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Review

Economic analysis of an off-grid solar PV for small scale desalination unit

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A B S T R A C T

Water scarcity, water quality difficulties, floods, and droughts are among the present challenges that climate change may exacerbate. Availability and easy access to safe and clean drinking water are fundamental human rights that have become a global challenge. Desalination of seawater is becoming a fast-growing alternative for water scarcity, due to the significant quantity of energy required to perform this procedure and also a large amount of CO_2 emission into the atmosphere while producing this energy, renewable energy is a significant alternative energy source as well as a readily available source of clean energy. Wind and solar power, in particular, can provide significant economic benefits by bringing electricity to rural areas without transmission lines. The off-grid Photovoltaic (PV) system is one that is not linked to the power grid. This means that the entire amount of energy produced is stored and used on-site. The specific goal of this study is to identify and assess the use of renewable energy for an off-grid photovoltaic system in small-scale desalination units, aiming to reduce water demand in an environmentally friendly manner. The data used are secondary in nature, primarily summarizing different articles and papers from previous research. The method used in this study is a meta-analysis (a literature review). This paper concluded that an off-grid solar PV system for small-scale desalination units is a cost-effective environmental solution because generating energy from renewable sources has no or less environmental consequences and reduces air pollution.

1. Introduction

The scarcity of water, issues with floods, water quality, and droughts are all current problems that may become even more severe as a result of climate change. Water is a critical resource for both socioeconomic growth and environmental conservation. Changes in temperature and precipitation as a result of shifts in the availability of water resources, affect all involved sectors [1]. In some regions, the effects of climate change will make water scarcity worse, while in others, it will reduce runoff (most notably the Mediterranean region, parts of Europe and Central Europe, as well as Southern America and Southern Africa) both the climate and the water systems are strongly linked to one another [2]. For example, the changing climate has an effect not only on the amount of water that is used but also on its quality and quantity. When temperatures rise, water consumption typically goes up, particularly for irrigation, while it goes down when the number of precipitations increases. The effects of climate change can be made worse when they strike regions that already have limited water resources and frequently experience droughts, which can lead to an imbalance between the amount of water demanded and the amount supplied. This implementation of environmental impact targets as a result of the impacts of climate change, such as the emission of greenhouse gases into the atmosphere all over the world, has highlighted the necessity to adopt alternative energy sources capable of meeting demand while causing minimal environmental damage. Renewable energy is a major alternative energy source and widely available source of clean energy. However, in order to promote and attract investors interested in installing solar energy systems for power generation, the economic viability of the projects must be evaluated. Economic analysis is basically a cost-benefit analysis. It begins by ranking projects based on their economic viability to better allocate resources. Its purpose is to evaluate the welfare impact of a project. It is also used to determine how efficiently the economy or a component of it operates; however, it is an efficient approach to determining the adequate use of scarce resources. An off-grid PV system is one that is not linked to the power grid. This means that the entire amount of energy produced is stored and used on-site. Off-grid photovoltaic systems use energy stored in a battery bank to power themselves. The PV system is an electric power system that generates usable solar power via photovoltaics. The process of removing salt from seawater is known as desalination.

