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Possibility of Seawater Desalination Using Reverse Osmosis Powered by Wind Energy Systems on the Island of Crete, Greece

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Abstract
The lack of sufficient water resources is a major problem in Mediterranean basin which is going to be exacerbated gradually due to climate crisis. Seawater desalination is an effective technology producing high quality potable water. Among different water desalination technologies reverse osmosis is a well-known, mature and reliable technology producing drinkable water. The island of Crete, Greece has rich wind energy resources which are currently used for green electricity generation. Wind electricity can be used in reverse osmosis desalination plants producing low-carbon potable water. The possibility of seawater desalination with reverse osmosis technology powered by wind energy in the island of Crete, Greece has been studied. It has been found that producing 20% of the potable water demand in Crete at 25.52 mil. M^3/year requires 114.84 GWh/year for powering the reverse osmosis desalination plants which corresponds at 3.83 % of the annual electricity consumption in the island. The nominal power of wind farms generating this amount of electricity is 46.82 MW_p while their installation cost is at 56.18 mil. €. Therefore, the development of reverse osmosis desalination plants powered by wind electricity is a realistic possibility for Crete in the near future. Our findings could be useful to public and municipal authorities which develop the required policies to avoid freshwater shortages in Crete in the coming decades.

Keywords: Crete-Greece, Desalination, Renewable Energies, Reverse Osmosis, Seawater, Wind Energy

1. Introduction
Climate crisis is severe in eastern Mediterranean region having adverse impacts on the local natural resources, including fresh water resources. Water availability in Crete is going to decrease according to the current projections until 2100 [1]. Greek islands have limited water resources and the development of seawater desalination plants producing potable water seems to be the best solution [2, 3]. Several seawater desalination technologies are commercially available nowadays which though require large amounts of energy [4, 5]. Renewable energy technologies,including solar photovoltaic systems, wind turbines and hybrid solar-wind energy systems, can power water desalination plants [6, 7, 8, 9, 10, 11, 12]. The island of Crete, Greece is water sufficient under the current metereological conditions but it is foreseen that it will face freshwater shortages by the end of the current century [13, 14].

The aim of the current study is the investigation of the possibility of seawater desalination with RO technology powered by wind energy in the island of Crete, Greece.

The text is structured as follows. After the literature review the water economy in Crete is examined followed by the development of wind power systems in the island. In the next two sections the seawater technologies are described followed by the characteristics of water desalination systems powered by wind energy. In the following two sections the water desalination plants powered by hybrid energy systems including solar photovoltaics and wind turbines as well as the possibility of seawater desalination with offshore wind turbines are analyzed. The text ends with estimation of the power of wind farms generating the required electricity in seawater desalination plants with reverse osmosis (RO) in Crete, the discussion of the findings, the conclusions drawn and the citation of the references used.

The current study is innovative since there are limited studies so far related to seawater desalination in Crete powered by wind energy while it fills the gap regarding the use of renewable energies in water desalination with RO in Crete. The results could be useful to public authorities, to municipalities, to hotel industry, to farmers' organizations, to technological companies related with water desalination and wind power systems as well as to all the citizens in the island affected by water shortage.

