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Use of Renewable Energy Sources for Water Desalination in Crete, Greece. A SWOT Analysis

Vourdoubas John

Consultant Engineer, 107B El. Venizelou Str., 73132, Chania, Crete, Greece

ABSTRACT: Sea water desalination is a developing technology producing potable water with many applications worldwide particularly in arid areas. It is an energy intensive process and its integration with renewable energies can produce low-carbon fresh water. Among several water desalination technologies reverse osmosis is the dominant method, based on semi-permeable membranes, producing high quality clean water. The island of Crete, Greece has moderate water resources while their demand is increasing for several reasons. Unfortunatelly, its supply is adversely affected by climate crisis. One method to increase the supply of potable water in Crete is the desalination of seawater using reverse osmosis. The water desalination plants can be powered by solar and wind energy which are abundant in the island. The integration of seawater desalination with renewable energies results in the production of fresh water with low carbon impacts. A SWOT analysis of using solar and wind electricity to power the water desalination plants in Crete has been implemented. It is indicated that there are several strengths and many opportunities for developing seawater desalination plants powered by green electricity in the island. It is concluded that the use of solar-PV and wind electricity for powering seawater desalination plants in Crete reduces the carbon footpritnt of the produced drinkable water minimizing the impacts to climate change.

KEYWORDS: Crete-Greece, renewable energies, integration, reverse osmosis, SWOT analysis, water desalination

1. INTRODUCTION

Seawater desalination is a method producing potable water used mainly in arid areas with water scarcity [1], [2]. The island of Crete, Greece is located in eastern Mediterranean region having moderate water resources which are not managed rationally [3], [4]. Water demand in Crete is increasing while its supply is decreasing due to incorrect management and the climate crisis. Among several water desalination methods reverse osmosis (RO) is currently the dominant technology which though is energy intensive [5], [6]. Crete has abundant renewable energy resources particularly solar and wind energy which are extensively used for energy generation. Green electricity generated from solar photovoltaic (solar-PV) systems and wind farms in Crete can be integrated with reverse osmosis seawater desalination plants to produce low-carbon potable water [7], [8], [9], [10]. Strengths, Weaknessess, Opportunities and Threats (SWOT) analysis is a strategic tool used in many sectors helping organizations to analyze the internal and external factors which affect their operation [11], [12].

The aim of the current work is the implementation of a SWOT analysis regarding the use of renewable energy sources for RO seawater desalination in Crete, Greece.

The text is structured as follows: After the literature survey the water balance in Crete and the water desalination technologies are stated. Next, the reverse osmosis technology used in water desalination is analyzed followed by a description of the current use of solar and wind energy for electricity generation in Crete. After that the SWOT methodology is described followed by a SWOT analysis regarding the use of renewable energies in powering RO seawater desalination plants in Crete. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used. The text is innovative since there are not many studies so far related with SWOT analysis of seawater desalination powered by renewable energies in Crete while it fills a gap regarding the production of potable water using the abundant renewable energies in the island. The results could be useful to policy makers, public authorities, municipal authorities, farmers' organizations, tourism facilities as well as to local stakeholders related to water resources in the island.