Seawater desalination is and will continue to be an important procedure in many places of the world where fresh water is scarce. However, every desalination technique uses a substantial quantity of energy during the process. Traditional energy sources are causing growing concern, not only due to rising costs but also to pollution issues caused by the combustion of fossil fuels. Traditional centralized water systems gather and filter water from fresh, brackish, or marine sources prior to transferring it to distant urban areas due to water scarcity in some areas (in particular the Middle East) for uses or distance from the water whereby water is transported, and they are closer to the seawater [3]. Among the basic and fundamental human rights is access to good and clean water for their daily basic needs. Hence, the study of solar energy has been conducted for decades so as to trim down the high cost of solar panels and at the same time enhance the efficiency of these panels, therefore making it a very practical renewable source. One potential solution, desalination, has been plagued by issues such as high energy requirements and harmful byproducts. As a result, recent research on solar-powered desalination has the potential to be a game changer and one of the most effective solutions to the present water issue. As such, this will give access to tap into an almost infinite supply of water while emitting no harmful pollutants. Water desalination has been practiced for thousands of years; hence it is important to study the economics of off-grid solar PV to know if it's a viable solution for small-scale desalination units. In many places today, using renewable energy sources (RES) to power desalination devices is a practical technique for producing fresh water. Renewable energy-powered desalination systems are especially promising for isolated areas where connection to the public electrical grid is either prohibitively expensive or impracticable and where water shortage is acute. RES desalination will become more attractive as technologies advance and as clean water and inexpensive conservative energy sources become scarcer. Several solar, wind, geothermal, and hybrid solar/wind desalination plants have been installed, the majority of which are limited-capacity demonstration projects [4]. The most significant advantage of using renewable energy is its long-term viability. This means it will never be depleted. On the contrary, fossil fuels will be depleted eventually. They do not emit any toxic gases that contribute to air pollution and, eventually, global warming. As a result, these sources are eco-friendly. Some sources, particularly wind and solar power, can provide significant economic benefits by bringing power to rural areas where transmission lines are lacking. They can also help to stabilize energy prices because the price tag of renewable energy is highly dependent on invested capital rather than the increasing or decreasing cost of fossil fuels. Renewable energy sources provide much more consistent power. This is as a result of the fact that wind turbines and solar panels are widely distributed and modular, respectively. This means that even if some equipment fails, the rest can continue to function normally and provide power to consumers. Last but not least, the renewable energy sector can employ many people because there is still a lot of wind, biomass, and solar potential to be explored globally, including in Pakistan [5]. Solar is the most adequate renewable energy source on almost all Philippine islands, despite some islands having relatively low potentials or high space constraints. Wind resources are only available in varying degrees of feasibility on a few islands. Combining the physical, socioeconomic, and energy potential characteristics for the majority of sample islands, solar photovoltaic-battery systems may be deemed a viable backbone for energy systems with different wind power capabilities [6].

Renewable energy is among the most important steps you can take to reduce your environmental impact. Reliable power resources and fuel variety provided by renewable energy improve renewable sources, reduce the likelihood of fuel leaks and reduce the need for imported fuels. Renewable energy as the most recent and advanced form of energy also helps to conserve the nation's natural resources. Electricity can be generated from renewable energy sources with less environmental impact. Carbon dioxide (CO_2), the primary cause of greenhouse gas emissions, can possibly be minimized by generating electricity from renewable sources. Furthermore, renewable energy reduces the effects of coal mining and gas extraction, hazardous pollution, toxic accumulation in our air and water, and debris. The Supreme Council of Energy has announced a determined plan to generate 20% of Egypt's total energy demands from renewable sources by 2020. Renewable solar energy sources in Egypt can play a very useful role in combating the energy shortage [7]. This study aims to identify and assess the use of renewable energy for an off-grid photovoltaic system in small-scale desalination units, with the objective of reducing water demand in a manner that is environmentally friendly. The world's solar energy map can be seen in Figure 1. This explains how solar energy can be harnessed and converted into a renewable energy source for global electric power solutions.

2. Literature review

2.1 Objectives

The main goal of this section is to compare different articles of economic analysis of an off-grid solar PV system for small-scale desalination units to:

- Identify the economics of an off-grid solar PV system for the desalination unit
- Evaluate the cost-effectiveness of desalination using an off-grid solar PV system
- Determine the benefit of using off-grid solar PV for desalination units.

