Desalination Technologies: Hellenic Experience

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Abstract

Desalination is growing very fast worldwide. However, there are still obstacles to wider implementation and acceptance of desalination in the world today such as: (a) high costs and energy use for fresh water production; (b) environmental impacts from concentrate disposal; (c) complex, convoluted and time-consuming project permitting process; and (d) limited public understanding of the role, importance, benefits and environmental challenges of desalination. In this paper a short review of desalination in Hellas is made. Data on the cost of desalination shows a decrease in the future and the potential of water desalination in Hellas. The paper summarizes the current status in southeastern Hellas (e.g. Aegean islands and Crete), and investigates the possibility for production of desalinated water from brackish water.

Keywords: Brackish water; cost of desalination; desalination worldwide; desalination plants in Hellas;

1. Introduction

Since desalination was discovered in ancient times different technologies had been developed. Aristotle, the Hellenic philosopher, in the fourth century BC, described a desalination technique by which non-potable water evaporated and finally condensed in potable. Also Alexander of Aphrodisias in AD 200, described a technique used by sailors on board. According to that the sailors boiled seawater and produced steam that was absorbed by sponges and finally was used as potable water (1). The technology of seawater desalination for the production of potable water evolved rapidly ever since and has become quite popular lately (2). Nowadays, a large number of desalination plants are in operation all over the world.

The most reliable processes that can be exploited in commercial scale can be divided in two main categories:

(a) Thermal (or distillation) processes like Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), Thermal Vapor Compression (TVC), and Mechanical Vapor Compression (MVC) processes, and
(b) Membrane processes: Reverse Osmosis (RO) and Electrodialysis (ED) processes. ED is usually used for brackish water installations while RO can be used for both, brackish and seawater (3).

A sharp increase in the number of desalination projects to supply water is indicated. This rose from 326 m^3/d in 1945 to over 5,000,000 m^3/d in 1980 and to more than 35,000,000 m^3/d in 2004. The annual new capacity has risen exponentially since 2004 to reach 68,000,000 m^3/d by the end of 2010 (4) and 79,000,000 m^3/d by the end of 2012 (5). Countries such as Israel and Singapore plant to have 30% or more of their water supplies from seawater desalination, while other Middle Eastern countries such as Saudi Arabia receive more than 70% of their water supplies from desalination (4). A very high increase of the daily produced desalinated seawater is also estimated by Lattermann and Hopner in 2008 (6).

During the last years, the production cost of desalinated water has been decreased considerably, and it is expected to decrease further (7), (8). This is due to the recent improvements in membrane technology and due to increase of the energy conversion coefficient for desalination processes (9). It is expected that in the near future the cost of desalinated water production may drop even below the cost for the exploitation of many conventional water sources. As water desalination cost is a strong function of the energy cost, novel processes, utilizing renewable energy sources are currently under development (2).

In this paper a short review of water desalination is considered, while cost data are examined and processed. This paper focuses on water desalination processes and projects in Hellas.

2. Desalination is growing around the World

During the last few years desalination of seawater is growing fast and it seems that in the future it will have a significant role to water supply. Desalination is growing particularly in the regions of the world under low water availability. Annual desalination capacity seems to increase rapidly as years go by, which related to the existing desalination plants as well as the ones under construction. To give an example, the annual increase of desalinated water was six times higher in 2007, compared to 1997 (10).

In 2000, the global production capacity of desalination plants was estimated in 22,000,000 m^3/d (1). In 2008, the total daily capacity was 52,333,950 m^3/d, while if we take into consideration the contracted desalination plants, capacity reached 62,750,220 m^3/d. At that same year, some 14,000 plants were in operation globally (11). In 2011 the total capacity was around 67,000,000 m^3/d, while in 2012 it was estimated at about 79,000,000 m^3/d. In 2012, there were some 16,000 plants worldwide (5). The Gulf Region (Middle East) hosts the main amount of desalination plants in the world, followed by the Mediterranean, South, North and Central America and Asia (12). The percentages of desalination plants for each geographical area are shown in Figure 1.

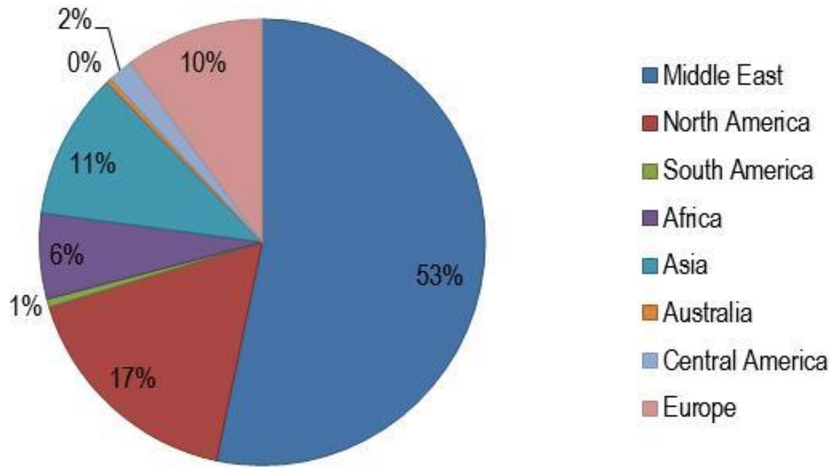

Fig. 1. World desalination plants per geographical area (%) (12).