2. Literature survey

The impacts of climate change on water resources in Mediterranean region have been studied [1]. The authors stated that most climate change projections show important decreases in water availability in Mediterranean region by 2100. They estimated that in northeastern Spain the reduction in water resources in the near future is estimated in the range 25% to 34%. The use of renewable energies in seawater desalination systems in island communities has been explored [2]. The authors stated that water and energy security will be top political priorities for Greece in the future. They mentioned that several water desalination technologies can be used in Greek islands powered from various renewable energies. The water desalination potential in Greek islands using renewable energy resources has been examined [3]. The author stated that water scarcity is a serious problem in Greek islands and a temporary solution adopted is the transportation of water using tanker ships. The author also examined the use of the rich solar and wind energy resources in the Greek islands for seawater desalination. The energy consumption, the greenhouse gas (GHG) emissions and the cost of seawater desalination in China have been evaluated [4]. The authors stated that RO is the major process for water desalination in the country. The average cost of desalinated water with RO was evaluate at 0.96 $/M^3$. They also mentioned that the cost of desalinated water is higher than the cost of other water supply alternatives. The water desalination technologies have been reviewed [5]. The authors stated that the current commercial technologies include RO, multi-stage flash desalination and multi-effect distillation. They also mentioned that several renewable energies like solar energy, wind energy and biomass can be used in seawater desalination plants. The possibility of seawater desalination with RO powered by solar photovoltaic (solar-PV) electricity on the island of Crete, Greece has been investigated [6]. The author stated that powering RO plants to meet 20% of Crete's annual potable water demand would require solar-PV systems with installed capacity at 76.56 MW_p while their installation cost was estimated at 84.22 mil. €. The seawater desalination systems powered by solar and wind energy have been compared using simulation techniques [7]. The author stated that solar-PV desalination systems have better performance compared to wind energy desalination plants. He also mentioned that the cost of producing desalinated water with solar-PV energy is at 0.08 $/M^3$ while the cost of producing it from wind energy at 0.19 $/M^3$. The use of wind energy in RO desalination has been studied [8]. The authors stated that wind energy can supply the required electricity in water desalination systems. They also mentioned that using hybrid energy systems including wind turbines can increase the reliability of water desalination plants. The recent progress in wind energy-powered desalination has been reviewed [9]. The authors stated that water desalination is an energy intensive process while renewable energy technologies can provide the required power. They mentioned that wind power and hybrid energy systems including wind turbines can be used in seawater desalination. The trends in wind-powered water desalination have been examined [10]. The authors reviewed the current patents related to wind power desalination. They stated that several patents combine wind power with RO water desalination while 80 % of them during the last 17 years were originated from China. The integration of wind energy with desalination systems has been explored [11]. The authors stated that wind-powered reverse osmosis plants is one of the most promising alternatives for renewable energy desalination. They also mentioned that one of the main factors hindering the penetration of wind driven desalination is the intermittency of wind availability. The wind-powered desalination on islands analyzing the existing literature has been reviewed [12]. The authors stated that only few studies have been published related to water desalination using wind energy focused on islands while the number of studies tackling wind-powered desalination is increasing year by year. The water resources in the island of Crete, Greece have been evaluated [13]. The authors stated that under average meteorological conditions the island is self-sufficient in water resources with mean annual precipitation at around 967 mm. They also mentioned that agriculture is by far the greatest user of water (78% of total water use) followed by domestic use (21%). The management of water resources in the island of Crete, Greece has been studied [14]. The authors stated that the island of Crete has limited water resources and growing water demand. They mentioned that the smooth cooperation among the stakeholders of water resources in the island is necessary to avoid water shortages in the future. The water desalination systems integrated with renewable energies have been reviewed [15]. The authors stated that water desalination systems are energy intensive while the integration of renewable energies in them is attractive. They mentioned that the solar still distillation system is the most practical desalination technology based on renewable energies to be used in remote arid areas. The specific energy consumption in RO water desalination has been estimated [16]. The authors used empirical data to determine which operational factors affect the specific energy consumption in desalination processes. They stated that water quality affects the specific energy consumption in these processes. The feasibility of resources recovery in seawater desalination in small islands focusing on Lampedusa, Italy has been examined [17]. The authors studied the benefits from the recovery of resources from the exit stream in seawater desalination plants. They stated that recovery of water, Mg and other useful substances from brine is not economically attractive. The hybrid renewable energy systems for water desalination have been explored [18]. The author stated that 69% of desalination plants worldwide use RO technology. He also mentioned that solar energy is a vital option for hybrid energy systems powering RO water desalination but wind energy has the best performance. A water desalination plant powered from solar and wind energy has been analyzed [19]. The authors have experimented with a water desalination device using water distillation powered with solar and wind energy. The use of hybrid solar-wind energy systems to power a large-scale RO desalination plant has been examined [20]. The authors stated that solar-PV powered RO is recommended over wind power systems while for large scale plants both thermal energy and wind power dominate. A new offshore wind power-based water desalination system in northern Crimea has been studied [21]. The authors stated that seawater desalination with RO using renewable energies is the best way to solve the water shortage problem particularly in areas lacking a centralized power supply. A floating desalination platform in Egypt has been studied [22]. The authors stated that floating seawater desalination systems are environmentally friendly compared to traditional land-based desalination plants. A floating wind desalination platform has been developed [23]. The authors investigated the development of a floating system using solar and wind power for seawater desalination in Aegean islands, Greece which face severe water shortage. The multi-use floating offshore platform utilizes wind electricity, solar electricity and a seawater desalination system with RO to produce electricity and drinkable water. The use of a hybrid wind turbine-diesel-battery system for RO seawater desalination in NEOM city has been analyzed [24]. The authors made a techno economic evaluation of the system producing 100 M^3/day drinkable water estimating the return of investment at 7.8% and the payback period at 8.3 years. The water-energy nexus in the island of Crete, Greece has been studied [25]. The author stated that the annual electricity consumption in Crete is at 4,793 kWh/capita while the annual water consumption is in the range of 763.9 M^3/capita to 962.2 M^3/capita. He also mentioned that electricity generation in Crete is not significantly depended on freshwater resources while water utilization is depended on electricity. The water desalination powered by wind electricity has been examined [26]. The authors studied the seawater desalination plant with RO using wind turbines. They stated that the estimated cost of desalinated water was at 0.64 $/$M^3$.