2. LITERATURE SURVEY

The advancements in reverse osmosis desalination have been studied [1].The authors stated that water desalination with RO is a very good solution to water scarcity. They mentioned that plant size, energy sources and geographical factors affect the economic feasibility of RO desalination. The seawater RO desalination has been examined [2]. The author stated that seawater desalination with RO has become one of the most important technologies in water desalination. He also mentioned that the development of low-carbon RO water desalination is necessary in the 21st century. The sustainable management of water resources in Crete has been explored [3]. The authors stated that under average meteorological conditions, with annual precipitation at around 967 mm, the island is water-sufficient. They also mentioned that agriculture is the main user of water, consuming 78% of the total water use, followed by the domestic sector consuming 21%. Additionally, they stated that water resources are unevenly distributed across the island while the western part of Crete has more water resources than the eastern part. The water management in the island of Crete has been studied [4]. The authors stated that Crete has limited water resources and growing water demand. They mentioned that the lack of cooperation among the stakeholders related to water resources has negative impacts on water management and its availability in the island. The water desalination technologies have been reviewed [5]. The authors stated that water desalination can be achieved with several processes using thermal energy, mechanical energy, electrical energy and chemical energy. They also mentioned that the main commercial technologies in water desalination include reverse osmosis, multi-stages flash desalination and multi-effect distillation. A report regarding the use of renewable energies in water desalination plants has been published [6]. The report stated that currently only 1% of the total desalinated water worldwide is based on zero-carbon green energy. It is also mentioned that solar energy is a key solution in water desalination plants in areas with high solar energy potential while wind energy is a good solution in coastal and island communities with rich wind energy resources. The possibility of seawater desalination with RO in Crete powered by wind energy has been investigated [7] .The author stated that among different water desalination technologies RO is a well-known, mature and reliable technology producing drinkable water. He mentioned that due to the abundant wind energy resources in Crete the development of RO water desalination plants in the island powered by wind electricity is a realistic possibility in the future. The RO water desalination powered by wind and solar-PV electricity has been studied [8]. The authors stated that the use of wind power and solar-PV electricity in large scale RO desalination plants is hampered by inefficiency and high cost of energy storage systems while large desalination plants are dependent on grid connection. They also mentioned that renewable energies can play an important role in stabilizing the operation and enhancing the efficiency of RO desalination plants powered by renewable energies. The use of renewable energies in a seawater RO desalination plant has been assessed [9]. The authors stated that when renewable energies are used in water desalination plants the carbon footprint of the potable water is reduced. They also mentioned that wind energy can provide the electricity needed to run a seawater desalination plant in Canary Islands, Spain. The possibility of producing drinkable water in Crete via seawater RO desalination powered by solar-PV energy has been investigated [10]. The author stated that in regions with limited water resources, like in eastern Mediterranean basin, seawater desalination with RO is expanding rapidly. He mentioned that in Crete, Greece RO water desalination can be powered with solar-PV energy. The SWOT methodology has been studied [11]. The authors stated that SWOT analysis is the most commonly used strategic planning tool to assess the internal and external factors affecting the operation of an organization. They also mentioned the advantages and drawbacks of SWOT analysis. The SWOT methodology has been examined [12]. The authors stated that SWOT analysis is a process that explores the internal and external environment affecting an organization based on its strengths, weaknesses, opportunities and threats. The use of renewable energies in seawater desalination plants has been reviewed [13]. The authors stated that water desalination requires the disposal of brines creating environmental problems while it is energy intensive using mainly fossil fuels resulting in GHG emissions. They mentioned that renewable energies can be used in water desalination plants eliminated the emissions of GHGs. The recent water desalination technologies including RO have been reviewed [14]. The authors stated that RO is the leading technology for desalination of brackish water and seawater. They also mentioned that thermal technologies still comprise an important portion of the world's desalination capacity. They proposed the hybridization between RO and thermal desalination technologies integrating renewable energies to decarbonize the produced potable water. A brackish water desalination plant with RO powered by wind energy has been studied [15]. The author stated that the smooth operation of a RO desalination plant driven by intermittent wind power is a challenging problem. He mentioned that with the use of an advanced control system the annual water deficit was reduced by 20%. The literature regarding several applications of SWOT analysis has been reviewed [16]. The authors reviewed SWOT studies historically providing a greater understanding of SWOT analysis in several sectors. They mentioned that the combined use of SWOT analysis with other techniques like PESTEL analysis can be more beneficial. The origins of SWOT analysis have been examined [17]. The authors stated that the original SWOT analysis was part of a design type of strategic theory. It was firstly emerged in California, USA during the period 1965-1972 