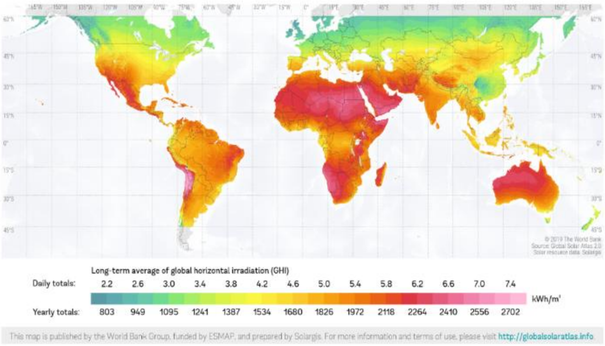

Figure 1. Global solar atlas

Different studies have been done on the economic analysis of renewable energy as a viable solution for desalination units. Thus, this section summarizes the main findings from these articles. Fadhila et al. demonstrated the viability of a photovoltaic grid-connected system for electrifying a seawater desalination plant. The findings revealed an interest in the hybrid system as a key solution to the electrification-generation process for an Algerian desalination plant. The optimal hybrid PV-grid-connected system configuration produced 3,054.32 MWh/year of PV power, accounting for 67 percent of the renewable fraction. Furthermore, the system met 100 percent of the primary charge and returned to the grid more than the purchased electricity, with an estimated annual income of $199,114/y from electricity sold to the grid [8]. Photovoltaic electricity prices have fallen dramatically in the last five years to levels comparable to unsubsidized electricity rates in areas of high solar irradiation in the Middle East and other arid regions where water desalination capacity needs to be expanded. When both the direct and fuel subsidy costs of electricity generation are considered, our analysis shows that using PV to power RO desalination plants results in significant cost savings. Thus, by implementing PV-powered desalination plants, freshwater demand in arid and sunny regions could be met cost-effectively while reducing air pollution caused by combustion [9]. According to Huseyin Oner, the PV/SWRO system appears to be one of the fastest evolving technologies in our analysis due to its feasibility and economies of scale in the production of both PV cells and desalination membranes. The findings of this thesis demonstrate that solar desalination is feasible and profitable in areas with limited water resources. Small PV/SWRO plants are expected to become cheaper than Grid/SWRO plants in the future, allowing every country with seawater and solar energy to use this technology to meet rising water demand [10]. The cost of PV-powered water pumping and desalination has been considerably lowered compared to prior studies due to the utilization of bigger system sizes, system optimization, and low-energy membranes. Only crops with high yields, relatively low water requirements, and optimal sites with shallow groundwater depths, low salt feed water, and strong solar irradiation were found to be lucrative for PV water pumping and desalination [11]. Rômulo de Oliveira Azevêdo et al. found that economic viability cannot be based just on lowering capital expenses, but also on lowering operating and maintenance costs and expanding electricity generating capacity. Brunini et al. observed that while the PV system had a greater initial cost than the others, the yearly cost of power was zero, demonstrating a superior efficiency in energy generation of this system in comparison to other sources [12]. Energy costs, which make up a majority of the cost of desalination and represent more than 30% of the total cost, determine the economics of using renewable energy sources in desalination. According to feasibility studies carried out by researchers or developers in Egypt, the cost of conventional desalination based on fossil fuels is still lower than the cost of desalination using renewable energy. However, the cost of renewable energy technologies is fast declining, and in distant areas where the cost of energy transmission and distribution exceeds the cost of distributed generation, renewable energy-based desalination can compete with conventional desalination [13]. Solar thermal desalination technology might be a potential solution to the world's mounting water problems. The economics of solar desalination, on the other hand, is determined by a number of factors, including but not limited to the cost of water, the cost of grid energy, and the efficiency of each component (solar collector, desalination subsystem, etc.) [14].