3. The Water Economy in Crete: Challenges and Sustainable Solutions

Crete, the largest island in Greece, is known for its diverse landscapes, rich history, and vibrant agricultural sector. However, beneath its picturesque surface lies a complex and evolving challenge: managing its water resources efficiently. The water economy in Crete is shaped by a combination of limited natural freshwater availability, seasonal rainfall, growing agricultural demand, and climate change, making sustainable water management essential for the island's future. Crete relies primarily on rainwater, surface water from rivers and reservoirs, and groundwater aquifers to meet its water needs. The island has no permanent rivers, and most streams are seasonal, flowing only during the wet winter months. This natural pattern creates a strong reliance on stored water during the long, dry summers. The largest consumers of water in Crete are agriculture and tourism. Agriculture, especially the cultivation of olives, vineyards, and vegetables, accounts for around 80% – 85% of total water use. Meanwhile, tourism, which peaks during the summer—when water availability is at its lowest—also places intense seasonal pressure on water resources. Urban consumption, while smaller by comparison, is still significant, particularly in growing cities like Heraklion and Chania. Table 1 indicates the use of water resources in Crete.

Table 1: Use of water resources in Crete

Sector	Annual water consumption (%)	Annual water consumption (mil. M^3)	Annual water consumption per capita (M^3 per capita)
Agriculture	78.3	478.4	753.5
Domestic uses	20.9	127.6	201.0
Others	0.8	4.9	7.7
Total	100	610.9	962.2

Source: [13]

Several challenges strain Crete's water economy such as:

1. Seasonal and Regional Imbalances: Water availability varies greatly between regions. Eastern Crete is generally drier and more water-stressed than the west, creating an uneven distribution of supply and demand across the island.
2. Groundwater Depletion: Intensive agricultural irrigation has led to over-extraction of groundwater in many areas. This has caused aquifer depletion and salinization, especially near coastal zones, where seawater intrusion degrades water quality.
3. Climate Change: Rising temperatures, decreasing rainfall, and increased frequency of droughts are projected to further stress Crete's water systems. These shifts reduce natural recharge of aquifers and increase water demand for crops and human use.
4. Inefficient Infrastructure: Water loss due to aging and poorly maintained distribution networks is a significant issue in both rural and urban settings. In some cases, more than 30% of piped water is lost due to leaks.
5. Tourism Pressure: The tourism industry not only increases water demand but also often competes with agriculture, particularly in coastal areas where both sectors thrive.

