

A Review of Desalination Potential in Greek Islands Using Renewable Energy Sources, a Life Cycle Assessment of Different Units

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Abstract

The scarcity of water is a long-standing problem in Greek islands. The government, as a temporary solution adopted the transportation of water using tanker ships. This type of water is of low quality non-potable and in some cases inappropriate for any use. Apart from that water transportation increases the carbon footprint of the islands that it is already stained due to the big thermal power plants that feed the grid using fossil fuels (mainly diesel). Apart from the environmental issues the economic consequences are extremely high. The cost of transported water in Dodecanese and Cyclades reached a total of 73,5 million € from 2002 to 2010. The aim of this paper is to bring forward the proposed solutions for desalination of sea water using renewable energy sources, as Greek islands have a great wind and solar potential that is hard to find in any other place on Europe. A Life Cycle Assessment is been conducted between two different desalination technologies (RES and Diesel operating desalination) to fully understand the impact these units have to the environment.

Keywords: Desalination, Renewable energy, Greek islands, carbon footprint, reverse osmosis, LCA

1. Introduction

Water scarcity is a timeless problem of Greek islands which lead to huge amounts of low quality and not potable water being transported to them with tanker ships. All this water is being subsidized by the Greek government [1]. Thus, the cost may reach 10€/m³. [14] Furthermore, on summer the water demand doubles and in some cases, triples due to tourism bloom in the last 6 years. All Greek islands are not connected to the terrestrial national grid therefore there are small grids in each group of islands. These grids are supplied with power, produced by fossil fuels (mainly diesel), a method that increases, not only the cost of KWh_e more than twice, but their carbon footprint as well [5]. Since 2010 renewable energy has penetrated the total energy production of islands and now covers 21,8% of their needs¹. [34]

In order to tackle the problem, desalination systems, have been developed in some islands but most of them use power from their grid to produce fresh water or independent units, exist operating with diesel. Facing this situation many research brought forward the need of renewable energy sources for sustainable desalination. A desalination system using wind power can achieve huge capacity factor (approx.. 250m³/day) with water cost of 2 €/m³. A PV based desalination unit needs more space

¹ Data from January to December 2015

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to achieve the same capacity factor and the cost of water is approximately 7,7 €/m³. [6] As the most expensive way is considered the Organic Rankine Cycle desalination, as it requires significant installation costs. [7]

The aim of this paper is to bring forward the need for autonomous desalination plants using renewable energy sources to cover their needs. In those cases reverse osmosis desalination method is preferred as it is easy to install and operate and the specific energy needed per cubic meter is low [2],[3],[4]. The grid independent desalination plants using RES help in clean water production, independency from the low quality transported water, significantly lower energy consumption, reduce the carbon footprint and maintain sustainability in the islands.