The global capacity of desalination plants, including renewable desalination, is expected to grow at an annual rate of more than 9% between 2010 and 2016. The market is set to grow in both developed and emerging countries such as the United States, China, Saudi Arabia (SA) and the United Arab Emirates (UAE) as shown in Figure 2. A very significant potential also exists in rural and remote areas, as well as in islands (Fig. 2, rest of world, ROW), where grid electricity or fossil fuels to generate energy may not be available at affordable costs. About 54% of the global growth is expected to occur in the Middle East and North Africa (MENA) region (Pike Research, 2010), where the 21 million m^3/d of desalinated water in 2007 is expected to reach 110 million m^3/d by 2030, of which 70% is in Saudi Arabia, the United Arab Emirates, Kuwait, Algeria and Libya (13).

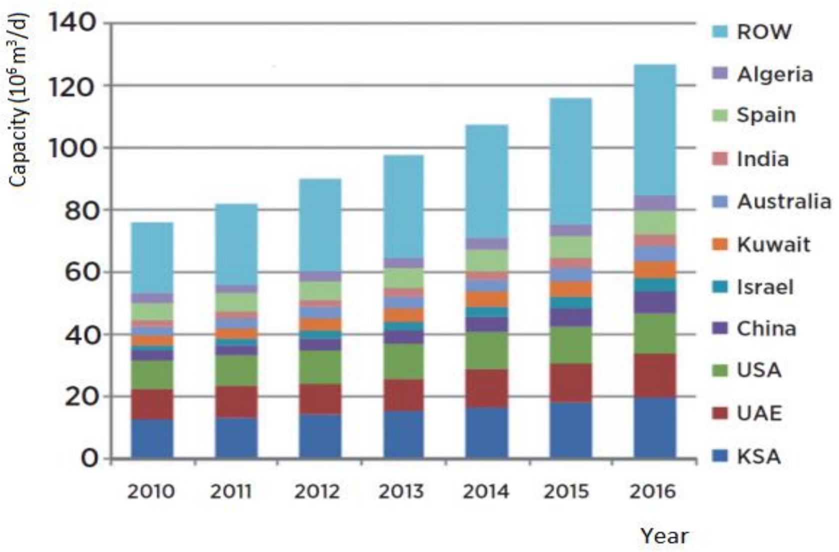

Fig 2. Global installed desalination capacity, 2010–2016 (13).

The majority of large desalination plants (in operation or under construction), use seawater and are located in the Middle East. The biggest desalination plant is the Ras Al-Khair (Ras Azzour) in Saudi Arabia, which uses both membrane and thermal technology with a capacity of over 1,000,000 m³/d, that will start its operation in 2013. The Ras Al-Khair plant will supply Maaden factories with 25,000 m³ of desalinated water and 1,350 MW of electricity. It will also supply with water the capital city of Riyadh and several central cities with a total need of 900,000 m³/d (14) (15). Another example is the 880,000 m³/d MSF "Shuaiba 3" desalination plant, that is located at the east coast of Saudi Arabia and supplies with potable water the cities of "Jeddah", "Makkah", and "Taif. Another large plant in this country is that of "Ras Al-Zour" producing 800,000 m³/d of water (16). Some of the bigger desalination plants, around the world are shown in Table 1.

Table 1
The biggest desalination plants around the world (17) (14) (15)

Country, Location	Capacity (m³/d)	Feedwater	Operation year
Saudi Arabia SA, Ras Al-Khair (Ras Azzour)	1,025,000	N/A	2013
Saudi Arabia SA, Shuaiba III	880,000	Seawater	2007
Saudi Arabia SA, Ras Al-Zour	800,000	Seawater	2007
Saudi Arabia SA, Al Jobail II Ex	730,000	Seawater	2007
UAE AE, Jebel Ali M	600,000	Seawater	2011
Kuwait KW, Al-Zour North	567,000	Seawater	2007

As far as the membrane technologies is concerned and specifically the RO desalination technology (one of the most renowned), there are big plants around the world with great potential in energy saving and reasonable cost of production (Table 2) (18). The largest membrane desalination plant in the world is that Victoria Desalination Plant in Melbourne Australia of a capacity 444,000 m³/d, started operating in 2012, but it will be soon be surpassed by the Magtaa plant in Algeria and the Soreq plant in Israel, with capacities 500,000 m³/d and 510,000 m³/d, respectively (15).

Table 2
Major RO desalination plants in the world (18) (15)

Country, Location	Capacity (m³/d)
Soreq plant, Israel	510,000
Magtaa plant, Algeria	500,000
Victoria Desalination plant, Melbourne Australia	444,000
Point Lisas, Trinidad	109,019

Tampa Bay Desalination Plant, USA	94,635

3. Desalination Status in Hellas

In Hellas, and particularly in several south-eastern regions, there is a very low water availability, which is exacerbated by the high water demand of water for tourism and irrigation in summertime. Therefore, the integration of desalinated water, treated wastewater and other marginal waters into water resources management master plants is of paramount importance to meet future water demands (19). The problem seems to be more evident in the Aegean islands (particularly the Dodecanese and Cyclades), Thessaly in Central Hellas, the eastern Continental Hellas (Sterea Hellas), the eastern Crete and the southeastern Peloponnese (Fig. 3). More specific in central Hellas (Thessaly and Sterea Hellas) there is a high water demand for agricultural irrigation (20), while in the islands the problem is mainly attributed to the increased demand in potable water during the summertime (21). That high water demand is also attributed to over exploitation of groundwater aquifers and to groundwater contamination including sea water intrusion in costal areas. In addition the small size of the islands and their geography does not allow other possible cost effective technologies to increase water availability (20).