Crete has made several strides in managing its water economy more sustainably. A combination of policy reform, technological solutions, and community initiatives is underway:

1. Water-saving irrigation techniques, such as drip systems, are being promoted to reduce agricultural water use.
2. Desalination plants and rainwater harvesting systems have been installed in some regions to augment freshwater supply.
3. The construction and maintenance of dams and reservoirs help store winter rainfall for summer use, such as the Aposelemis Dam near Heraklion.
4. Educational campaigns and pricing reforms encourage conservation among consumers.
5. Reuse of treated wastewater, especially for irrigation can help to close the loop in the water cycle.

Looking ahead, an integrated and adaptive approach will be crucial. This includes regional water planning, investment in smart technologies (such as remote sensing for irrigation), and stronger regulatory frameworks to protect aquifers and monitor water quality.

4. Electricity Production from Wind Turbines in Crete: Harnessing the Island's Renewable Potential

Crete, the largest island in Greece, is not only rich in history and culture but also blessed with abundant natural resources—particularly solar and wind energy. The island's geography and climate make it an ideal location for wind power generation, and in recent decades, Crete has emerged as a leader in renewable energy development in Mediterranean region. The use of wind turbines to produce electricity plays a key role in the island's energy strategy, contributing both to local energy security and to Greece's broader transition toward a greener energy future. Crete's position in the southern Aegean Sea provides it with strong and consistent winds, especially in the mountainous and coastal areas. The Meltemi winds, which blow during the summer months, are particularly favorable for wind energy production. As a result, the island has some of the highest wind energy potential in Europe. This has led to the installation of numerous wind farms across the island, with turbines often located in elevated or remote areas to maximize energy capture and minimize environmental and visual impacts. As of recent years, wind energy accounts for a significant portion of Crete's electricity production, alongside solar and conventional sources. The island hosts many wind parks, with a combined capacity exceeding 200 MW. These facilities feed electricity into Crete's independent power grid, which until recently operated separately from mainland Greece.

The typical modern wind turbine in Crete ranges from 850 kW to 3 MW per unit, depending on the site and technology used. These turbines are connected to local substations and distribution systems, supplying clean electricity to homes, businesses, and public services. The use of advanced grid management systems allows for better integration of variable wind power into the grid. Despite its success, wind energy development in Crete faces several challenges. One of the main issues is the island's isolated grid, which until recently limited how much wind power could be safely integrated without causing instability. Overproduction during windy periods sometimes led to curtailment of renewable energy, reducing efficiency and economic return. However, a major development that will transform Crete's energy future is the interconnection with the Greek mainland. The Crete-Attica interconnection project, partially completed, involves laying undersea cables to connect Crete to the national grid. This will allow excess renewable electricity to be exported to the mainland, improve grid reliability, and reduce reliance on polluting diesel generators that have historically been used on the island.

5. Seawater Desalination Methods: Technologies for a Thirsty World

As the global population rises and freshwater resources become increasingly strained, seawater desalination has emerged as a vital technology for addressing water scarcity. With oceans covering more than two-thirds of the Earth's surface, desalination provides a nearly unlimited supply of water. However, turning salty seawater into fresh, usable water requires advanced methods. The most common seawater desalination methods fall into two main categories: thermal processes and membrane-based technologies.

5.1 Thermal Desalination Methods

Thermal desalination involves heating seawater to produce water vapor, which is then condensed into freshwater, leaving salts and impurities behind. There are two main types:

1. Multi-Stage Flash Distillation (MSF): In MSF, seawater is heated and then passed through multiple chambers with decreasing pressure. This causes the water to "flash" into steam, which is collected and condensed. MSF is reliable and produces high-quality water, but it requires significant energy and is generally more expensive than other methods.
2. Multiple Effect Distillation (MED): MED works similarly to MSF but uses a series of vessels or "effects" where steam from one stage is used to heat the next. This reuses heat more efficiently, making MED slightly more energy-efficient than MSF. Both methods are commonly used in regions with cheap energy or where waste heat from power plants can be utilized.

5.2 Membrane Desalination Methods

The most widely used modern desalination method is Reverse Osmosis (RO), a membrane-based technology.