The product flow rate and the salinity of feed water appreciably affected the specific energy consumption [15]. The research revealed that utilizing wind to power a desalination facility is economically advantageous at 145 of the 193 sites, while using solar is preferred at the other 48. Although both solar and wind resources are abundant in Texas, wind's extremely high-capacity factors over much of the state allow wind to offer the lowest-cost power [16]. The findings of this study support the use of reverse osmosis (RO) technology in conjunction with solar Photovoltaic (PV) units as an economically viable option for brackish water desalination. Obtaining economic data has revealed that the RO-PV system is a cost-effective desalination option to use [17]. According to the American Society of Mechanical Engineers, for off-grid systems, solar photovoltaic powered electrodialysis (PV-ED) has been justified as a more cost-effective alternative than the present dominant reverse osmosis technology. The system was designed to produce potable water cost-effectively using off-shelf components and has been operating since early 2017 with some downtime. In India, the rapid drop-off in the cost of renewable energy generation and the increased awareness of environmental sustainability have led many to explore photovoltaic-RO (PV-RO) desalination in many countries which have freshwater shortages [18]. RO systems that are powered by PV panels provide a number of benefits, including low operational costs, ease of operation, environmental friendliness, high reliability, simplicity of installation and maintenance, and suitability for use with brackish water [19]. Previous studies related to this topic have been listed in Table 1 (Appendix).

3. Designing a desalination unit

This section discusses briefly the factors for designing a desalination unit powered by renewable energy and also how the plant is designed.

3.1 Water Demand

Half a billion people live in water-stressed or water-scarce countries, and that number is expected to rise to three billion by 2025 due to population growth. Population and income growth will drive up demand for irrigation water to meet food production needs as well as household and industrial demand [46]. Drought is currently a widespread phenomenon around the world. Drought has hit many isolated areas in Greece, particularly the Aegean islands [47]. The problem worsens in the summer when tourism increases water demand by up to 4-5 times that of the winter. Most islands' existing water stocks cannot meet such rising demand; thus, the problem must be addressed with long-term and viable solutions. As a result, seawater desalination can play an important role in a long-term solution to the problem [48]. Hence, helping ease water scarcity is one of the driving factors for designing a desalination unit.

3.2 Energy

The need for generating energy to power the desalination unit has environmental impact targets as a result of the effects of climate change, such as the emission of greenhouse gases into the atmosphere, this has been one of the factors for the need to adopt alternative energy sources capable of meeting demand while causing minimal environmental damage around the world. As such, designing a desalination unit powered by renewable energy. Renewable energy is a significant alternative energy source as well as a readily available source of clean energy.

3.3 Plant design

Below is a block diagram (Figure 2) of a proposed water desalination plant that combines PVT and RO technology. It is assumed that the feed water source is a brackish water reservoir. This source is sufficiently large to provide a constant mass flow to the system, a portion of which flows through the PVT array to gain thermal energy and reduce the PV cell temperature in the array.

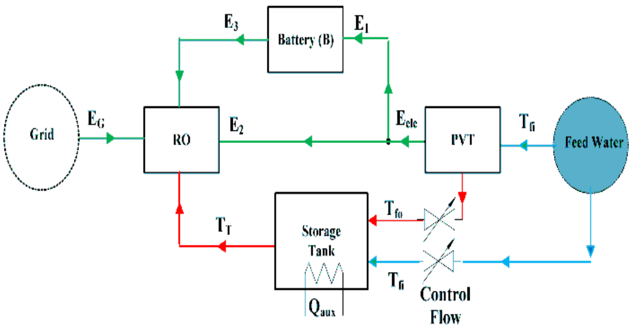

Figure 2. Diagram for PVT- and RO-based technology system for water desalination plant (T refer to thermal and E refer to electrical energy).

The PVT array tilts to track the sun's path. At night or when the air temperature is too low, the feedwater is routed around the PVT array to prevent heat loss. To maximize the benefit of acquired thermal energy over time, a thermal storage tank with a fixed volume is utilized. If the temperature in the storage tank falls below a certain minimum threshold, supplementary heating is available. As a result of its lower viscosity, the heated water stored in the tank provides a constant flow to the RO, and its higher temperature reduces the electrical power requirements of the system's various pumps. On the electrical side of the system, the PVT array provides as much electrical power as possible for pumping needs. The system stores excess electricity generated during the day in a battery for use at night. After the battery is depleted, the remaining electrical needs are met by grid power, particularly in the early morning hours [49].

