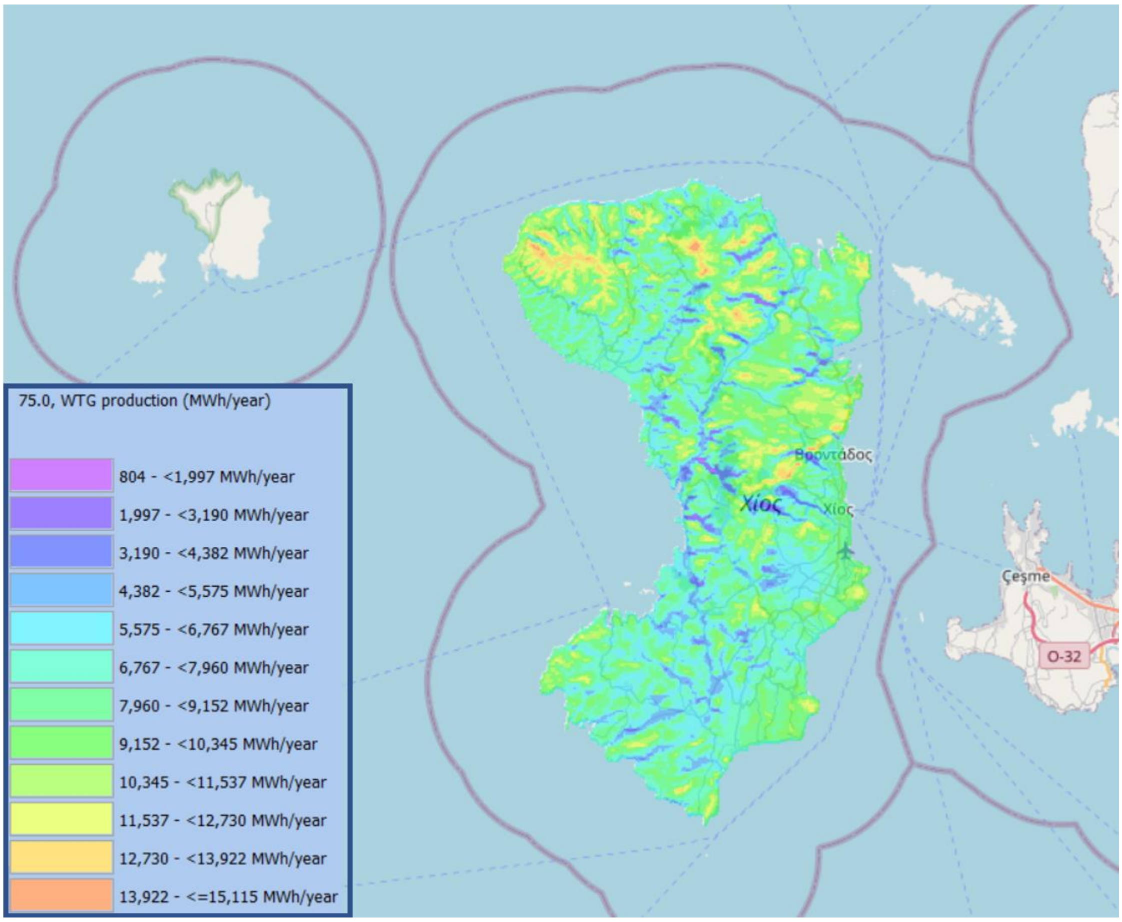


Figure 14: Annual wind production at 75.0m AGL based on the Vergnet GEV MP-R 275kW wind turbine [MWh/an]

Net energy production of the two proposed sites

Based on the locations shown in Figure 1, two layouts are indicatively proposed for the wind turbine Vergnet GEV MP R 275 kW with 32 m of hub height, based on the following scenarios:

- Phase I: considering the existing plants RO Linari and RO Dei (close to the airport) which will be provided with energy by on-site solar energy plants and 8 wind turbines at Merovigli,
- Phase II: considering the existing plants RO Linari, RO Dei and, in addition, the potential plant of RO Kontari (in the vicinity of the airport) which will be provided with energy by on-site solar energy plants and 14 wind turbines at Merovigli.