1. Reverse Osmosis (RO): In RO systems, seawater is pretreated to remove particles and then forced under high pressure through semi-permeable membranes that block salt and impurities while allowing fresh water to pass. RO has become the dominant method worldwide due to its lower energy consumption compared to thermal methods and its rapidly advancing technology. Modern RO systems often include energy recovery devices, which help reduce electricity use.
2. Electro dialysis (ED) and Electro Dialysis Reversal (EDR): These methods use an electric current to move salts through ion-exchange membranes, separating freshwater from brine. While efficient for low-salinity water like brackish water, ED and EDR are less effective for full-strength seawater due to energy requirements and membrane limitations.

Table 2 indicates the main water desalination technologies while Table 3 indicates the energy consumption and the clean water cost in several water desalination processes.

Table 2: The main water desalination technologies

S. No	Technology	Energy use in water desalination
1	Reverse osmosis	Electricity
2	Multi-Stage Flash Distillation	Heat
3	Multi-Effect Distillation	Heat
4	Electro dialysis	Electricity
5	Vapor Compression Distillation	Heat or electricity

Source: own estimations.

Table 3: Energy consumption and clean water cost in several water desalination processes

Desalination process	Electricity consumption (kWh/M^3)	Thermal energy consumption (MJ/M^3)	Potable water cost (\$/M^3)
Mechanical vapor compression	6-12	0	2.00-2.60
Multi-stages flash evaporation	4-6	190-390	0.56-1.75
Thermal vapor compression	1.5-2.5	145-390	0.87-0.95
Multi-effect distillation	1.5-2.5	230-390	0.52-1.50
Electro dialysis	2.64-5.50	0	0.60-1.05
Reverse osmosis of brackish water	1.5-2.5	0	0.26-1.33
Reverse osmosis of sea water	3-6	0	0.45-1.72

Source: [5]

New desalination technologies are being developed to improve efficiency and reduce environmental impact. Hybrid systems that combine RO with thermal or renewable energy sources (like solar or wind energy) are also gaining interest for their potential to lower costs and carbon emissions.

6. Harnessing the sea and wind: Seawater desalination through reverse osmosis powered by wind energy

As freshwater scarcity intensifies globally, seawater desalination has become a crucial technological solution to address the increasing demand for potable water. Among the various desalination methods, reverse osmosis stands out as one of the most energy-efficient and widely implemented technologies. However, its reliance on electricity, traditionally derived from fossil fuels, raises environmental concerns. Integrating wind power into desalination processes presents a sustainable path forward by reducing carbon emissions and promoting renewable energy use.

6.1 Reverse osmosis desalination

Reverse osmosis is a membrane-based desalination process that removes salt and other impurities from seawater. The principle behind RO involves applying pressure to saline water to force it through a semi-permeable membrane. This membrane allows water molecules to pass while blocking salts, bacteria, and other contaminants, resulting in freshwater on one side and a concentrated brine on the other. The RO process typically involves several stages:

1. Pre-treatment: Seawater is filtered to remove large particles, organic matter, and other debris. Chemicals may be added to control scaling and biofouling.
2. High-pressure pumping: The filtered water is pressurized—typically between 55 to 70 bar for seawater RO—to overcome the natural osmotic pressure and push water through the membrane.
3. Membrane separation: The semi-permeable membrane allows only water molecules to pass, producing freshwater.
4. Post-treatment: Minerals may be added back to the desalinated water for taste and health, and the water is disinfected before distribution.
5. Brine disposal: The concentrated saltwater is returned to the ocean or treated further, depending on environmental regulations.

While reverse osmosis is efficient compared to thermal desalination methods, it is energy-intensive, with energy consumption ranging from 3 to 6 kWh per cubic meter of freshwater produced. This energy demand makes the integration of renewable energy sources particularly attractive.