3.4 The energyergy required for desalination plants powered by solar energy

Antonyan examined two major parts to better understand the energy requirements for solar-powered desalination plants (membrane and thermal technologies). Membrane methods use approximately five times less energy than thermal methods. As a result, it is more cost-effective to combine renewable energy sources with membrane technologies rather than thermal ones. Solar energy is mostly combined with brackish water RO, seawater RO, and brackish water ED. However, some MED desalination plants are still powered by solar energy. The energy consumption of these plants ranges from 18.2 to 25.8 KWh/m^3. The energy demand of brackish water RO ranges between 0.9 and 29.1 KWh/m^3. There is a wide range of energy requirements, which is highly dependent on the capacity of the desalination plant, which can range from 100 m^3/day to several hundred m^3/day. The total average energy consumption, however, is 10.2 KW h/m^3. The energy demand for seawater RO is also given in a wide range, ranging from 2.4 to 17.9 KW h/m^3, with an average energy consumption of 5.5 KW h/m^3. According to the study, brackish water ED has the lowest energy demand ranging from 0.8 to 3.2 KW h/m^3, with an average energy consumption of 2 KW H/m^3[50].

4. Discussion

In this section, we will look at the main findings from previous studies conducted and also the objectives of these studies. From the different findings, a few problems with off-grid solar PV for desalination were observed during the study. These problems are discussed below:

The major problems facing desalination using off-grid PV are climate conditions and the initial cost of implementing the PV for desalination. First, we need to understand the full term of climate, which is a long-term weather pattern of an area, location, or region, typically an average of 30 years. In this meaning, using the off-grid for desalination, the term climate factor needs to be considered, between winter and summer. Where there is extreme and high-temperature weather favored more for using off-grid. But in a location where there is low temperature, no excess of energy or required energy is expected to manage the solar PV. However, most of the problems associated with climate and off-grid solar PV for desalination are during winter when energy is not abundant, which sometimes cannot operate the reverse osmosis to function in pressuring water. Moreover, the installation of the off-grid Solar PV is costly (expensive). Many of the isolated villages cannot afford off-grid solar PV installation. And also, there are a lot of technical issues, there is always a need for proper maintenance. Ironically, the majority of water-stressed areas are also energy-stressed. In some circumstances, the expense of adding grid electricity may be too expensive. The difficulty is magnified in rural/remote areas such as highlands and islands.

4.1 Solution

The findings determined the kind of solution desired; meanwhile, there are different problems that required different solutions for off-grid solar PV systems for desalination units. However, the solution may vary depending on the location. In some locations where water is being transported from a distant city, and the climate condition is favorable, the use of an off-grid solar PV system for desalination will be in consideration. Solar requires energy from the sun, and the energy that comes from the sun is clean energy, to that fact, the solution for using off-grid solar desalination depends on this basis, without batteries, solar-powered reverse osmosis is the best aspect that is available when needed of the day. Off-grid reverse osmosis technology directly uses solar, wind, or wave energy, using the natural force of gravity, the reverse osmosis process receives its required feed: pressurized seawater. It ensured that the salt water cache always contains water for constant fresh water production. In some aspects, the use of off-grid solar PV for desalination can generate water of 10L/h, using a solar off-grid costs less than electricity since energy is stored in a battery. Moreover, it is an abundant and free source of clean energy on the planet. Since it requires energy from the sun for reverse osmosis power, in summer, more energy is expected, and it gives freely more than enough/required for desalination. Despite the fact that using off-grid solar PV will have more environmental significance since it has zero carbon emission and also has no effect on the environment. It is considered to be environmentally friendly. Small plants for remote consumers in areas where there is no electrical network and population density is low. PV panels will be used to provide electricity to power reverse osmosis system pumps.