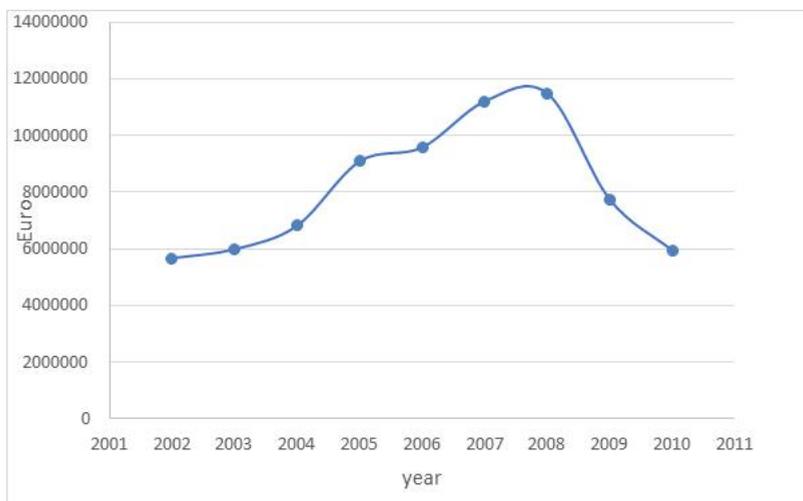


Fig.1: cost of transported water in Dodecanise and Cyclades from 2002 to 2010

1.1 Current Situation in Greek islands

The Greek islands separate in tow main categories. The Ionian Sea islands and the Aegean Sea islands. In the Ionian Sea, the rainfall is intensive during winter and there is no significant requirement of fresh water [fig.2]. On the other hand, Aegean Islands face a severe lack of water especially during summer months. The boost on tourism the last years intensifies the problem of water scarcity [8]. The Aegean Islands can be further divided in large and small islands. Larger islands usually have a sufficient water network contrary to the smaller ones that water supply is served by private wells and tanks. [9]

To tackle the situation the Greek government proceeded in the transportation of water with tanker ships. Some data about the amount of transported water in Greek islands in Aegean sea are demonstrated in fig.3. The transportation causes three crucial problems. Firstly, the cost for the government is huge and requires a significant amount of the seasonal budget which reaches approximately 6 to 12 million €/year, an amount really high for a country that faces the economic crisis. [10] Furthermore, the environmental impact of transportation is significantly high as tanker ships have a huge CO₂ footprint that adds the already busy footprint that thermal power plants contribute. Last but not least, water transportation doesn't give a permanent solution to the problem that Aegean

Islands face.

In many cases due to tourism boost the water quantity that is been transported is insufficient because the population on the big islands of Aegean expands dramatically.

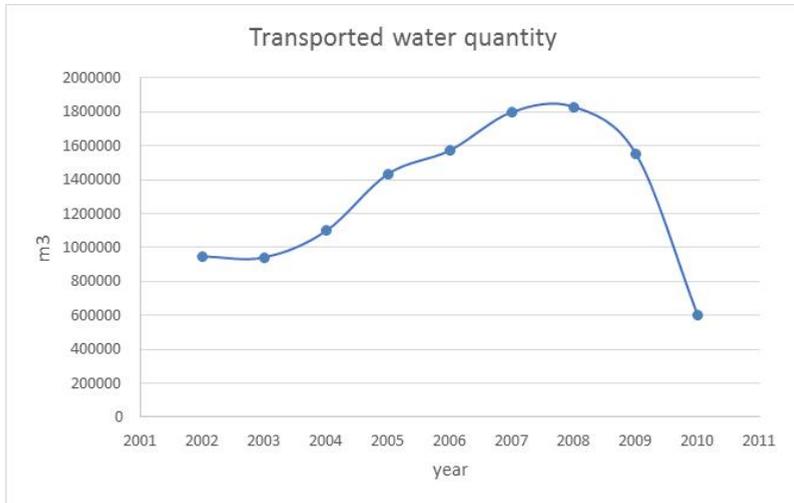


Fig.3²: Transported water quantity from 2002 to 2010. The total water transported was 10,808,903 m³