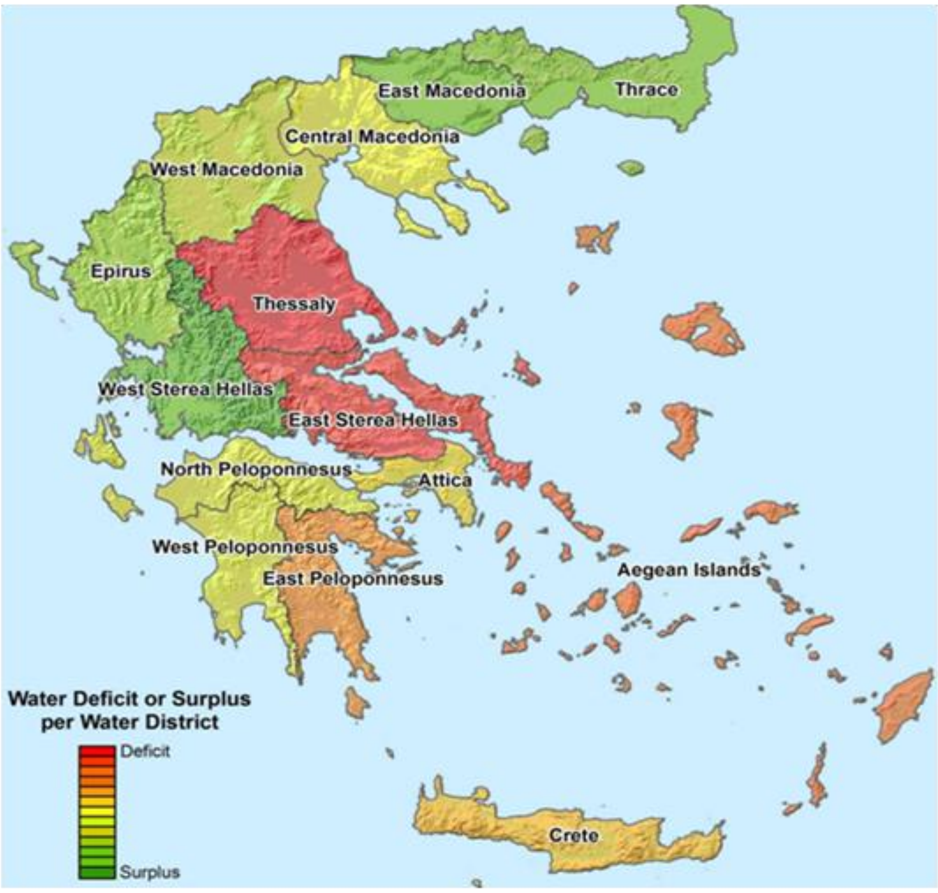

Fig. 3. Deficit and/or surplus of potable water per water district in Hellas (20).

In Hellas there are many desalination plants, especially in southeaster Water Supply and Sewerage Municipalities and big Hotels. Many desalination plants have been installed on islands, using the RO technology. Apart from the desalination plants which are owned by public enterprises, there is in operation a number of private plants, most of which are owned by hotels. A significant number of desalination plants are currently under construction or under planning.

According to the 2011 IDA Worldwide Desalting plants Inventory, there are currently 157 operating desalination plants, with a total capacity of 109,115 m^3/d, while there are presumed to be operating 35 more, with a total capacity of 40,135 m^3/d. Moreover, in 2011, there had been 5 more desalination plant under construction with a capacity reaching the 32,800 m^3/d (22).

Regarding the feedwater used 56% are used sea water, while 41% are fed with brackish water (Fig. 4). Regarding the end use of the produced desalinated water, 48.08% is used for water supply of municipalities, 31.07% for industrial use, 15.94% for cover touristic demands, and 4.24% and 0.16% for power production and water supply of military camps, respectively (Fig. 5) (22).

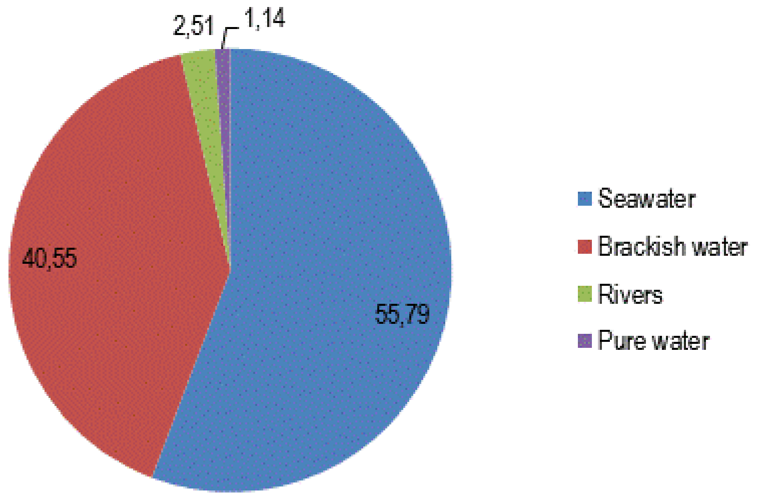

Fig. 4. Desalinated water production according to origin of the water used to feed the plant.