as an innovative tool in the holistic strategic management. The use of hybrid energy systems in water desalination has been studied [18]. The authors stated that concentrated solar power can be used for thermal desalination while solar-PV electricity in membrane desalination systems. However, he mentioned, the main problem in using solar and wind energy in water desalination systems is their intermittent nature. The impacts of climate change on water resources in Catalonia, Spain have been analyzed [19]. The authors stated that most climate change projections show important decrease in water availability in Mediterranean region by the end of this century. Using hydrological and climate projection models they found that water resources in three catchments in Catalonia, Spain are going to decrease by around 25% in the period 2076-2100. The wind-powered water desalination in islands has been studied [20]. The authors analyzed the islands’ desalination needs and described the wind-powered desalination systems. They reviewed many published articles in this topic mentioning that the number of papers focused on wind-powered desalination is increasing year by year. The water desalination in Greek islands powered by renewable energies has been explored [21]. The authors examined the energy and fresh water needs, the state-of-the-art technological solutions and the cost of renewable energy desalination. They also mentioned the characteristics of pilot and commercial water desalination plants using renewable energies in Greek islands. The desalination potential in Greek islands using renewable energies has been investigated [22]. The author stated that the rich renewable energy potential in Greek islands can be used for seawater desalination replacing the use of fossil fuels. Implementing a life-cycle analysis in two RO desalination plants in Paros island using diesel oil and in Milos island using wind power, the author stated that the desalination plant in Paros island using diesel oil had significantly higher life-cycle environmental impacts compared to the system in Milos island. The water desalination systems integrated with renewable energies have been analyzed [23]. The authors stated that integration of renewable energies with water desalination plants is attractive due to increasing demand in water and energy as well as to low carbon emissions during desalination. They also mentioned that solar energy is the best alternative to fossil fuels compared to other renewable energies in water desalination. The energy consumption, the greenhouse gas (GHG) emissions and the cost of seawater desalination in China have been analyzed [24]. The authors stated that RO was the major process used in water desalination in China while the installed capacity of desalination plants increased significantly in the country during the period 2006-2016. They also mentioned that the cost of potable water with RO desalination was at 0.96 $\$/M^3$ compared to 2.5 $\$/M^3$ for the multi-effect distillation process A water desalination plant using solar and wind energy has been studied [25]. The authors stated that wind energy can satisfy the high energy consumption in desalination plants reducing the costs and the CO_2 emissions. They also mentioned that the mismatch between the intermittent availability of wind electricity and the power demand in desalination plants makes the integration of these two technologies critical. A water desalination plant using solar and wind energy has been explored [26]. The authors stated that according to United Nations China is one of the poorest 13 countries in the world in terms of water availability. They described a seawater desalination device using solar and wind energy which can be used in different environments. The trends in wind-power desalination have been examined [27]. The authors analyzed the applied patents in this field stating that China accounts for almost 80% in patents applications in the last 17 years. They mentioned that there is immense potential of integrating wind energy and RO desalination in remote areas with water shortages and without access to electricity. A hybrid solar-wind energy system to power a large-scale desalination plant with RO has been optimized [28]. The authors stated that solar-PV electricity is recommended over wind electricity while for large capacity plants the use of both thermal and wind energy is better. The use of solar and wind energy in RO water desalination in Egypt has been analyzed [29]. The author stated that when using solar-PV and wind power the energy cost in water desalination plants is less compared to the cost of using conventional energy sources. He mentioned that the cost of drinkable water is significantly lower when using solar-PV energy than wind power. The possibility of using low-enthalpy geothermal energy for thermal desalination of brackish water in Tunisia has been investigated [30]. The author stated that thermal waters having temperatures in the range of 30ºC to 80ºC can be used for thermal desalination of brackish water based on multi-effect distillation. Using SWOT analysis, the author indicated that geothermal energy is appropriate to supply remote communities with fresh water in southern Tunisia. The water desalination using geothermal energy has been studied [31]. The authors stated that the use of geothermal energy for thermal desalination can be justified only in the presence of cheap geothermal reservoirs. They also mentioned that a geothermal desalination project carried out in Milos Island, Greece has demonstrated the technical feasibility of this technology using a multi-effect distillation unit. A report regarding the use of low-temperature geothermal energy for water desalination in the western US has been published [32]. The report stated that geothermal fluids with temperature in the range of 50ºC to 90ºC cannot be used for power generation while they can be used for water desalination with membrane distillation technology. It is also mentioned that the integration of geothermal energy with water desalination using membrane distillation can produce potable water at 1.5 $\$/M^3$ compared to cost of potable water in large-scale RO desalination plants at 1.7 $\$/M^3$.