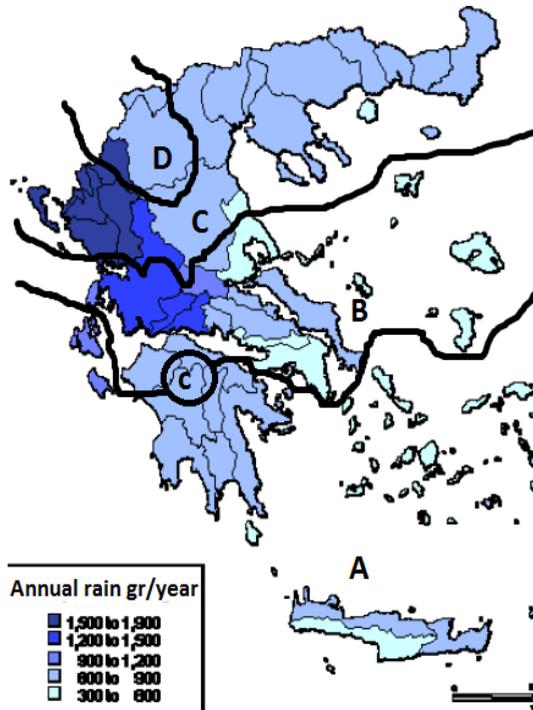


Fig.2: Climatic Zones in Greece and annual rain in Aegean and Ionian Sea

² The 2010 results defer to the period January-May

1.2 Current Desalination Status of the Islands

The current situation concerning the desalination infrastructures and operation is categorized in thermal processes and membrane processes. Thermal processes require low pressure steam or hot water at 70°C while membrane processes require energy to pressurize water from a membrane. The energy that membrane processes (like reverse osmosis which is mainly used) is produced by fossil fuels or renewable energy. Only the last ten years, renewable desalination has dominated in the islands. Traditionally since 80s fossil fuel operating units used to be build. Table 1 is an example of installed desalination units in Aegean Islands. The main problem with fossil fuel operating units is that they use power from the local grid of each island. [11] In Greece there are 32 autonomous thermal power plants using diesel to cover their needs. [35]

- 19 small autonomous grids with peak need of 10MW.
- 11 middle sized grids with peak need from 10MW to 100MW.
- 2 big size autonomous grids with peak need above 100MW (Rodes and Crete).

Therefore reverse osmosis, a technique that requires a significant amount of energy, burdens the local society economically and environmentally. [12] [13]

Table 1: Desalination Units in Aegean Sea using fossil fuels

Location	Capacity [m ³ /day]	Year of construction	Method of Desalination
Syros	27.370 (14 units)	Began 1992	Reverse Osmosis and Solar thermal Desalination and MSF
Ios	1.000	2001	Reverse Osmosis
Mykonos	9.250 (5 units)	Began 1989	Reverse Osmosis
Paros	1.200	2002	Reverse Osmosis
Sifnos	500	2001	Reverse Osmosis
Tinos	500	2001	Reverse Osmosis
Santorini	380	1995	Reverse Osmosis
Megisti	50	1990	Reverse Osmosis
Nisiros	650	2002	Reverse Osmosis

Source: Aegean and Island Policy Ministry

Since 2010 Renewable desalination is preferred as an economic and sustainable solution to the problem. Table 2 presents the method and the capacity of desalination units been built since 2013. The most innovative of all the installed unites was the floating desalination unit in Irakleia that operates using a 30kW wind turbine and PV panels. The capacity of this unit is 80 m³/day and costed 1.5million euros in 2010.

Table 2: Renewable Desalination in Aegean Islands

Location	Capacity [m ³ /day]	Technology
Kimolos	576	Low enthalpy Geothermal Energy
Irakleia	80	30kW WT and PV
Milos	3600(3 units)	850kW WT
Symi	360	MVC
Strogili	20	10kWp PV



Fig.3: Installed desalination units using Fossil Fuels (red ones) and Renewable Energy (green ones)

2. Environmental Impact on the Islands

At this chapter a Life Cycle Assessment comparison between two different technologies is being conducted, in order to determine the environmental impact of each one. The desalination systems compared are one in Milos island, which uses renewable energy and one in Paros operating with power from the grid (means fossil fuels, mainly diesel).

Life Cycle Assessment (LCA) is a methodology for evaluation the environmental impact of a product or a process during their life cycle. Mainly this technique used on building sector [18] but lately is been used to assess any procedure as well as wind turbines and PV panels. [19] [20] LCA is based on the ISO 14040 and consists of four steps: defining the goal, create the inventory, assess the impact and interpret the results. [21]

As the carbon footprint of the Aegean islands is really big due to water transportation and diesel operating thermal power plants we need to determine the impact of the desalination units in order to be able to fully assess the situation. Being able to reduce environmental impact, local authorities save money and boost tourism rating. The goal of this Life Cycle Assessment is to give a clear image of the impact of each technology (renewable energy and diesel operating units) to the environment of the islands. At this study, we consider as main environmental impacts the embodied carbon dioxide (EC) and embodied energy (EE).