6.2 Synergy Between Reverse Osmosis and Wind Power

Integrating wind energy with reverse osmosis desalination offers a sustainable approach to freshwater production. The synergy between these two technologies can yield environmental, economic and social benefits:

1. Environmental Sustainability: By replacing fossil fuel-based electricity with wind energy, desalination plants can significantly reduce their greenhouse gas emissions and ecological footprints. This is crucial in regions where climate change is already exacerbating water scarcity.
2. Energy Cost Reduction: Wind energy, especially in high-wind regions, can be more cost-effective over the long term due to low operational costs. Although the initial capital investment is high, the return on investment improves as fuel costs are eliminated.
3. Distributed and Off-Grid Potential: Wind-powered desalination systems can be deployed in remote or island communities where grid access is limited or absent. This enhances water security in vulnerable areas.
4. Technological Compatibility: RO systems can be adapted to operate with variable energy inputs by incorporating energy storage systems, energy recovery devices, or by managing operational cycles in response to wind availability.

Table 4 indicates the percentage of renewable energies used in desalination systems powered by renewable energies worldwide.

Table 4: Percentage of renewable energies in desalination systems powered by renewable energies worldwide

Renewable energy source	Share of renewable energy in desalination systems powered by renewable energies worldwide (%)
Solar electricity	43
Solar thermal energy	27
Wind electricity	20
Other	10
Total	100

Source: [15]

6.3 Challenges related to wind power use in seawater desalination

Despite the potential of wind-powered water desalination, several challenges must be addressed:

1. Intermittency of Wind: Wind does not blow consistently, which can disrupt continuous desalination operations. Solutions include:
   - Energy storage systems (e.g., batteries, flywheels).

- Hybrid systems combining wind energy with solar energy or backup generators.
- Flexible desalination technologies that can ramp production up or down based on energy availability.

2. High Capital Costs: Both wind turbines and desalination plants require substantial upfront investment. However, government incentives, green financing, and public-private partnerships can help overcome this barrier.
3. Brine Management: The disposal of brine remains an environmental concern. Techniques like zero-liquid discharge and beneficial reuse are being explored to mitigate impacts.
4. Technological Integration: Seamlessly linking wind turbines with RO systems requires advanced control systems, smart grids, and predictive maintenance.

Table 5 indicates the typical cost of several renewable energy desalination systems.

Table 5: Typical cost of several renewable energy desalination systems

Process	Renewable energy used	Plant capacity (M^3/day)	Cost of clean water (\$/M^3)
Multi-effect distillation	Solar thermal energy	>5,000	2.5-3.0
Electro dialysis	Solar electricity	>100	11.2-12.6
Reverse osmosis	Solar electricity	>100	12.5-16.8
Mechanical vapor compression	Wind energy	>100	5.6-8.4
Reverse osmosis	Wind energy	>50	7.0-9.8
Reverse osmosis	Wind energy	>1,000	2.1-5.6

Source: [15]

Several pilot projects and operational facilities around the world have demonstrated the feasibility of wind-powered desalination:

a) El Hierro Island, Spain: The island runs almost entirely on wind and hydro energy and operates a desalination plant that contributes to its water supply.
b) Australia and the Middle East have launched multiple initiatives exploring wind-powered or hybrid renewable desalination solutions to ensure water security.
c) Chile's northern desert regions, with abundant wind and solar resources, have tested systems that provide water for mining and isolated communities.

These examples illustrate that, while challenges remain, the integration of wind energy into desalination processes is both technically and economically viable under the right conditions.

7. Hybrid Solar and Wind Energy Systems for Seawater Desalination with reverse osmosis in Crete

Hybrid renewable energy systems—specifically those combining solar-PVs and wind turbines—offer an innovative and sustainable pathway for powering desalination with RO in Crete. The island is particularly well-suited for such systems due to its abundant solar radiation and strong, consistent wind patterns, especially in coastal and mountainous areas. Hybrid energy systems leverage the complementary nature of solar and wind energy resources: solar energy is typically most available during the day and summer months, while wind energy can be harnessed during nights and throughout the year. This synergy ensures a more stable and continuous energy supply, which is essential for the efficient operation of desalination plants. By integrating photovoltaic panels and wind turbines, these hybrid systems can generate electricity to power reverse osmosis desalination units. The use of locally available renewable energy not only reduces greenhouse gas emissions but also lowers operational costs in the long term by minimizing reliance on imported fuels. Advancements in energy storage and smart grid integration can further enhance system reliability, allowing excess energy to be stored and used during low-generation periods. These technologies can also be scaled to meet the needs of remote communities or agricultural sectors, fostering local resilience and reducing pressure on centralized water infrastructure. Hybrid solar and wind energy systems present a promising solution for sustainable seawater desalination in Crete. By harnessing the island's natural resources, such systems can provide a reliable, environmentally friendly water supply while promoting energy independence and economic development. Table 6 indicates the renewable energy desalination systems in Greece.