3. WATER BALANCE IN CRETE, GREECE

Crete, the largest and most populous island of Greece, is a region with diverse geography, rich agricultural activity, and a growing tourism sector. These factors contribute to high and fluctuating water demand throughout the year. Understanding and managing the water balance — the relationship between water inputs (like rainfall) and outputs (such as evaporation, runoff, and consumption) — is critical to ensuring long-term water sustainability for the island. Crete’s climate is classified as Mediterranean, characterized by mild, wet winters and hot, dry summers. The island receives most of its annual rainfall between October and March. Average annual precipitation ranges from 400 mm in the eastern and southern lowlands to over 1,500 mm in the mountainous western regions. Despite this seasonal abundance, water availability often falls short of demand during the long, dry summer period, when both agricultural irrigation and tourism peak. The island's natural water inputs come from rainfall and, to a lesser extent, snowfall in the mountains. Water is stored temporarily in surface reservoirs, underground aquifers, and natural lakes. However, Crete’s steep terrain and limited surface water storage infrastructure mean that a large portion of rainfall runs off quickly into the sea, reducing effective water capture. Groundwater plays a crucial role in balancing water needs in Crete. Aquifers, especially in lowland areas and coastal plains, are heavily used for agriculture, which consumes around 80% of the island’s water. However, decades of over-extraction have led to problems such as aquifer depletion and seawater intrusion, particularly in coastal zones. This not only reduces water availability but also deteriorates water quality.The demand side of the water balance is also significant. Agriculture remains the dominant water user, especially for crops like olives, grapes, and vegetables. Tourism which is a major economic driver places intense seasonal demand on water supplies, especially in coastal resort areas during summer. Urban consumption and industrial use also contribute to the overall water load, though to a lesser extent. Several challenges disrupt the water balance in Crete. These include climate change, which is causing more irregular rainfall patterns, longer droughts, and higher temperatures, increasing evaporation rates. Additionally, outdated irrigation methods, inefficient infrastructure, and limited water recycling further stress the system.To improve water balance and sustainability, Crete has begun adopting integrated water resource management (IWRM) strategies. These include the construction of reservoirs and dams to store winter rainfall, investments in drip irrigation systems to reduce agricultural water waste, and programs to monitor and manage groundwater use. Desalination plants and wastewater recycling are also being explored as alternative sources, especially in water-scarce regions. Moreover, public awareness and education campaigns aim to encourage water conservation among residents and tourists. Collaboration between local authorities, farmers, researchers, and policy-makers is essential to create a more resilient water management framework. Currently, Crete’s water balance is under pressure from natural and human-induced factors. Ensuring a sustainable water future for the island requires a combination of better water use efficiency, infrastructure investment, and long-term planning. With coordinated efforts, Crete can achieve a more stable and sustainable water system to support its people, environment, and economy. 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: [3]

4. WATER DESALINATION TECHNOLOGIES

Freshwater is essential for human survival, agriculture, and industry, yet over two billion people worldwide face water scarcity. With climate change, population growth, and pollution intensifying this crisis, the need for alternative freshwater sources is more urgent than ever. Water desalination that is the process of removing salt and impurities from seawater or brackish water offers a promising solution. Over the years, various desalination technologies have been developed, each with its own advantages, limitations, and applications. The most widely used method today is reverse osmosis. This membrane-based process uses pressure to force saline water through a semipermeable membrane, separating salt and other impurities from freshwater. RO is efficient, capable of removing up to 99% of dissolved salts, and has become more cost-effective due to advances in membrane technology and energy recovery systems. RO plants are prevalent in countries like Saudi Arabia, Israel, and the United States, where seawater is a critical water source.