Another source of environmental encumbrance is the so-called brine, which is the high salinity water that produced by desalination procedure. Moreover, the chemical discharges to the marine environment affect the water salinity and local ecosystem. [22] For Reverse Osmosis procedure, that interests us, rejected brine is deposited in water ecosystems in significantly high temperature and along with additives like chlorine and halogenated organics and cleaning chemicals that filters use, may cause the disruption of the local environment.[24]

$$\text{Embodied Carbon} = \sum_{i=1}^n Q_i * EF_i$$

$$\text{Embodied Energy} = \sum_{i=1}^n Q_i * EEC_i$$

Where:

Q_i is the quantity of the material

EF_i is the emission factor of material i

EEC_i is the embodied energy coefficient of the material i

Table 3. Case studies we apply the LCA method to compare.

Location	Primal Source of Energy	Technology	Capacity [m ³ /day]	
Milos	Wind Turbine	Reverse Osmosis	1200	CASE 1
Paros	Diesel	Reverse Osmosis	1200	CASE 2

2.1 CASE 1

2.1.1 Implementation

At this study we consider a wind turbine of 850kW that is the one that operates in Milos desalination plant. The RO unit is constituted from a CRTE-2-7 pump and XLE-4012 membrane. The estimation of the embodied carbon and embodied energy at Table 5 refer to 1 m³/day production, therefore, for 1200m³/day capacity the final results multiplied.

Table 4. Estimation of embodied energy and embodied carbon of a typical wind turbine³ [16]

	Mass [tn]	EF [CO ₂ /ton]	EEC [GJ/ton]	Embodied CO ₂ [tons CO ₂ /ton]	Embodied Energy [GJ]
Blades					
Aluminum	0,11	1,13	88,07	0,13	10,01
Fibre Glass	4,26	4,60	56,82	19,61	242,12
Epoxy resin	2,56	3,36	79,15	8,59	202,37
Polyethene	0,40	1,10	47,22	0,44	18,78
PVC	0,84	1,37	43,86	1,15	36,76
Paint	3,07	2,02	38,64	6,21	118,54
Rubber	0,11	1,81	57,78	0,21	6,57
Iron	0,85	1,09	14,20	0,92	12,11
Towers					
Steel	81,93	1,56	13,86	128,02	1135,87
Galvanized steel	3,81	1,60	22,16	6,10	84,36
Generator					
Copper	8,75	2,18	28,41	19,04	248,58
Steel	32,39	4,01	69,66	129,91	2256,00
Nacelle					
Steel	5,68	1,52	27,50	8,65	156,25
Cast Steel	2,10	1,61	14,43	3,38	30,34
Iron	11,93	1,08	14,77	12,88	176,27
Polyester resin	1,25	1,10	64,20	1,38	80,26
Electronics	1,42	1,55	45,74	2,20	64,97

The total Embodied Energy in an 850kW wind turbine is 4880,15 GJ while the total Embodied CO₂ is 341,8 tons CO₂/ton. The theoretical disposal scenario of a wind turbine reaches 100% as all of the above materials are recyclable.