Table 6: Renewable energy desalination systems in Greece

Location	Desalination method, productivity	Renewable energies used	Current status
Syme island	Vapor compression distiller, 450 M^3/day	Wind turbine, 750 kW	The system does not operate to day
Kimolos island	Multiple effect distillation, 80 M^3/day	Low enthalpy geothermal fluid at 61°C	The system does not operate to day
Keratea Attica	RO, 3 M^3/day	Hybrid system, solar-PV 4 kW_p and wind turbine 0.9 kW	In operation
Milos island	RO, 3,360 M^3/day	Wind turbine, 600 kW	In operation
Heraklia island	RO, 80 M^3/day	Floating wind turbine 30 kW and a small solar-PV system	The system does not operate to day
Strogylle island	RO, 0.85 M^3/h	Solar-PV at 10 kW_p	In operation

Source: [2]

8. Desalination Powered by Offshore Wind Farms in Crete: A Sustainable Solution for Water Security

One promising solution to water shortage in Crete is the integration of seawater desalination with offshore wind energy — a clean, renewable power source that aligns with Crete's environmental and sustainability goals. The National Climate and Energy Plan foresees the development of several offshore wind farms in Crete in the coming decades. Crete has significant wind energy potential, especially offshore, where wind speeds are higher and more consistent. Recent advancements in offshore wind turbine technology and floating platforms make it feasible to harness this energy in the Aegean and Libyan Seas surrounding the island. By pairing this abundant wind energy with desalination plants, Crete could sustainably convert seawater into freshwater, helping alleviate pressure on its natural aquifers and reservoirs. Desalination, particularly through reverse osmosis, is an energy-intensive process. However, when powered by renewable sources like wind, it becomes a much greener and economically viable solution. Offshore wind farms, once established, could provide a steady, clean energy supply directly to coastal desalination facilities. This synergy could reduce dependency on fossil fuels and lower greenhouse gas emissions associated with traditional desalination projects. Moreover, combining these two technologies could boost Crete's resilience to climate change. With rainfall patterns becoming less predictable, renewable-energy-powered desalination ensures a more reliable and independent freshwater supply. It also supports Crete's broader goals of energy independence, especially as the island transitions away from oil-fired power generation and becomes a hub for green energy in Mediterranean basin. However, challenges remain. Offshore wind projects require significant investment, environmental assessments, and careful integration into marine ecosystems. Additionally, desalination plants must be designed to minimize brine discharge impacts on coastal waters. Despite these hurdles, the long-term benefits of combining offshore wind energy with desalination — including energy security, water availability, and reduced emissions — make it a forward-thinking strategy.

9. Estimation of the power of wind farms generating the required electricity in seawater desalination plants with RO in Crete

The increasing demand for water resources in Crete, combined with their limited availability due to climate crisis, necessitates the development of seawater desalination technology to produce potable water in the island. In the current analysis it is assumed that seawater desalination using RO can meet 20% of the current domestic water demand in Crete. The domestic water demand is estimated at:

$$127.6 \text{ mil. M}^3\text{/year} \times 0.20 = 25.52 \text{ mil. M}^3\text{/year}.$$

Assuming an energy consumption of 4.5 kWh per cubic meter for seawater RO desalination, the total electricity demand in this process is approximately 114.84 GWh/year. Assuming that the capacity factor of wind farms in Crete is 0.28, a wind farm at 1 MW in the island will generate annually 2,453 MWh. Therefore, the required power of wind farms generating 114.84 GWh/year in Crete is estimated at 46.82 MW. Assuming that the installation cost of wind farms is at €1,200 per kW the total installation cost for a wind farm at 46.82 MW is evaluated at € 56.18 mil. Table 7 indicates the detailed estimation of the power of wind farms required to generate the electricity needed for seawater desalination via RO in Crete.