The first layout aims at covering the energy needs involved with the first scenario. The selected location for the wind farm is the hilly area of Merovigli, characterized by wind speeds suitable for wind exploitation (average wind speeds around 6.7 m/s at 32m of height). The second layout further increases the total production by increasing the number of wind turbines in the same area of Merovigli. The layouts of Phase I and Phase II are displayed in Figure 15 and Figure 16, respectively. Their coordinates are provided in Table 18.

The expected annual energy production and other energy production figures are presented in Table 18. These results are preliminary, as it must be specified that they do not include additional losses related to curtailments or access to grid and grid limitation. In addition, the proposed locations, based on the local wind map, are indicative and slight modifications in the disposition/coordinates of the turbines would still be possible and would not result in a drastic performance change/reduction.

Table 18: Expected wind farm energy production figures and wind turbines coordinates for the Scenarios Phase I and Phase II

Configuration	Vergnet MP R 0.275MW @*32*m			
Scenario	**Phase I**		**Phase II**	
Mean wind speed [m/s]	6.5 - 7.3		6.3 - 7.7	
Gross energy production [MWh/y]	6,196		10,694	
Annual net energy production [MWh/y]	5,481		9,286	
Coordinates [Geo (deg)-WGS84]	Longitude	Latitude	Longitude	Latitude
WT1	26.14762° E	38.31336° N	26.14762° E	38.31336° N
WT2	26.14925° E	38.31252° N	26.14925° E	38.31252° N
WT3	26.14600° E	38.31215° N	26.14600° E	38.31215° N
WT4	26.14736° E	38.31168° N	26.14736° E	38.31168° N
WT5	26.14879° E	38.31093° N	26.14879° E	38.31093° N
WT6	26.15004° E	38.31034° N	26.15004° E	38.31034° N
WT7	26.14684° E	38.31017° N	26.14684° E	38.31017° N
WT8	26.14803° E	38.30957° N	26.14803° E	38.30957° N
WT9	-	-	26.15067° E	38.31327° N
WT10	-	-	26.15227° E	38.31215° N
WT11	-	-	26.15082° E	38.31150° N
WT12	-	-	26.14537° E	38.30822° N
WT13	-	-	26.14672° E	38.30810° N
WT14	-	-	26.14807° E	38.30796° N

Figure 15: Location of the proposed wind turbines for the scenario Phase I

Figure 16: Location of the proposed wind turbines for the scenario Phase II

Conclusions on wind potential

Regarding the wind potential on Chios, the mean wind speed ranges between 1.5 m/s and 12.0 m/s at 50.0 m and between 2.5 m/s and 12.1 m/s at 75.0 m which represent favourable conditions for wind exploitation. The proposed horizontal axis wind turbine Vergnet GEV MP R 275 kW should be considered as an indicative model used for the purposes of this study. Other models of wind turbines with the same size and the same/higher power class can be considered for this specific site. The Vergnet GEV MP R 275 kW wind turbines at the proposed locations lead, indicatively, to the following annual productions: 5,481 MWh/y for the scenario Phase I and 9,286 MWh/y for the scenario Phase II. These results together with the high wind speeds already at low altitudes underline that this site is suitable for wind exploitation.

Task 3: Circular Desalination

Desalination plants in the island & chemicals consumption

After consultation with the relevant local stakeholders (Municipal Company for Water and Sewage of Chios Island) a list of chemicals required was identified. The total quantity of these chemicals is estimated at approx. together with the individual quantities as follows:

- Caustic soda (NaOH): 11,000 kg/year
- Sulfuric acid (H_2SO_4): 52,000 kg/year
- Sodium Metabisulfite ($Na_2S_2O_5$): 1,200 kg/year
- Sodium Hypochlorite (NaOCl): 60,000 kg/year
- Hydrochloric acid (HCl): 150 kg/year
- Calcium carbonate (CaCO3): 100,000 kg/year

Total: 224,350 kg/year

Market specifications:

Caustic soda: The solution of caustic soda used should be around 50% w/w (suitable for drinking water applications).

Sulphuric acid: Concentration 98% (CAS no. 7664-93-9) – suitable for drinking water applications.

Sodium Metabisulfite: Food grade (CAS no 7681-57-4), purity 98% w/w (form: powder, supply today in 25 kg of packaging)

Sodium Hypochlorite: Solution of sodium hypochlorite suitable for drinking water applications according to the ELOT EN 901:2013 standard.