³ The results have been adjusted to an 850kW wind turbine

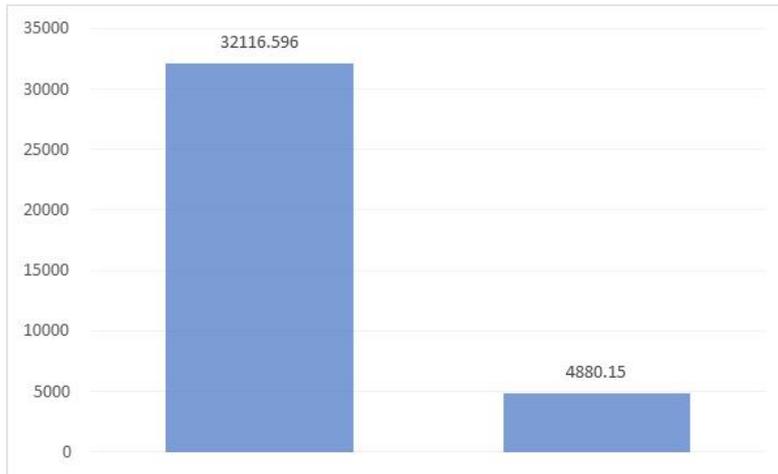


Fig. 4: Embodied Energy (GJ) in 1200m³/d RO unit and 850kW Wind turbine

Table 5. Estimation of embodied carbon and embodied energy on a Desalination unit using reverse osmosis technology.

		Mass [kg]	EF [CO ₂ /kg]	EEC [MJ/kg]	Embodied CO ₂ [kgCO ₂ /kg]	Embodied Energy [MJ]	
pressure vessels							
	RO module	fiber glass	11,28	2,60	30,30	29,33	341,78
	feed spacer	polypropylene	3,68	3,61	95,40	13,28	351,07
pipng							
	High pressure pipe	10%steal 90% polypropylene	6,71	3,43	89,06	22,99	597,59
reservoir							
	premate tank	80% PVC 20% plastic	4,2	2,32	78,20	9,73	328,44
motor							
	7,5kW	90% steel 5%iron 5%cooper	130	6,62	32,74	861,12	4255,55

			Type
Embodied Energy	Pump	509,4 MJ	CRTE 2-7
Embodied Energy	Membrane	20380MJ	XLE 4021

The above data are for a typical RO unit operating with a motor of 7,5 kW and for 1 m³/day production. [23] The total embodied energy in the RO unit is 26763,83 MJ/m³produced water or 32.116GJ for the hole unit.

2.2 CASE 2

2.2.1 Implementation

At this case, we consider the same desalination unit as the embodied energy and embodied CO₂ doesn't show a significant alteration between different types of RO units as it has been studied in [23]. Therefore, the main change in the environmental footprint of the units is the type of fuel. In Paros case the motors and the pump of the unit are

connected to the local grid.

Diesel engines are characterized by concentration of power, low efficiency and a lot of heat waste along with harmful emissions to the environment. Due to isolation from terrestrial grid, Paros island, imports each year diesel to cover its 9.964 MWh_e needs. The desalination unit of the island uses 850kW of equivalent diesel to operate.

The total embodied energy of a liter of diesel fuel equals to 45,71 MJ. To follow the 850kWh consumption 66,98 liters needed so the total embodied energy appropriate for this desalination unit is 3061,74 MJ. [36] The point that needs to be mentioned here is that for the hole year diesel consumes this energy contrary to the wind turbine. So, for the hole year the embodied energy to the diesel engine is 26.790.225GJ/year. The embodied CO₂ for a year is 2231 tonsCO₂.

2.2.2 Results

At this stage, we assess the results of the LCA method on the two Cases. Noticing fig.6 we understand that more energy is needed to manufacture a wind turbine rather than a diesel engine production. However, for a year operation (8750h) the diesel engine requires 250 times more energy. For the carbon footprint diesel requires 4 times more CO₂ to produce a kW of energy. WT embodied carbon is found during manufacturing process and after that it operates with zero CO₂ emissions. Concluding, the Renewable energy unit doesn't burden the island with further environmental impact while the diesel operating unit constantly adds a great amount of CO₂ to the local environment.