Table 7: Estimation of the power of wind farms generating the required electricity in the sea water desalination plants with RO in Crete

	Production of 20% of the total water demand in the domestic sector in Crete	Production of 50% of the total water demand in the domestic sector in Crete	Production of 100% of the total water demand in the domestic sector in Crete
Potable water demand	25.52 mil. M^3/year	63.8 mil. M^3/year	127.6 mil. M^3/year
Electricity demand for sea water desalination with RO	114.84 GWh/year	287.1 GWh/year	574.20 GWh/year
Electricity demand in RO water desalination to total electricity consumption in Crete (3,000 GWh/year)	3.83 %	9.57 %	19.14 %
Nominal power of wind farms generating the required electricity in sea water desalination with RO in Crete	46.82 MW_p	117.04 MW_p	234.08 MW_p
Installation cost of wind farms generating the required electricity in sea water desalination with RO	56.18 mil. €	140.45 mil. €	280.90 mil. €

Source: Own estimations

10. Discussion

The possibility of seawater desalination using reverse osmosis powered by wind energy systems on the Island of Crete, Greece has been investigated. Reverse osmosis is the dominant technology used in water desalination systems worldwide. Several studies have indicated that the cost of desalinated water depends significantly on the size of the desalination system. Several water desalination technologies and the use of renewable energies for powering the RO desalination systems have been examined. The use of wind energy, hybrid energy systems and offshore wind farms for powering the desalination plants has been examined. Finally, estimation of the power of wind farms required to generate the electricity needed for seawater desalination via RO in Crete has been made. The future predictions indicate that due to climate crisis the island is not going to be self-sufficient in water resources in the next decades. It has been mentioned that Crete has rich renewable energy potential, particularly solar and wind energy, capable to generate green electricity at low cost which can be used for powering the desalination plants that should be developed in the island. Our results indicate that the cost of wind farms generating the required electricity to power the RO desalination plants producing 20% of the water demand in the domestic sector in the island is not prohibitive. Therefore, the development of RO desalination plants and wind farms, probably coupled with solar-PV systems, powering these desalination plants is a realistic possibility for Crete in the near future. The accuracy of our estimations depends on the accuracy of the data used regarding the local requirements in water resources, the assumption for the capacity factor of the wind parks as well as on the installation cost of wind farms in Crete. Future research should be focused on a comparative analysis regarding the technical and economic feasibility of using solar-PV energy, wind energy and hybrid energy systems for the generation of the electricity required in seawater desalination plants in the island.

11.Conclusions

The possibility of seawater desalination with RO technology powered by wind energy in the island of Crete, Greece has been explored. The water economy in Crete is a delicate balancing act between natural limits and human needs.

While the island enjoys relatively better water conditions than some other Mediterranean regions and Greek islands, it still faces significant risks, especially as climate change intensifies. Wind power production in Crete is a shining example of how natural resources can be harnessed sustainably to meet energy needs. Seawater desalination has evolved into a critical solution for supplying freshwater in regions facing water shortages. As technology improves and the demand for sustainable solutions grows, the focus is shifting toward more energy-efficient, environmentally friendly, and cost-effective water desalination methods. Seawater desalination is foreseen to play an increasingly important role in securing water supplies in Crete. By combining the strengths of mature membrane technologies and wind energy, Crete having access to both seawater and wind energy can develop resilient, low-carbon water infrastructure. Our findings indicate that producing 20% of the potable water demand in Crete at 25.52 mil. M^3/year requires 114.84 GWh/year for powering the reverse osmosis desalination plants which corresponds at 3.83 % of the annual electricity consumption in the island. The nominal power of wind farms generating this amount of electricity is 46.82 MW_p while their installation cost is at 56.18 mil. €. Therefore, wind energy as well as hybrid energy systems using solar and wind energy can provide the necessary green electricity for powering the RO water desalination plants in Crete producing low-carbon potable water in the island.

12. References

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