Hydrochloric acid: Concentration 30-32% w/w

Calcium carbonate: purity > 98%, form: powder (2 mm particles), delivered in packages of 20 – 25 kg

The following table summarizes the main information relevant for caustic soda concentration.

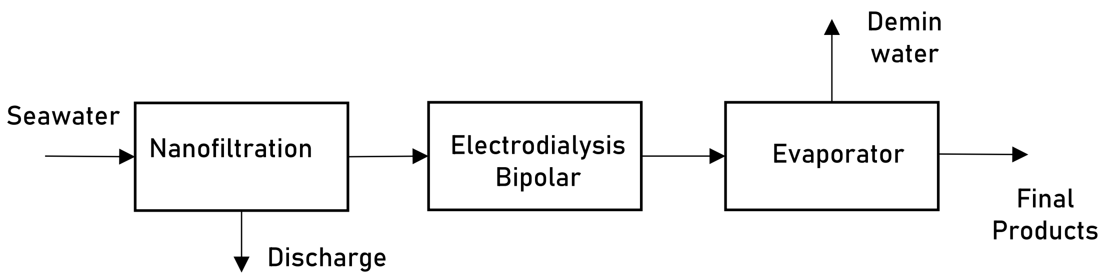
Concentration			Density (kg/L)
Mass (% w/w)	In g/L	Molarity (mol/L)	
5.86%	62.5	1.56 M	1.067
10.3%	114.9	2.87 M	1.116
25.50%	327.7	8.19 M	1.285

Concentration			Density (kg/L)
Mass (% w/w)	In g/L	Molarity (mol/L)	
30.00%	399.6	9.99 M	1.332
50.10%	766.5	19.16 M	1.530

Note: Molecular weight (NaOH): 40 g/mol (data retrieved from: https://www.jsia.gr.jp/data/handling_01e.pdf)

Circular Desalination

The analysis below has as a starting point the composition of the seawater, which is assumed as presented in the table below. Given the interest of the end-user to recover caustic soda at 50% w/w (~19 M) concentration, the following Circular Desalination system is proposed:



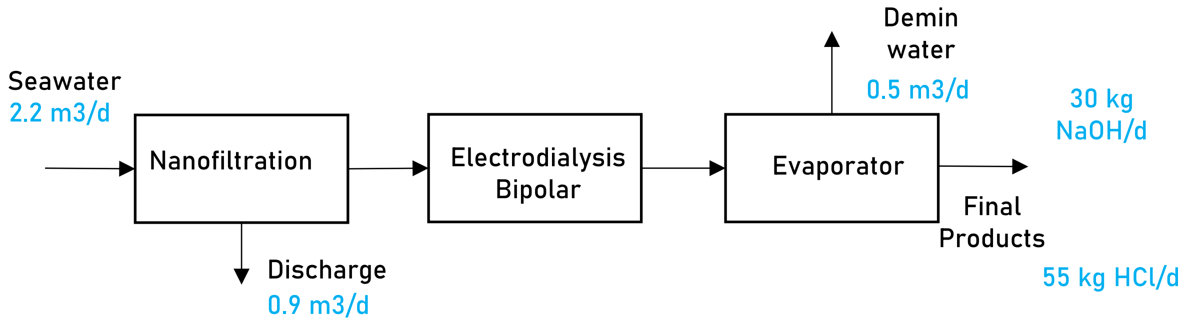
	MW [g/mol]	Valence [eq]	Conc. [mg/L]	meq/L
Sodium (Na+)	22.99	1	21,400.00	930.84
Magnesium (Mg2+)	24.31	2	2,700.00	222.13
Calcium (Ca2+)	40.08	2	880.00	43.91
Potassium (K+)	39.1	1	780.00	19.95
Chloride (Cl-)	35.45	-1	39,000.00	- 1,100.14
Sulphates (SO4 2-)	96.06	-2	5,500.00	- 114.51
Bicarbonate (HCO3-)	61.00	-1	180.00	- 2.95
			70,440.00	(0.77)

According to the Electroneutrality principle the sum of positive and negative charges within the water sample must be equal to zero.