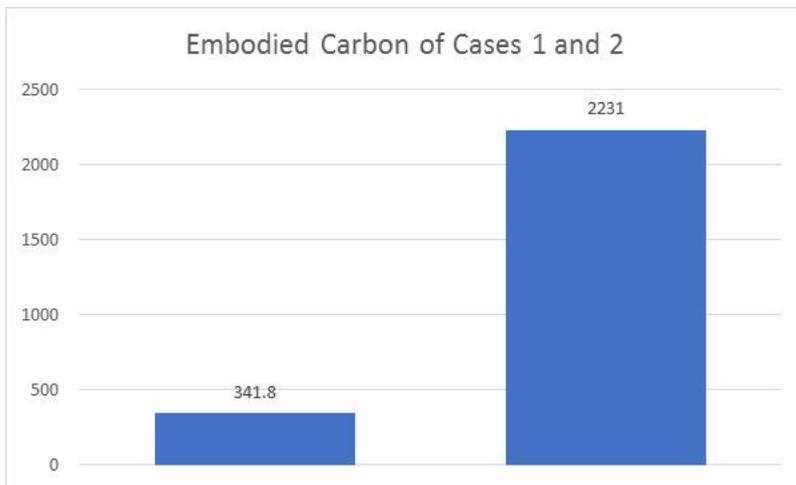


Fig.5: Embodied CO₂ in two Cases in tons

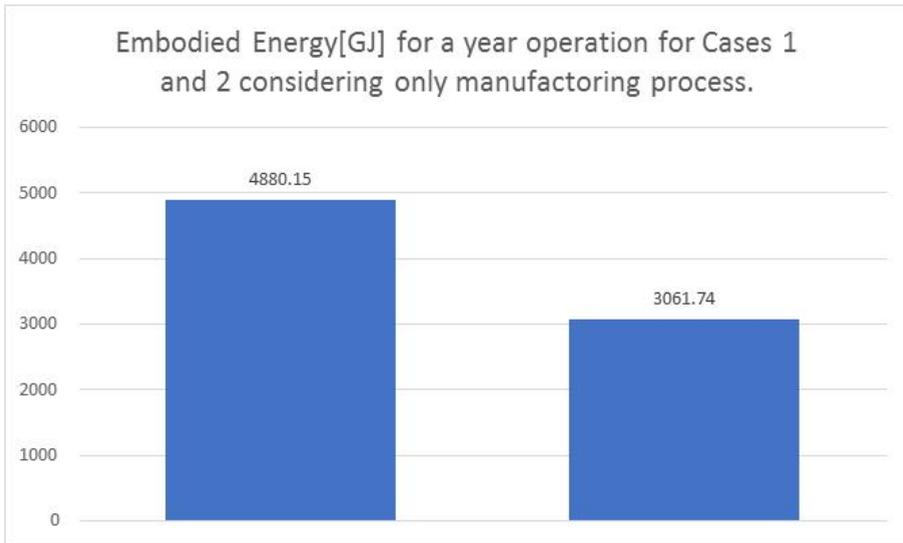


Fig.6: Embodied energy between case 1 and 2 considering only manufacturing process