5. Conclusion

In Conclusion, an off-grid solar PV system for small-scale desalination units is a cost-effective solution for the environment this is because generating energy from the sun does not have any environmental impacts, and it reduces air pollution. Also, when the implementation cost and the operation cost of this system are compared to that of the traditional system for generating energy, the solar PV system cost less while the traditional systems are more expensive to work with because of the large amount of capital that it requires for electricity. Furthermore, a solar PV-powered system has more advantages than any, which can be seen widely as the system doesn't run out, unlike fossil fuel, also the absence of harmful gases, i.e. environmentally friendly than other sources of energy. However, it is also cost-effective and has less pollution. According to the majority of these articles, the cost of PV-powered systems has decreased over time, making them less expensive as compared to the early stages of transforming to solar PV systems for desalination units. Consequently, this system can be used especially in rural areas where freshwater availability is inadequate. It will be placed on the site to desalinate the water to be free of harmful substances and meet the demand of the populace. In this reviewed study, using off-grid solar PV for small-scale desalination is recommended. However, for which photovoltaic-battery systems would be the favorable backbone of a future energy system based on renewable energies it was considered to be environmentally friendly and cost-effective. In the prospect of the reviewed research, it will be the most used technology and economically accessible alternative. It was also recommended for the cost and the use of it in the future as it will solve many future challenges. The climate condition of the location should be studied over a long time period to know whether the climate condition will be favorable to power the off-grid solar PV for desalination.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The author declares no potential conflict of interest.

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Appendix I

Table 1. List of previous studies

Ref.	Year	Location	Aim	Method	Data	Main Findings
[7]	2015	Egypt	This study defines the main economic parameters used in the estimation of desalination costs and limitation of the stand-alone, small-size SWRO plants powered by photovoltaic (PV) at the northwest coast of Egypt. Moreover, a techno-economic study is made to estimate the actual cost of m3 /freshwater production on real field measurements.	Modeling Software (HOMER Energy LLC) was used in conjunction with Desalination Economic Evaluation Program 4.0 (International Atomic Energy Agency) desalination software to examine the techno	water, All cost estimations will be based on the prevailing prices during 2012–2013 and with the exchange rate of about 6.75 Egyptian Pound (LE) for US$1.	In the future, the use of nuclear or renewable energy for desalination may be cost-effective. The cost of desalination using the PV/RO system battery-less is 9.3–5.6 LE/m^3. The investment cost present 87.9% of the total project cost; the operation and maintenance cost present 12% of the total project cost. The cost of a water unit can decrease dramatically if we use conventional sources of energy; however, even at this level of cost, the PV/RO system could provide the necessary quantities of potable water for a small zone, like the area selected in the northwestern coastal, at a cost not far from that of water hauling.

[8]	2019	Algeria	To demonstrate how a reverse osmosis desalination system coupled to a solar system connected to the grid (hybrid PV-Grid) may be a sustainable choice for meeting Algeria's and the world's rising fresh water needs.	The research methodology (economic modelling)	In the first phase, research data such as determining local meteorological resources and estimating the electrical demand for the RO unit were collected. The second phase included modeling of the PV generation subsystem using the HOMER software based on input parameters (technical and economic parameters of the system components), Load profile, weather data, and limitations parameters). The energy balance criteria (EB), net present cost (NPC), and levelized cost of energy are used in the third phase (COE)	The findings revealed an interest in the hybrid system as a significant option in the electrification-generation process for an Algerian desalination plant. The ideal hybrid PV-grid-connected system design produced 3,054.32 MWh/year of PV power, which accounts for 67% of the renewable component According to the findings, global solar radiation is the most impactful variable on energy costs, PV production, and grid sales. It is obvious that this option is technically and economically sound, and environmentally suitable for small and medium-sized marine plants, but troublesome for giant plants
[9]	2016	Saudi Arabia	This paper presents up-to-date performance and cost analysis of reverse osmosis (RO) desalination powered with PV connected to the Saud	Modeling Software (HOMER Energy LLC) was used in conjunction with Desalination Economic Evaluation Program 4.0 (International Atomic Energy Agency) desalination software to examine the techno	CPV is $0.16/kWh, whereas that from CdTe PV is $0.10/kWh and $0.09/kWh for fixed-tilt and one-axis tracking systems	we infer that there are great business prospects associated with large deployment of PV-RO plantsin the greater Middle East, and we estimate the reduction in regional CO2 emissions from such deployment.