Another common method is Multi-Stage Flash Distillation (MSF), a thermal desalination process. MSF heats seawater until it vaporizes, then condenses the steam into freshwater. This method is energy-intensive but highly reliable, often used in regions with abundant energy resources. MSF plants are particularly common in the Middle East, where they are integrated with power stations to utilize waste heat, improving efficiency. A related thermal method is Multi-Effect Distillation (MED). In MED, seawater is evaporated in a series of vessels (or effects) at progressively lower pressures, allowing for multiple cycles of evaporation and condensation using less energy than MSF. MED is used in smaller-scale applications or where energy efficiency is a priority. Emerging technologies like Electro dialysis (ED) are gaining interest, especially for treating brackish water. Electrodialysis uses electrically charged membranes to separate ions from water, making it effective for lower-salinity sources. Electrodialysis is generally less energy-intensive than RO or thermal methods but is limited in treating highly saline water like seawater. While desalination technologies have made great strides, challenges remain. High energy consumption, environmental impacts from brine discharge, and capital costs are significant concerns. Brine which is the concentrated saltwater byproduct can damage marine ecosystems if not carefully managed. Furthermore, most large-scale desalination still relies on fossil fuels, contributing to greenhouse gas emissions. To address these issues, researchers and engineers are exploring innovative solutions such as solar desalination, zero-liquid discharge systems, and hybrid plants that combine different technologies for greater efficiency. Solar desalination, for example, uses solar energy to power distillation or membrane systems, making it especially useful in sunny, off-grid regions. Water desalination technologies are vital in the global effort to ensure water security. From well-established methods like reverse osmosis and thermal distillation to newer, energy-efficient alternatives, each technology plays a role depending on local needs and resources. With continued investment and innovation, desalination will become an increasingly sustainable and accessible solution to the world's growing freshwater challenges. Table 2 indicates the main water desalination technologies.

Table 2. The main water desalination technologies

	Technology	Energy use in water desalination
1	Reverse osmosis	Electricity
2	Multi-Stage Flash Distillation	Heat
3	Multi-Effect Distillation	Heat
4	Electrodialysis	Electricity
5	Vapor Compression Distillation	Heat or electricity

Source: Own estimations

5. WATER DESALINATION WITH REVERSE OSMOSIS: A SUSTAINABLE SOLUTION TO GLOBAL WATER SCARCITY

With freshwater resources becoming increasingly strained due to climate change, population growth, and industrial demands, innovative technologies are crucial to securing a sustainable water future. One of the most promising and widely adopted solutions is reverse osmosis desalination, a process that transforms seawater or brackish water into clean, potable water. Reverse osmosis is a water purification method that removes dissolved salts and other impurities from water by using a semipermeable membrane. In this process, pressure is applied to saline water, forcing it through the membrane. The membrane selectively allows water molecules to pass through while blocking salts, bacteria, and other contaminants. The result is two separate streams: fresh water and concentrated brine.The core advantage of RO lies in its high efficiency and effectiveness. It can remove up to 99% of dissolved salts, as well as harmful substances such as heavy metals, pathogens, and chemicals. This makes it particularly suitable for producing drinking water in arid regions and island nations where freshwater sources are limited or non-existent. Moreover, reverse osmosis has become increasingly cost-effective due to technological advancements. Improved membrane materials, energy recovery devices, and optimized plant designs have significantly reduced energy consumption and operational costs. Solar-powered RO systems are also emerging as an environmentally friendly option, especially in remote or off-grid areas. Despite its benefits, reverse osmosis desalination also faces several challenges. One major concern is the environmental impact of brine disposal. The concentrated saline byproduct, if not managed properly, can harm marine ecosystems when discharged into the ocean. Efforts are ongoing to develop more sustainable methods of brine management, such as dilution, deep-sea discharge, or brine mining for valuable minerals. Another issue is the high energy demand of the RO process, which can contribute to GHG emissions if powered by fossil fuels. While energy recovery systems have improved efficiency, continued research is needed to further reduce energy use and integrate renewable energy sources. Additionally, RO membranes require regular maintenance and replacement, adding to long-term costs and potential waste generation. Therefore, reverse osmosis desalination represents a vital technology in addressing global water scarcity. Its ability to produce safe, clean water from saline sources makes it an indispensable tool for water security. With continued innovation and responsible environmental practices, RO can play a central role in building a resilient, sustainable water future for communities around the world.