Considering the presence of 930.84 meq per liter, in theory, it is possible to recover 37,233.6 mg of NaOH per liter of seawater. Taking into account that the maximum quantity used per year is 11 tons, the required capacity of a Circular Desalination system is presented below.

Using the Circular Desalination system illustrated above, the following results apply.

- Seawater (feed stream): 2.2 m^3/d
- NF permeate: 1.3 m^3/d (recovery = 58%)
- NF concentrate: 0.9 m^3/d
- BPMED water for base: 0.6 m^3/d
- BPMED water for acid: 0.6 m^3/d
- BPMED base (1.5 mol/L NaOH): 0.6 m3/d (evaporator feed)
- BPMED acid (1.5 mol/L HCl): 0.6 m3/d (55 kg-HCl/d)
- BPMED salt solution: 1.3 m^3/d
- Evaporator effluent (10 mol/L NaOH): 0.1 m^3/h (~30 kg-NaOH/d)
- Evaporator distillate (demi water): 0.5 m^3/d



Conclusions

A small "Circular Desalination" pilot with a capacity of 2.5 m3/day is proposed to be tested and operated in Chios island, to get sufficient knowledge on its benefits and results. Connection with existing EU-funded projects such as WATER-MINING can be beneficial in this respect.

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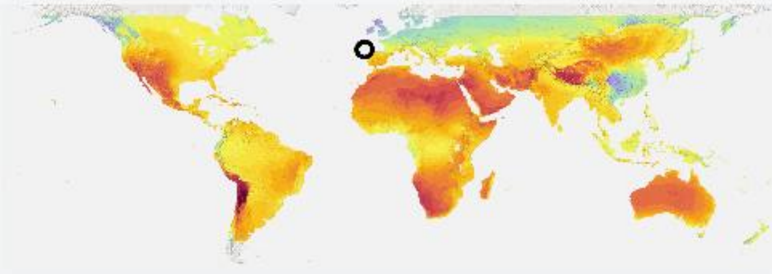
ANNEX

ANNEX A: Solar report

SOLARGIS PROSPECT



Preliminary assessment of the photovoltaic electricity production

Project: A Illa de Arousa (Spain)

Geographical coordinates	42.549732°, -008.86734° (42°32'59", -008°52'02")
Report number	SG-P-s14197-221017-143307
Report generated	10/17/2022
Generated by	Solargis
Customer	3E NV (Belgium)

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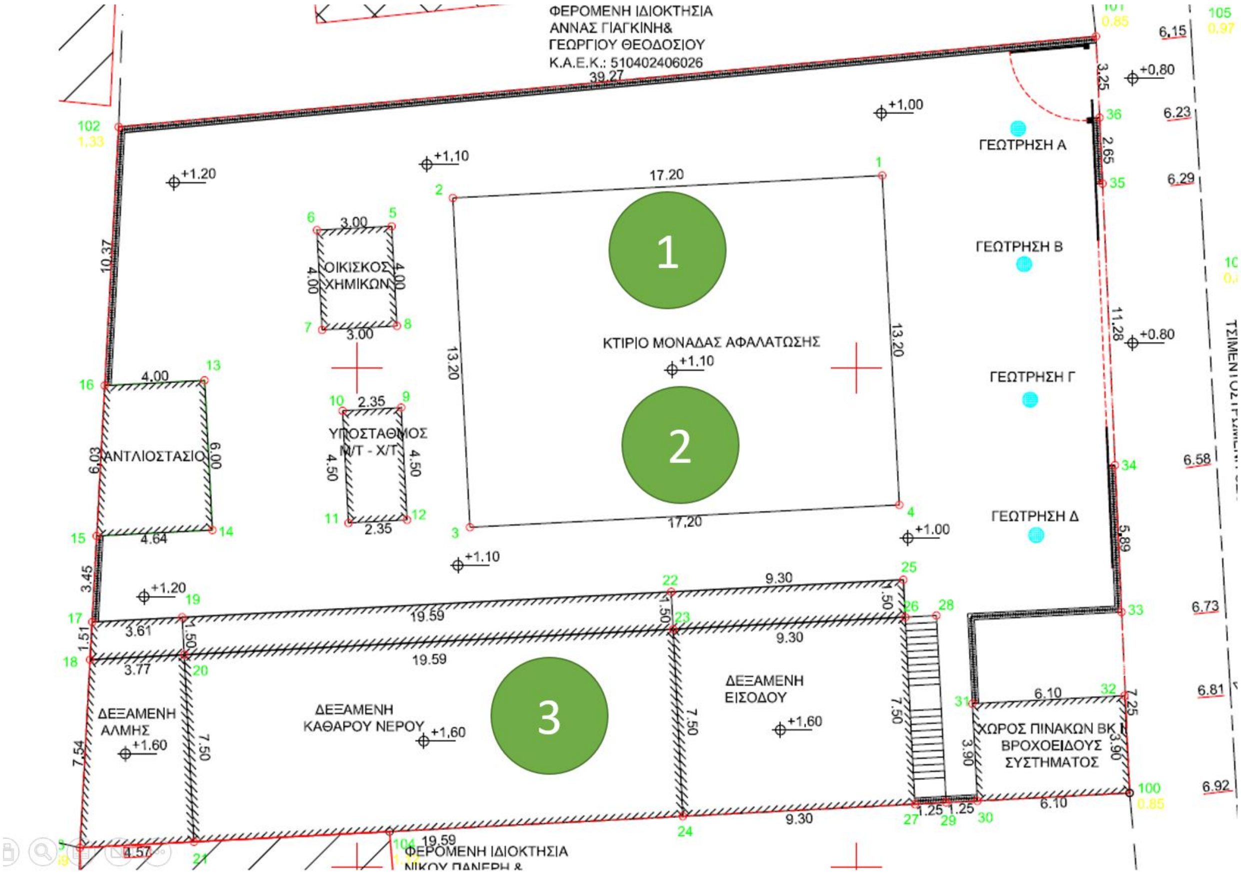
ANNEX B: Solar PV site dimensions