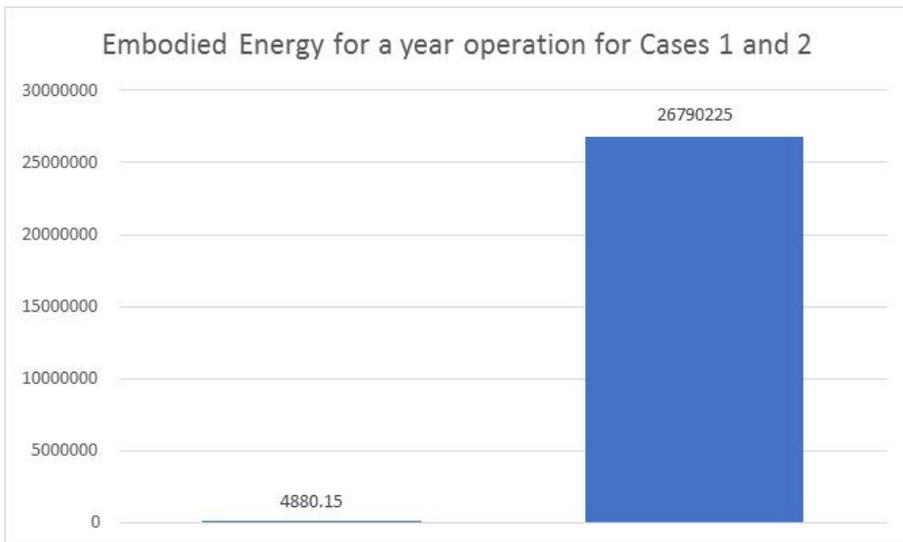


Fig.7: Embodied Energy in GJ for Cases 1 and 2

3. Renewable Energy Desalination Potential in Dodecanise and Cyclades

In an attempt to overcome the serious situation of fresh, potable water shortage problem, renewable energy desalination has been proposed as a sustainable solution. In the last 10 years, there was a boost on renewable energy sources installation (especially wind farms) however the fluctuation of seasonal load leads to under-consumption at low consumption periods (October-April) and the electricity can't be absorbed by the local grid. That leaves islands with plenty energy for sustainable desalination units.

Apart from that solar irradiance is abundant both in Dodecanese and Cyclades and can reach 1950 kWh/m² and 1800 kWh/m² respectively as it is seen in *fig.9*. Combining that with the fact that the terrain is ideal for the use of solar panels, solar driven desalination plants could be easily installed. In fact, Karimi et. al [13], Karagiannis et. al [11], Wei He [3], Helal et. al [20], have presented full studies of PV driven desalination units that operate either with or without storage in order to produce fresh water. Using the software provided by the European Commission (<http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php>) we calculate the estimated production of electricity for an off grid 1kWp PV plant installed in Hrakleia (an arid island south of Naxos). It can reach 5.6 kWh/day at June and July, which is sufficient enough to cover the fresh water needs of the 200 permanent residents, based on information from [11].

From *fig.8* it is obvious that the wind potential is really high in the studied areas as wind speed may reach 8-9 m/s. Several studies including Ma and Lu [40], Malek et. al [41], Arafat et. al [42] were conducted in regions where high wind potential was available. Wind turbines produce vast amounts of energy and therefore wind-driven desalination plants in Greek islands can achieve great capacity factors and therefore cover the needs of the islands.