6. HARNESSING SOLAR AND WIND ENERGY FOR POWER GENERATION IN CRETE, GREECE

Crete, the largest island in Greece, is known for its stunning landscapes, ancient history, and abundant sunshine. In recent years, Crete has also emerged as a key player in Greece's energy transition, utilizing its rich renewable energy potential, particularly solar and wind energy, to reduce dependence on fossil fuels and enhance energy sustainability. With its favorable Mediterranean climate and strong wind conditions, the island is ideally positioned to become a model for clean energy development in the region. Solar energy plays a significant role in Crete's renewable energy mix. The island enjoys over 300 days of sunshine per year, making solar-PV systems highly effective. Residential rooftop panels, small-scale installations, and larger solar farms contribute to the island's electricity supply. Technological improvements and declining costs have made solar power more accessible, even for individual households and businesses. Moreover, Greece's supportive policies and EU funding programs have further encouraged solar adoption across the island. Wind energy is another crucial renewable source for Crete. The island's mountainous terrain and coastal geography create strong and consistent winds, especially in the northern and central regions. Wind farms have been developed in various parts of Crete, producing a significant share of the island's electricity. These installations reduce reliance on imported oil, which historically powered Crete's isolated grid. Wind turbines in Crete often operate at high capacity factors, indicating both reliability and efficiency in local conditions.

Despite these advances, Crete's renewable energy efforts have faced several challenges. One key issue is the island's limited grid infrastructure. For many years, Crete operated an isolated electricity grid, which restricted the amount of variable renewable energy it could accommodate without risking instability. During periods of high solar or wind output, some renewable power had to be curtailed due to insufficient storage or transmission capacity. To overcome this, a major milestone was achieved in 2021 with the completion of the Crete-Peloponnese interconnection, linking the island's grid to mainland Greece. This underwater cable allows surplus renewable energy generated in Crete to be exported to the mainland and enables more stable electricity imports when needed. A second, more powerful interconnection is also in progress, which will further improve grid resilience and support increased renewable penetration. Another consideration is environmental and community impact**.** While renewable projects are crucial for sustainability, local concerns about landscape disruption, noise from wind turbines, and the impact on wildlife must be carefully addressed. Future development must balance energy goals with environmental protection and community involvement. Crete aims to become carbon-neutral in its energy sector by increasing renewable capacity, investing in energy storage technologies, and promoting energy efficiency. Projects like hybrid solar-wind systems, battery storage facilities, and smart grids are being explored to maximize the benefits of renewables. Crete's use of solar and wind energy highlights the island's strong potential to lead Greece's clean energy transformation. With abundant natural resources and growing infrastructure, Crete is well-positioned to become a blueprint for sustainable power generation, not just for Greece but for island regions around the world. Table 3 indicates the share of renewable energies in desalination systems powered by renewable energies worldwide**.**

Table 3. Share 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: [23]

7. SWOT ANALYSIS: A STRATEGIC PLANNING TOOL FOR SUCCESS

In the fast-paced and competitive environment in several sectors, strategic planning is essential for making informed decisions. One of the most widely used tools in strategic analysis is the SWOT analysis. Standing for Strengths, Weaknesses, Opportunities, and Threats, SWOT is a simple yet powerful framework that helps organizations evaluate their internal capabilities and external environment. By identifying these four key elements, decision-makers can build effective strategies, minimize risks, and maximize potential. SWOT analysis is a structured planning method that provides a clear snapshot of where an organization currently stands. It is often used in organizations during planning, market research, project development, and self-assessment. The analysis is typically represented in a 2x2 matrix, divided into internal factors (Strengths and Weaknesses) and external factors (Opportunities and Threats).

a) Strengths are internal characteristics that give an advantage over others. These may include skilled personnel, strong brand reputation, proprietary technology, financial stability, or loyal customers.

b) Weaknesses are internal limitations or areas where improvement is needed. Examples include poor infrastructure, lack of experience, outdated technology, limited resources, or inefficient processes.
c) Opportunities are external chances for growth, improvement, or success. These might include emerging markets, changes in consumer behavior, technological advancements, or favorable government policies.
d) Threats are external challenges that may negatively affect performance. These include competition, economic downturns, regulatory changes, supply chain disruptions, or negative public perception.