Linari



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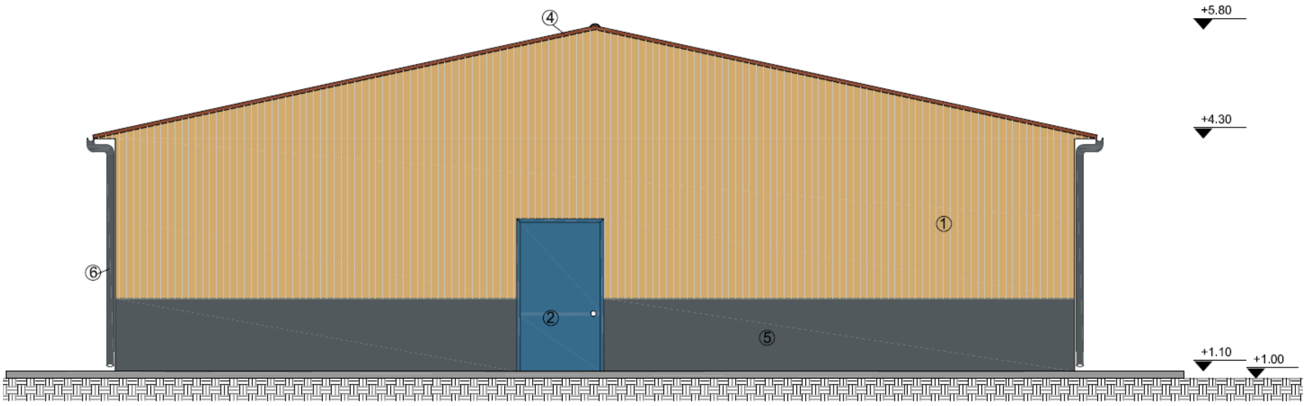