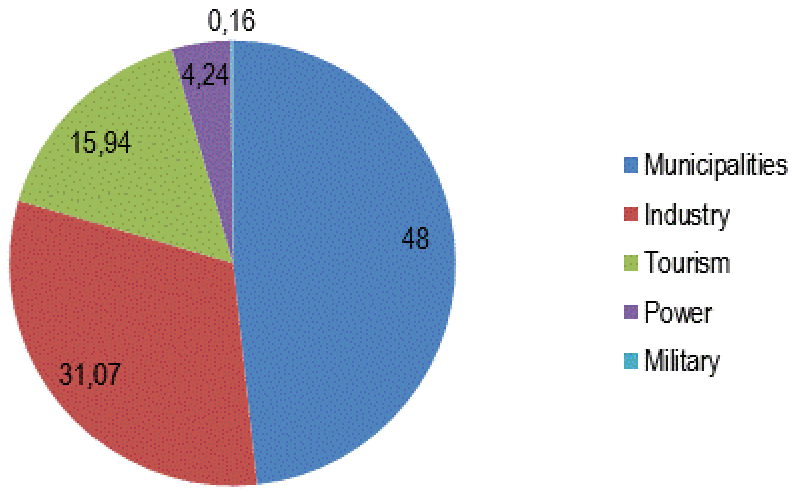

Fig. 5. Desalinated water production according to its uses, in Hellas

RO is the most popular desalinating technology in Hellas, since it produces the 74.41% of the desalinated water. ED is used for the desalination of the 10.20% of the total desalinated water produced, MED is used for the 8.47% of the produced water and MSF is used for the 6.75% (Fig. 6).

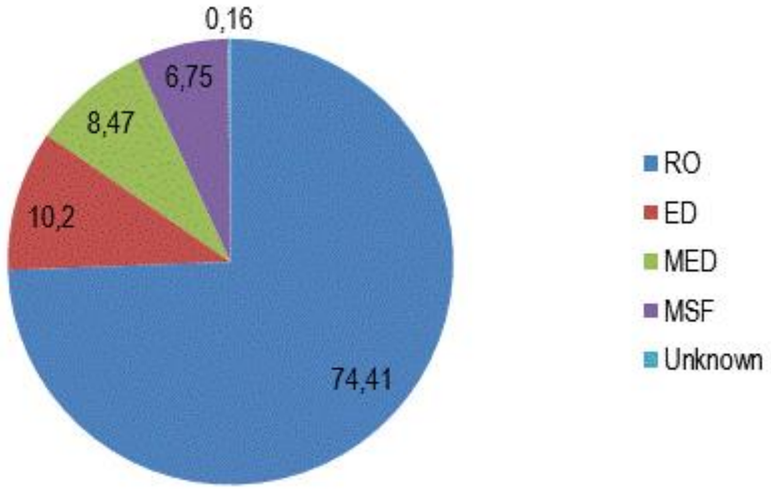

Fig. 6. Desalinated water production according to the used technology, in Hellas

There are 35 RO plants operating in the Hellenic island municipalities with total capacity of 22,860 m^3/d and operating cost ranging from 0.13 to 2.70 €/m^3 (Table 3). The newest desalination plant in Almyros (Iraklion, Crete), with a capacity of 2,400 m^3/d, is planned to operate in October 2013. This project is the first one, where the produced water will be sold by the contractor to Municipality of Iraklion, at a guaranteed price of 0.27 €/m^3 for 5 years (data from Sychem S.A.). Also a future upgrading of its capacity up to 20,000 m^3/d is planned. Note that the Almyros brackish spring, from where the plant will be fed has a capacity more than 50,000 m^3/d.

Table 3
RO desalination plants in Hellenic islands Municipalities (Data from Sychem S.A.)

Project	Year	Type	Capacity (m^3/d)	Initial Cost (M €)	Oper. Cost (€)	Contractor	Acceptance
Almyros Iraklion	2013	RO & UF	2,400	0.850	N/A	Sychem S.A., GR	Under Construction
Syros 1st Ermoupoli	1992	RO	800	0.589	2.70	Christ, CH	Good
Syros 2nd Ermoupoli	1997	RO	800	1.482	2.70	Christ, CH	Good
Syros 3rd Ermoupoli	2001	RO (SW)	40	0.346	2.00	Culligan Hellas	Good
Syros 4th (Ano Syros)	2000	RO	250	0.215	0.50	Temak, GR	Good
Syros 5th (Ano Syros)	2002	RO	500	0.400	0.50	Temak, GR	Good
Syros 6th (Ermoupolis)	2002	RO (SW)	2,000	0.313	0.40	Temak, GR	Good
Syros 7th (Ano Syros)	2005	RO	1,000	1.000	0.40	Temak, GR	Under Construction
Shinousa	2004	RO	100	0.120	0.70	Temak, GR	Under Construction
Mykonos (Korfou) old	1981	RO	500	N/A	2.00	Metek,IT	Good
Mykonos (Korfou) new	2001	RO	2,000	1.276	0.50	Culligan Hellas	Good
Paros (Naousa)	2001	RO	1,200	0.415	0.50	Ionics Itaba	Good
Tinos (old)	2001	RO	500	0.434	0.62	Culligan Hellas	Good
Tinos (new)	2005	RO	500	0.376	0.62	Culligan Hellas	Good
Ia, Santorini 1st	1994	RO	220	N/A	2.00	Matrix, USA	Good