[10]	2019	Northern Cyprus	to research and debate solar-powered seawater desalination as an alternative option for the Water Supply Project in order to deliver the same quantity of water yearly to the region by utilizing the island's sun energy potential and available desalination technology.	Economic Feasibility, data acquisition	RET Screen energy project modeling software for generator and grid calculations, LCOE, Microsoft Excel, NREL SAM, and RETScreen 4 renewable energy project evaluation software for CSP, PV, and Wind systems.	In the study, the PV/SWRO system appears to be one of the quickest emerging technologies due to the practicality and economies of scale in the manufacture of both PV cells and desalination membranes. The findings of this thesis demonstrate that solar desalination is practical and profitable in areas with limited water supplies. Small PV/SWRO facilities are predicted to become cheaper than Grid/SWRO plants in the future, allowing every country with seawater to benefit. and solar energy would use this technology to meet increasing water demand.
[11]	2015	Jordan and Palestine.	This research offers a complete assessment of medium to large-scale variable speed PV pumping and desalination systems. System performance is evaluated using hourly simulations over the course of a year. Simulating a wide range of system topologies, including three types of power supply, yields optimal system configuration There are four different inverter configurations, four different membrane types, two different RO system recovery rates, and energy recovery device possibilities. Crop salt tolerance, water needs, yields, and net profits are among the agricultural criteria used to determine crops most suitable for desalination in agriculture. An economic analysis is performed to determine water unit pumping and desalination costs, return on investment, internal rate of return, payback periods, and total lifetime costs.	Simulations, System Modelling and MATLAB, Economic analysis	Primary economic indicators such as the water unit desalination cost (WUDC), water unit pumping cost (WUPC), and total water unit cost (TWUC) were used to evaluate and optimize the design of the system.	The cost of PV-powered water pumping and desalination has been greatly reduced compared to previous research due to the use of larger system sizes, system optimization and low-energy membranes. The use of PV water pumping and desalination for agriculture was found tobe profitable only for crops with high returns, fairly low water requirements, andideal locations with shallow groundwater depths, low salinity feed water and highsolar irradiation.

[12]	2020		The goal of this study is to give a systematic analytical framework for identifying and analyzing the primary parameters that influence the financial feasibility of solar energy plant construction projects.	Research	Articles	It was determined that economic feasibility cannot be determined just by lowering capital expenses, but also by lowering operating and maintenance costs and boosting power generating capacity. Brunini et al. observed that while the PV system had a greater initial cost than the others, the yearly cost of power was zero, demonstrating a superior efficiency in energy generation of this system in comparison to other sources.
[13]	2020	Abu Dhabi	The primary goal of this research is to demonstrate and assess the feasibility of using solar energy to power a RO system using photovoltaic cells (PVC) to desalinate either brackish or saline groundwater pumped from shallow groundwater aquifer systems in the western region of Abu Dhabi Emirate, with salinities ranging from 5,000 to 20,000 ppm.	Simulation, Economic analysis	IMSDesign software, the initial cost of the PV system is consideredin this research.	PVsyst findings revealed that during a working time of 10 hours with batteries, the PV panels will deliver enough energy in all seasons. In the summer, though, the panels will offer more energy than the load.
[14]	2020	7 Coastal cities in the United States	To create a technoeconomic model that evaluates the feasibility of combining solar collectors with thermal desalination systems. The techno-economic model seeks to forecast the economics of a multi-stage solar flash distillation system.	Economic analysis (the National Renewable Energy Laboratory's (NREL)HOMER software was used), Simulation	Cost of solar collectors per unit area, typical cost of photovoltaic modules	Solar thermal desalination technology might be a potential solution to the world's mounting water problems. The economics of solar desalination, on the other hand, are determined by a number of factors, including but not limited to the cost of water, the cost of grid energy, and the efficiency of each component (solar collector, desalination subsystem, etc.).