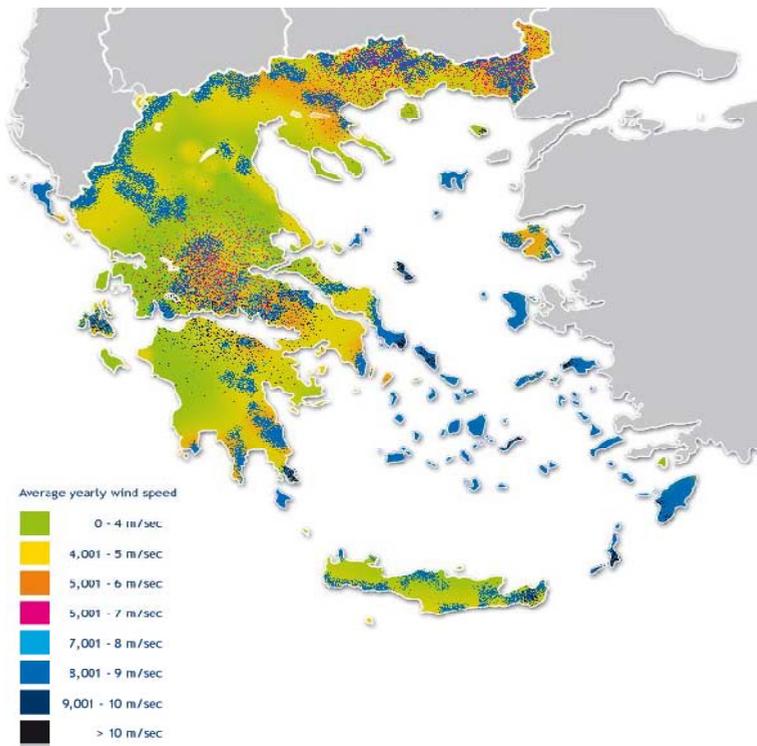


Fig.8 Annual wind speed map in Greece m/s

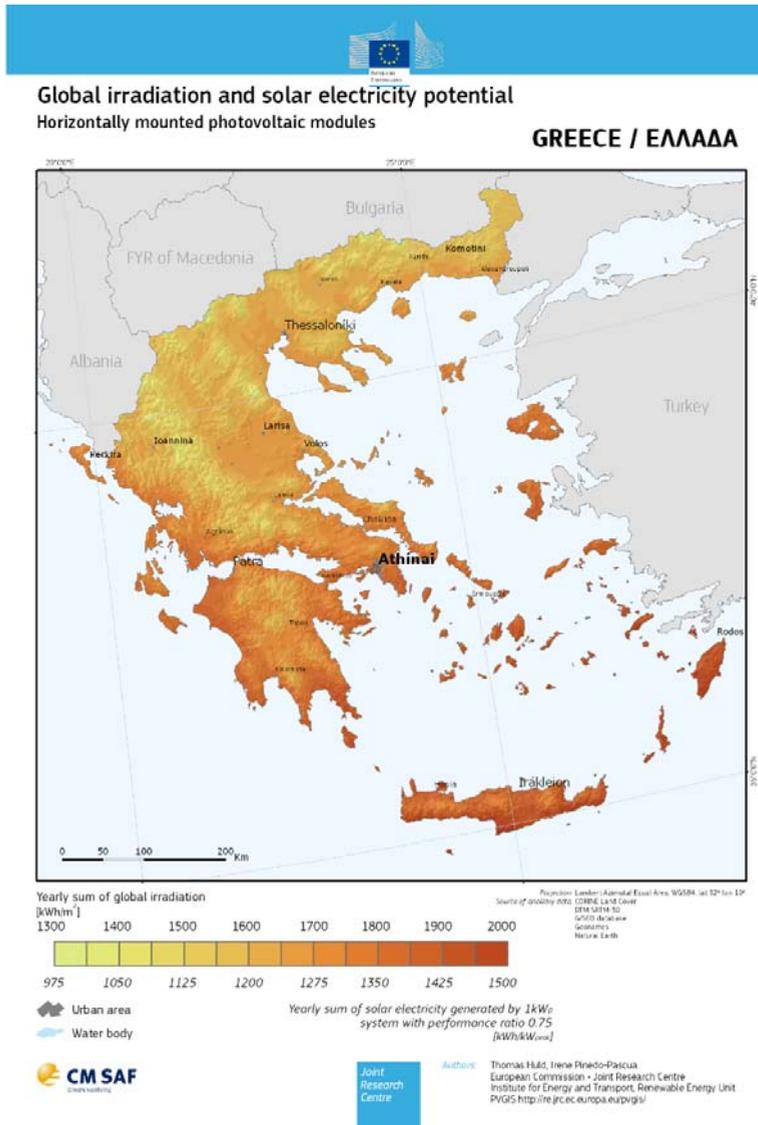


Fig.9: Annual solar irradiance in Greece kWh/m^2 [39]

4. Conclusions

Almost all Aegean Islands used to cover their needs in water by the transported one that Greek government supplied to them. This solution to water scarcity didn't face the problem, but covered it temporarily. Last years since renewable energy sources penetrated local grids many municipalities from Aegean Islands undertook projects for PV or Wind driven desalination projects. In this way, they got advantage the abundance of wind and solar irradiance they have. Apart from that the environmental impact of the old, outdated desalination units operating with diesel is really high and adds to the

already stained carbon footprint that tanker ships contribute. The Life Cycle Assessment method showed the great differences on the environmental impact between the two desalination units operating in Paros (with diesel) and in Milos operating with a wind turbine.

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