Ia, Santorini 2nd	2000	RO	320	0.210	2.00	Culligan Hellas	Good
Ia, Santorini 3rd	2002	RO	160	N/A	2.00	Matrix, USA	Good
Sifnos	2002	RO (BW)	500	0.224	3.50	Hoh, DM	Good
Omiroupolis, Chios, Municipality, 1st	2000	RO (BW)	600	0.205	0.30	Culligan Hellas	Good
Omiroupolis, Chios, Municipality, 2nd	2005	RO	3,000	0.710	0.26	Culligan Hellas	Under construction
Omiroupolis, Chios, Municipality, 3rd	2005	RO	500	0.200	0.26	Culligan Hellas	Under construction
Nisiros (old)	1991	RO	300	0.572	N/A	Metek,IT	Out of operation
Nisiros (new)	2002	RO	350	0.295	0.66	Temak, GR	Good
Ithaki, Kefalonia 1st	1981	RO	620	0.264	2.88	Christ, CH	Good
Ithaki, Kefalonia 2nd	2003	RO	520	0.587	0.58	Judo, DE	Good
Lerou (Municipal Enterpr.)	2001	RO	200	0.074	0.13	Culligan Hellas	Good
Kassopeon (Municipality)	2001	RO	500	0.170	0.13	Culligan Hellas	Good
Posseidonias (Municipality), 1st	2002	RO	500	0.464	0.56	Culligan Hellas	Good
Posseidonias (Municipality), 2nd	2005	RO	1,000	0.574	0.45	Culligan Hellas	Under construction
Agios Georgios (Municipality)	2002	RO	500	0.102	0.30	Culligan Hellas	Good
Paksoi (Municipality) 1st	2005	RO	330	0.260	0.51	Culligan Hellas	Good
Paksoi (Municipality) 2nd	2005	RO	150	0.162	0.59	Culligan Hellas	Good
Total: 32	-	-	22,860	-	-	-	-

The average operating cost of 30 RO plants of seawater desalination (Table 3) in Hellenic islands has been estimated at 0.85 €/m³. More precisely the 4,800 m³/d capacity plant in Leros has a minimum operational cost of 0.13 €/m³, while the 500 m³/d capacity in Sifnos reaches the highest registered value of 3.5 €/m³. The range of this cost is being depicted in Figure 7 (23).

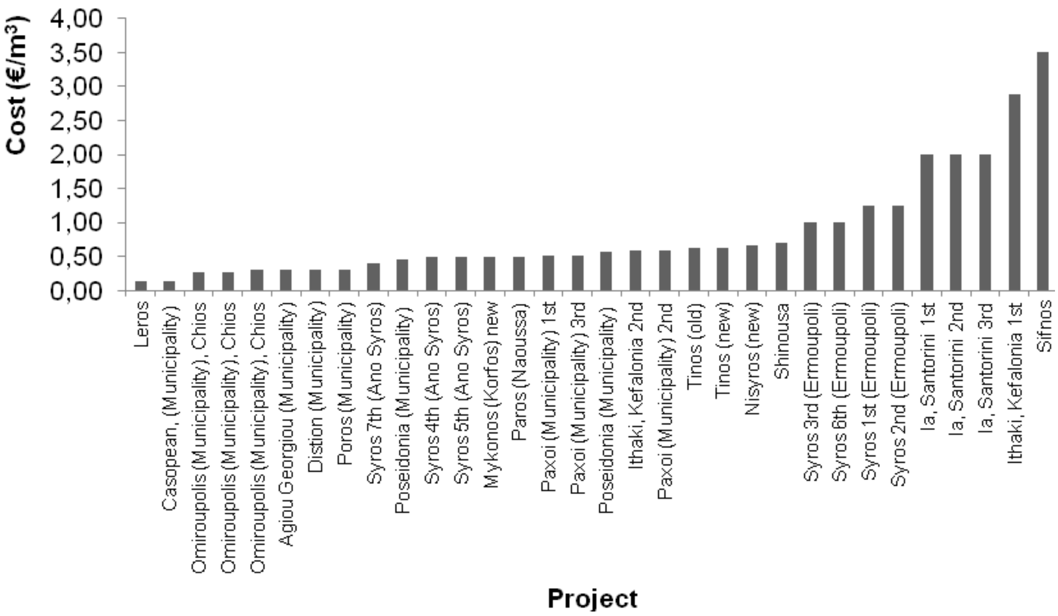

Fig. 7. Operating cost (€/m^3) of seawater RO desalination plants in the Hellenic islands (23).