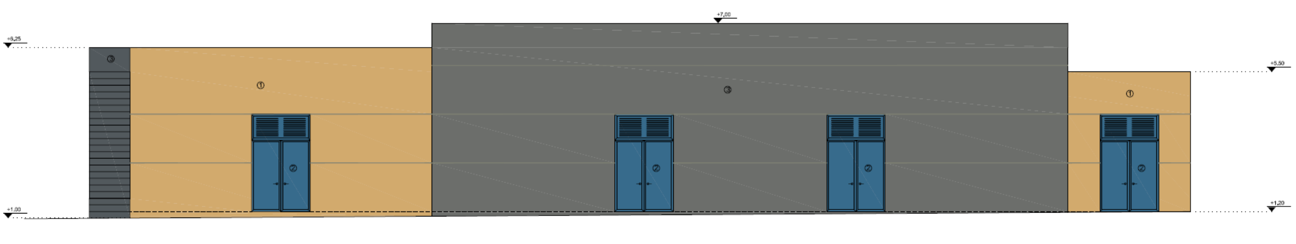
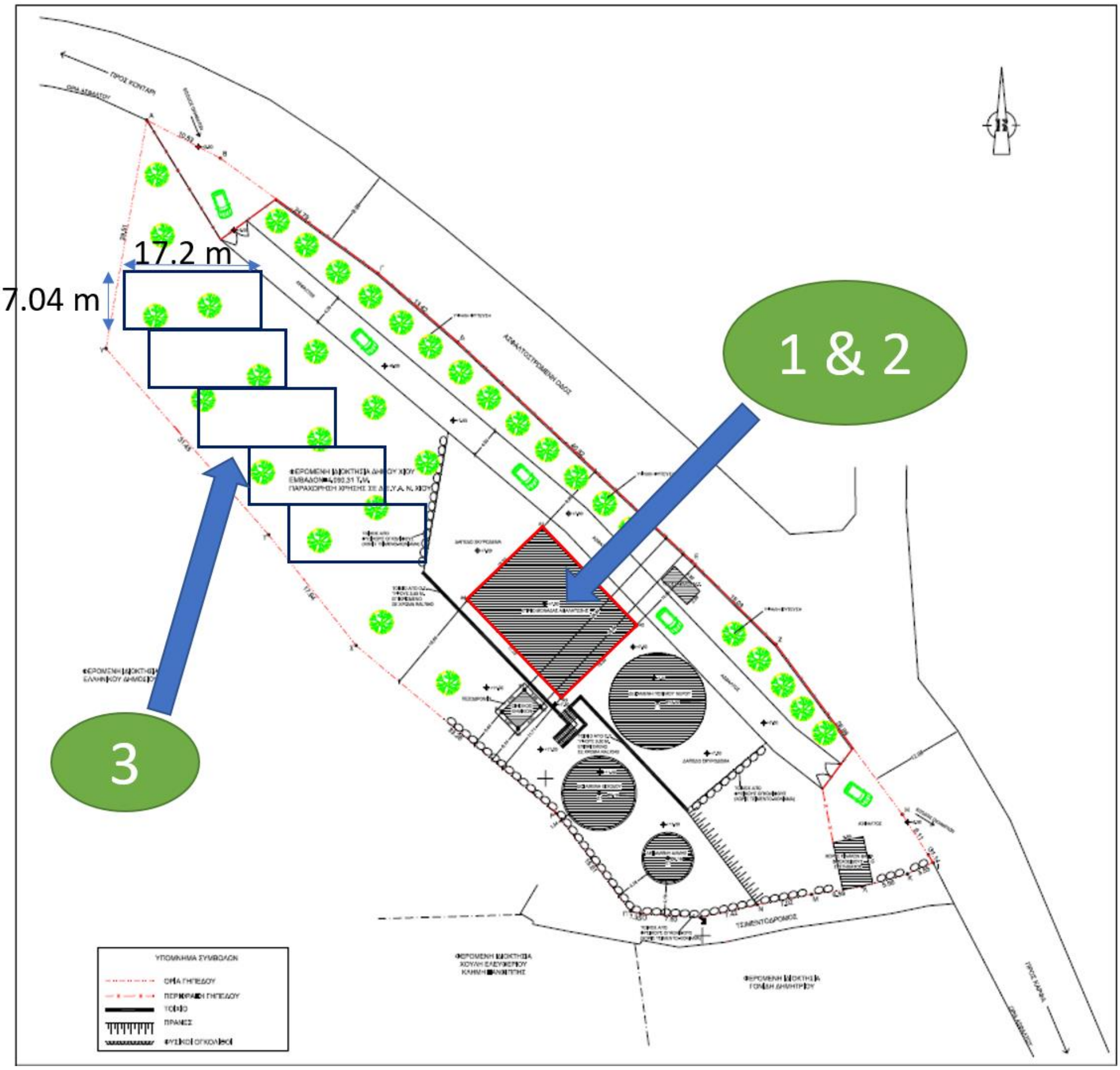




Dei



Kontari