SWOT analysis is used across various fields and industries. Non-profit organizations can use SWOT to strategize operations, assess community needs, and set realistic goals. Its versatility and simplicity make it accessible and valuable across different sectors. One of the main advantages of SWOT analysis is its clarity and ease of use. It does not require complex tools or software and can be completed quickly with basic knowledge of the organization. It promotes critical thinking, encouraging users to honestly evaluate their position and understand both internal and external influences. SWOT analysis also enhances strategic decision-making. By having a clear picture of what works and what doesn't, organizations can focus their resources on areas with the highest return while preparing for potential threats. Despite its usefulness, SWOT analysis has some limitations. It is often subjective, relying on the perspectives and assumptions of those conducting the analysis. This can lead to bias or an incomplete picture if not all relevant factors are considered. Another limitation is that SWOT does not prioritize the factors identified. While it lists strengths or threats, it doesn't indicate which are most critical. For this reason, SWOT analysis is often used in combination with other tools like PESTLE analysis (Political, Economic, Social, Technological, Legal, Environmental) or Porter's Five Forces for a deeper strategic assessment. Table 4 indicates a 2X2 matrix for SWOT analysis

Table 4. A 2X2 matrix in SWOT analysis

	Helpful factors	*Harmful factors*
Internal factors	Strengths	Weaknesses
External factors	Opportunities	Threats

Source: own estimations

8. SWOT ANALYSIS OF SEAWATER DESALINATION USING REVERSE OSMOSIS POWERED BY SOLAR-PV AND WIND ENERGY IN CRETE

The strengths, weaknesses, opportunities and threats of using RO seawater desalination powered by solar-PV and wind energy in Crete are stated below.

8.1 Strengths

1. Abundant Renewable Energy Resources: Crete enjoys high solar irradiance and strong, consistent wind patterns, making it an ideal location for renewable energy generation. Utilizing solar-PV and wind power to operate RO desalination plants significantly reduces dependence on fossil fuels and lowers greenhouse gas emissions.
2. Mature Technology: Reverse osmosis is a well-established and widely adopted desalination technology. Coupling it with renewable energy systems has already been demonstrated in various global projects, offering a proven path forward with known technical and operational parameters.
3. Energy Cost Savings in the Long Term: Although the initial capital investment for renewable-powered desalination is high, operating costs are generally lower compared to conventional desalination using grid electricity or diesel generators. Over time, the decreasing costs of solar and wind technologies will further enhance economic feasibility.
4. Water Security and Climate Resilience: Desalination provides a non-rainfall-dependent source of freshwater. By diversifying Crete's water portfolio, this approach increases resilience against droughts and climate change impacts.
5. Mitigation of climate change: Seawater desalination with RO powered by renewable energies produces potable water with low-carbon content. Therefore, it contributes in climate change mitigation.

8.2 Weaknesses

1. High Initial Capital Costs: Establishing desalination infrastructure along with renewable energy systems involves significant upfront investment. These costs can be a barrier for local governments and may require external funding, subsidies, or public-private partnerships.
2. Intermittent Energy Supply: Solar and wind energy are inherently variable. Without adequate storage systems or hybrid grid connections, ensuring a stable and continuous supply of electricity to the RO desalination plants could be challenging.
3. Environmental Impact: While desalination addresses water scarcity, it produces brine which is a highly concentrated saltwater byproduct that must be responsibly managed to avoid ecological damage to marine environments. Additionally, the physical infrastructure may impact local ecosystems and landscapes.

4. Technical Complexity and Maintenance: Integrating renewable energy with desalination requires careful engineering to balance load demands. Maintenance and skilled operation are critical, especially in remote areas with limited technical capacity.
5. Stakeholders’ cooperation: The cooperation among the stakeholders related to water resources in the island is not smooth.

8.3 Opportunities

1. Tourism and Agricultural Support: Crete’s economy heavily depends on tourism and agriculture which are both water-intensive sectors. Providing a reliable freshwater supply can support economic stability and growth, especially during dry seasons when demand peaks.
2. Innovation and Research Leadership: By investing in renewable-powered desalination, Crete can position itself as a leader in sustainable island water management. It can attract academic research, EU funding, and international partnerships for green infrastructure development.
3. Job Creation and Local Industry Growth: Developing and maintaining these systems can create new jobs in the fields of renewable energy, engineering, and environmental management, helping to diversify the island’s employment base.
4. Financial support from EU structural funds: The investments in RO desalination plants powered by renewable energies in Crete can by partly subsidized by EU structural funds.
5. Energy-Water Nexus Synergy: Coupling desalination with renewable energy opens doors for broader energy-water management strategies, including grid stabilization through demand-side management and distributed energy systems.