The cost of desalinated water depends on the technology that is used. Moreover, as in most industrial processes, the production cost per plant is a negative function of the size of the process. Thus the cost of desalinated water in Hellas is between 0.5-3.5 €/m^3 (24)(25), however, in most cases the cost is above 1.2 €/m^3. The cost is relatively higher compared to the cost of large desalinations plants, like those operating in Israel, Malta, and Cyprus, where the cost is usually below 0.7 €/m^3 due to the size of the Hellenic plants and their age (24). However, due to the critical importance of desalinated water, it is expected that the Hellenic Government will subsidize the electric energy consumed for this purpose. In southeastern Hellas, water supply in the future is expected to be mainly based on desalination. Modern desalination processes of utilizing solar (26)(27), wind (28), or wave (29) energy, instead of fossil fuels are under development. Desalination plants utilizing renewable energy sources have also been operating in Hellas. Such plants are:
(a) A vapor compression plant charged with a 750 kW wind turbine is located in the island of Symi producing 450 m^3/d is operating since 2009.
(b) A MED plant using geothermal energy built in the island of Kimolos in 2000. This unit has a 188 m well and is considered to be a low enthalpy one (61^{o}C), capable of producing 80 m^3/d.
(c) A Hybrid RO was constructed in Keratea in 2002 combining wind turbines with photovoltaic panels. The capacity of this hybrid plant reaches 3 m^3/d, while the wind turbines and photovoltaic cells are of 900 W and 4 kWp, nominal power respectively (30).
(d) Another plant of today's capacity 3,360 m^3/d is in the island of Milos. It is a RO plant which used the electrical energy needed from an 850 kW wind turbine operating at 600 kW (31).
(e) Finally, in Irakleia island there is a removable RO desalination plant, which uses both wind and solar energy, through a 30 kW wind turbine and a backup photovoltaic panel system.

4. Production Cost of Desalinated Water

The overall cost of desalination can be divided to investment cost and maintenance-operation cost. Investment cost has to do with land, buildings and devices, as well as transportation cost, insurance, construction, legal fees and unforeseen costs. Maintenance and operation cost is divided in energy cost, maintenance, repairs, personnel/staff, spare parts, and reconstruction needed throughout the time operated. Energy cost is the higher portion of operation cost and thus a high portion of the overall cost. In many cases, energy cost can reach almost the 60% of the operation and maintenance cost. A comparison of the total cost of the RO and MSF technologies is given in Table 4 (32).

Table 4
Cost percentage in conventional RO and MSF of the same capacity in Lybia (32)

Desalination technology	Investment cost (%)	Energy cost (%)	Maintenance & repair cost (%)	Membrane replacement cost (%)	Personnel cost (%)	Chemicals cost (%)
RO (membrane)	31	26	14	13	9	7
MSF (thermal)	42	41	8	0	7	2

Cost evaluation for desalination is a difficult process as data are influenced by different factors such as energy cost, materials and labor which differ significantly from place to place. Moreover, cost is influenced by factors like desalination technology, TDS concentration of the raw water used to feed the plant, and other economic parameters that related to local conditions of each place (33). In conclusion, desalination cost is significantly decreasing when brackish water is used instead of sea water and when the capacity of the plant is increased (Table 5).

Table 5
Desalinated water production cost from sea water and brackish water (Data from the company *Veolia*)

Capacity (m^3/d)	Cost (€/ m^3)	
	Sea water	Brackish water
3,800	0.97	0.50
7,600	0.70	0.27

19,000	0.54	0.21
38,000	0.50	0.17
57,000	0.49	0.15

Membrane desalination technologies such as RO are known for their lower energy demands compared to thermal technologies which can be further reduced using energy recovery systems. Such limited energy demands have direct effect on the cost of the produced desalinated water, which in most cases is lower than the cost of water produced by thermal technologies. The RO cost per feeding water and capacity is shown in Table 6, while the cost of the most common thermal desalination technologies per capacity is shown in Table 7.

Table 6
RO desalination production cost per feeding water and production capacity (34)

Feedwater	Plant capacity (m^3/d)	Cost (€/m^3)
	<20	4.50-10.32
Brackish water	20-1,200	0.62-1.06
	40,000-46,000	0.21-0.43
	<100	1.20-15.00
	250-1,000	1.00-3.14
Seawater	1,000-4,800	0.56-1.38
	15,000-60,000	0.38-1.30
	100,000-320,000	0.36-0.53

Table 7
Thermal desalination technologies cost per technology and production capacity (34)

Thermal desalination technology	Plant capacity (m^3/d)	Cost (€/m^3)
	<100	2.00-8.00
MSF	12,000-55,000	0.76-1.20
	>91,000	0.42-0.81
MED	23,000-528,000	0.42-1.40
VC	1,000-1,200	1.61-2.13

Hybrid desalination systems, which are used to combine desalination technologies, are suitable for big installations in order to accomplish scale economies that are reducing the production cost. In such plants membrane technologies can be combined with thermal technologies and vice versa in order to reduce the cost. To give an example in a plant where the brine flow of RO is the feed flow of membrane distillation the cost is 0.94 €/m^3. In case that the system uses only RO, the respective cost would be 0.94 €/m^3, whereas the same system operating under membrane distillation has a production cost of 0.99 €/m^3. In other words when technologies are combined the double quantity of water is produced at the same or less cost than the alternatives. Another example is a MSF used in a desalination plant of 528,000 m^3/d, that produces water of 0.32 €/m^3, while when it is combined with RO its cost is reduced by 15% (33). It should be noted that the water production cost of desalination plant that uses renewable energy is estimated to be higher than one that uses conventional energy (35). An example of the cost per feeding water and energy source used is shown in Table 8.