8.4 Threats

1. Climate Variability Affecting Renewables: Ironically, the same climate changes that reduce freshwater availability can also affect wind and solar patterns. Anomalies in weather could impact renewable energy generation reliability.
2. Regulatory and Bureaucratic Barriers: Greece’s regulatory framework and bureaucratic processes can slow down large infrastructure projects. Delays in permitting, environmental assessments, or public opposition to coastal developments could hinder implementation.
3. Competing Land Use and Aesthetic Concerns: Renewable installations and desalination facilities require land and access to coastal zones. Competing uses such as tourism development or environmental protection can create local opposition.
4. Economic Uncertainty and Funding Risks: In times of economic instability or shifting political priorities, long-term infrastructure projects like renewable desalination may face funding cutbacks or deprioritization.

Table 5 indicates the strengths, weaknesses, opportunities and threats of using RO seawater desalination powered by solar-PV and wind energy in Crete.

Table 5. Strengths, weaknesses, opportunities and threats of using RO seawater desalination powered by solar-PV and wind energy in Crete

Strengths	Weaknesses
Abundant Renewable Energy Resources, Mature Technology, Energy Cost Savings in the Long Term, Water Security and Climate Resilience, Mitigation of climate change.	High Initial Capital Costs, Intermittent Energy Supply, Environmental Impact, Technical Complexity and Maintenance, Stakeholders’ cooperation.
Opportunities	Threats
Tourism and Agricultural Support, Innovation and Research Leadership, Job Creation and Local Industry Growth, Financial support from EU structural funds, Energy-Water Nexus Synergy.	Climate Variability Affecting Renewables, Regulatory and Bureaucratic Barriers, Competing Land Use and Aesthetic Concerns, Economic Uncertainty and Funding Risks.

Source: own estimations

9. DISCUSSION

A SWOT analysis regarding the use of renewable energies in RO seawater desalination in the island of Crete, Greece has been implemented. Water demand in Crete is increasing while the island has abundant solar and wind energy resources which can be used in powering desalination plants. The use of renewable energies for water desalination in Crete is complying with three out of seventeen sustainable development goals of United Nations such as: a) Good health and well-being, b) Clean water and sanitation, and c) Climate action [33]. Our results indicate that RO water desalination can be developed in Crete meeting part of the water demand in the island. Solar-PV and wind electricity can power these plants, which are energy intensive, producing low-carbon drinkable water. Although the development of water desalination plants in Crete requires upfront investments they can provide fresh water in the island covering its increasing demand in water resources. The integration of solar and wind power systems with seawater desalination plants can contribute in the production of low-carbon potable water using mainly local renewable natural resources. The implemented SWOT analysis is subjective based on personal views while it does not prioritize the factors identified in SWOT analysis. The disposal of the co-produced brine has not been analyzed in our work. Future research should be focused in the implementation of PESTEL analysis on the same topic and compare the results with the results of the present study.

10. CONCLUSIONS

A SWOT analysis regarding the use of renewable energy sources for RO seawater desalination in the island of Crete, Greece has been implemented. The main findings are summarized below.

a) The island of Crete, Greece faces increasing water demand. Seawater desalination can increase the supply of fresh water in the island. Reverse osmosis is the main water desalination technology used worldwide today,
b) Crete has abundant solar and wind energy resources which are currently used for electricity generation by solar-PV systems and wind farms,
c) RO water desalination is energy intensive process while locally generated solar-PV and wind electricity can power RO desalination plants in the island,
d) SWOT analysis is a vital tool in the strategic planning toolkit. It provides a structured and balanced way to evaluate internal strengths and weaknesses alongside external opportunities and threats,
e) The implemented SWOT analysis indicates that RO seawater desalination powered by solar-PV and wind energy in Crete has many advantages and various drawbacks. There are several opportunities and various threats regarding the development of seawater desalination plants powered by renewable energies in Crete.

Conclusively, seawater RO desalination can supply potable water in Crete covering part of the demand. Seawater desalination plants can be powered by solar and wind electricity generated locally in the island resulting in the production of low-carbon drinkable water.

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