Table 8
Cost of desalinated water production per feeding water and energy source used (34)

Feedwater source	Energy source	Cost (€/m^3)
	Conventional energy	0.21-1.06
Brackish water	Photovoltaic panels energy	4.50-10.32
	Geothermal energy	2.00
	Conventional energy	0.35-2.70
Seawater	Wind power	1.00-5.00
	Photovoltaic panels energy	3.14-9.00

A decreasing attitude is observed to the cost of desalination for production of potable water, comparing with other technologies (36). The cost decrease is occurring mostly because: (a) the expected further improvement on membrane technology (e. g. microfiltration, ultrafiltration, nanofiltration, and RO) and (b) in the comparison of desalination technologies with the conventional water sources, in the total cost of the conventional it is not taken into account treatment and transportation cost. Thus, in the future a further reduction of the desalinated water production cost is expected.

In Hellas and other Mediterranean areas several comparisons of declined water production with that of produced by conventional technologies (e.g. dams and groundwater wells) are undertaken. However, in such comparisons the rapid improvement of the RO membrane technology should be considered. In the near future it is expected that desalinated water cost (especially coming from brackish water) will be less than any other conventional technologies. It is estimated that desalination cost is lowered 4 to 5% per year due to the continuous improvement of membrane technology. Some examples of water production cost in different regions worldwide are presented:

(a) In Malta, where 70% of the total water consumption comes from desalination, cost varies between 0.30 and 0.45 €/ m^3.

(b) In Cyprus, the country with a high density of dams worldwide, the last decade potable water supply was reinforced by three desalination plants. The total cost at the two plants at Larnaca varies today from 0.45 to 0.54 €/ m^3.

(c) In Israel the cost of water production in the Ashkelon plant is around 0.50 €/m^3 (Fig. 5). This quantity consists of desalinated sea water (48%), desalinated brackish (45%) recycled wastewater (7%). The total cost for desalination at the five plants was ranged from 0.61 to 0.94 €/m^3. Increased cost is due to: (i) the technology chosen (multiple stage evaporation) for the energy consumed and (ii) very high TDS concentrations (47,000-50,000 mg/L) of sea water in the Arabic golf.

(d) In East Australia, in areas with very low water availability (Perth), water supply was based on desalination for the past 10 years. Total cost was as low 0.33–0.42 €/m^3.

(e) In Hellas and especially in touristic areas there are numerous RO containerized installations. Today the average water production cost from sea water for such technology is 0.60-0.70 €/m^3. The production cost in case that brackish water is used, ranges from 0.3 to 0.4 €/m^3 depending on the feedwater TDS concentration and the condition of operation and management (data from Sychem S.A., 2011). On the other hand, for the RO desalination plant in the island of Milos (with capacity 3,360 m^3/d and energy produced from wind turbines) the cost is 1.80 €/m^3 (39), whereas in the geothermal MED plant at the same island, the cost is less than 1 €/m^3 (30).

(f) In California, USA, there are over 20 desalination plants operating or under construction that in 2015 will reach 2,600,000 m^3/d, a quantity that covers the 15% of the total water needs (37). One of these plants (Carlsbad) with a capacity of 190,000 m^3/d, is called 'Green desalination plant' because includes environmental friendly installations, total energy reclamation as well as the respective minimization of greenhouse gasses. The plant was constructed as a BOT project and is the biggest in the US, producing 8% of the water needs in the region of San Diego. Water production cost is estimated at 0.50 €/m^3.

(g) In general the cost of RO plants constructed last years (e. g. in Tampa Bay USA in 2003 and in Singapore in 2005) have been reduced up to 1/3 in comparison with that of the plants constructed 13-18 years ago (e. g. in Bahamas in 1995, in Dekeleia, Cyprus in 1997, and in Limassol, Cyprus in 2001) (Fig. 8). Such a decrease is not only attributed to the rapid evolution of desalination technology during recent years but also to the cost reduction due to the increased size of those plants. It is difficult to quantify the effect that these parameters have, since they seem to act simultaneously (38).

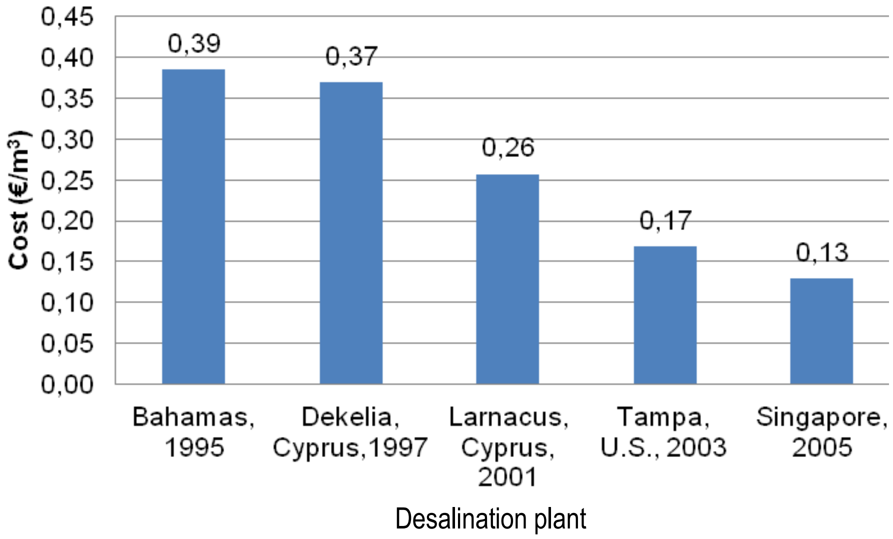

Fig. 8. Cost of desalination plants that installed between 1995 and 2005 (38).

5. Desalination Environmental Impacts

Desalination process has relatively low environmental impact. However, it has reported that the discharge of brine into the sea may erode the seashore (40) or may harm of the aquatic life (41). Moreover, to avoid unruly development of coastal areas, desalination activity should be included into the regional development plants (42).

The main environmental impacts concern is land use, brine disposal, and energy consumption. Land usage problems emerge from the fact that seawater desalination plants are situated at coastal sites, with particularly sensitive environmental habitats and many social, economic, ecological, and recreational functions. The search for an appropriate plant location has to be carried out with great care in order to minimize adverse impacts (43). Furthermore, desalination processes produce a particularly high salinity flow (brine) and its disposal directly to the sea may result to environmental consequences. Potential environmental impacts should be minimized by avoiding of discharging brine directly into the sea. Finally, as far as energy consumption is concerned, despite the great achievements in this field, still desalination processes like RO remain an energy-intensive. Since most of the energy is taken from fossil sources, the CO_2-emissions, is an issue that cannot be ignored. However, the use of modern processes and alternative energy sources can reduce the emissions of CO_2 and other air pollutants (44).

6. The Potential of Using Brackish Waters for Desalination in Hellas.

Several studies indicate that throughout Hellas, especially in island areas, million m^3/yr of brackish water are available. Only discharges of the well-known source of brackish springs (known as *Almyroi*) in Crete Iraklion are more than 500 million m^3/yr, e. g. one Almyros in the western of Iraklion city has ab average discharge of 220 million m^3/yr, quantities that correspond to 50% of the total annual water used in Crete. Today, the brackish water is not exploited. However, such water could be used either by mixing with fresh water, or during some winter months when its TDS concentration is greatly reduced. According to the measurements of Monopolis (2004), water from Almyros of Iraklion, could be used even as potable for 45-75 d/yr when the TDS < 200 mg/L, which means it could be saved about 4 million m^3/year of fresh water (25). Similar examples could one draw from islands.

7. Discussion and Conclusions

As a result of worldwide population growth, urbanization, and climate change, public water supplies are becoming stressed and tapping new water supplies for metropolitan areas is becoming more difficult, if not impossible. In the future, it is anticipated by "newwater" technologies such as desalination and direct potable reuse of treated wastewater will become an imperative (Leverenz *et al*., 2011). Desalination, especially in coastal areas, is the most cost-effective approach to long-term water supply sustainability, compared with other options.

Desalination of sea and brackish water for both water supply and irrigation in arid and semi-arid coastal regions of the world, seems to be a very promising technology. As a matter of fact, desalination is already a competitive alternative in regard with other options, as the water produced is low-priced in most cases, energy requirements have been significantly reduced and last but not least, it is friendly to the environment, especially when the process powered by renewable energy sources. Also it should be noted that the combination between desalination and renewable energy sources in autonomous independently operating desalination systems, is a unique solution for water in coastal, relatively isolated areas with weak and limited possibilities of local energy supply networks.

As far as Hellas is concerned, desalination could be a sustainable option to face water scarcity in the 'waterless' islands, especially during the summer months, when an increased water demand occurred. With adequate public support, desalination plants could become highly competitive in regard with alternatives such as water transfer from the mainland. Transfer cost varies from 4.91 €/m^3 to 8.32 €/m^3 and is currently the main way of meeting deficient water balance of the semi-arid" islands (23). Finally, desalination plants could be used as storage of redundant renewable energy in RES installations.

Today RO desalination technologies turns out to be the most appropriate in Hellas, especially for water supply of the semi-arid islands in the southeastern regions of the country. These technologies have the lowest energy requirements, which can be covered by air turbines or solar panels, e. g. renewable energy sources are abundant in those areas (such as wind and sun) and thus burdening to the minimum the rather sensitive local networks and the environment. Also RO technologies have limited spatial requirements and are adaptable to changes in productivity. Their manufacture process is simple, a feature absolutely necessary for installations in limited areas, where water demands change permanently. Finally, cost of water, which is an important criterion, is kept low, although it remains somewhat higher than in other desalination processes. However, it remains lower than the cost of transporting water, while in the case of hybrid RO system cost is kept at the lowest possible level.

All in all, the main conclusions that can rise from this study are the followings:

(a) The RO desalination cost over the last 15 years is significantly reduced. The use of alternative energy sources will further reduce the cost in the near future.

(b) Research and technology on the desalination membrane processes will continue to develop during next years to the direction of becoming friendly to the environment and cost effective.

(c) Water demand will continue to increase and desalination and water reuse will be sustainable options in increasing the low water availability.

(d) Hellas has the potential to move forward on research and technology on water management internationally and especially in the Mediterranean region as soon as investment is made in relative sectors. Focusing need to be made on the green view of the desalination technology.

(e) The use of desalination technologies to solve the problem of water shortage in the "waterless" Hellenic islands may lead, under certain circumstances, to the best economic, environmental, and social results, for both the island environment and the local communities, contributing substantially to a comprehensive and worth-living growth.

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