[15]	2015	Alamogordo, New Mexico	To investigate the techno-economic feasibility of using renewable energy to power distant, rural desalination facilities.	qualitative research	Constant 896.24 83.68 10.71 <0.01 Flow rate 10.09 3.27 3.08 <0.01 Temperature 2.49 2.27 1.10 0.28 Conductivity 0.56 0.02 30.88 <0.01 R-squared 94.04% F-statistic 357.73 Adjusted R-squared 93.7% Prob (F-statistic) 0.00 Predicted R-squared 93.17% Number of observations	The product flow rate and the salinity of feed water significantly affected the specific energy consumption
[16]	2019	Texas, United state.	To assess the technical and economic viability of using these renewable forms of energy to power desali-nation facilities.	Quantitative analysis	$24.61/kgal and $7.38/kgal when powered by solar PV and wind respectively	The analysis showed that using wind to power a desalination facility is economically preferable at 145 of the 193 sites; solar was preferable at the remaining 48 sites. Solar and wind resources are both abundant in Texas; however, the particularly high capacity factors for wind across much of the state helps wind deliver the lowest cost electricity.
[17]	2018	Jordan	investigates the feasibility of using solar energy coupled to reverse osmosis (RO) units for the desalination of brackish water	data were processed and categorized using Excel software package, and then inserted into GIS software	The average desalination cost for the produced water is calculated at US$0.183/m3 compared to US$0.346 /m3 where the produced water costs can reach US$ 0.314 /m3 compared to US$ 0.105 /m3	The results obtained in this study favour the usage of reverse osmosis (RO) technology coupled with solar Photovoltaic (PV) units as an economically feasible alternative for brackish water desalinationObtained economic data showed that RO-PV system is an economical feasible desalination alternative

[18]	2018	South India	To present preliminary results from an ongoing field pilot of a village-scale PV-ED system in Chelluru, which is a small village in South India.	Simulation	Preliminary data, Experimental data	Solar photovoltaic powered electrodialysis (PV-ED) has been justified as a more cost-effective alternative for off-grid systems than the present dominant reverse osmosis technology. The system was designed to produce potable water cost-effectively using off-shelf components and has been operating since early 2017 with some downtime. Including India, the rapid decrease in the cost of renewable energy generation and the increased awareness of environmental sustainability have led many to explore photovoltaic-RO (PV-RO) desalination in many countries which have freshwater shortages
[19]	2016	Babil, south Iraq	To estimate an optimum PV system to power the RO that produces 20 l/h (0.35 M3/day) at constant daily load profile.	quantitative and simulation	=(3120 *0.8*0.85)/(1350.8) = 1.58 day = 38 h	The RO systems powered by PV panels have many advantages, such as lowest operation cost , simple operation , environmentally friendly , easy installation and maintenance, high reliability and suitability for brackish water.
[20]	2020	Saudi Arabia	To investigate the feasibility of combining Saudi Arabia's existing thermal and membrane desalination facilities with various solar energy technologies, such as concentrated solar power and photovoltaic, in order to generate drinkable water while remaining economically viable.	Analytic Process and Practical process	Pilot plant, PT, CRT,LFR	Combining a MED thermal desalination plant with technology and running them without thermal energy storage found to be more cost-effective under specified climatic conditions..
[21]	2016	Myanmar	This study focuses on the problems of shifting from a country with limited access to electricity to a renewable energy-based economy reinforced by photovoltaics (PV). We investigate the viability of PV-powered desalination systems for the Ayeyarwady and Tanintharyi regions based on optimization modeling and analyses of Myanmar's present energy constraints.	economic modelling	price of water for economic sustainability should be approximately US$0.0224/litre	According to a review of the technical and economic viability of a standalone solar-powered desalination plant, the required water price for economic sustainability should be around US$0.0224/litre. According to our economic modeling, the biggest capital cost is the installation of PV and maintenance.

[22]	2019	Abu Dhabi (UAE), and Perth (AUS),	The aim of generating electricity at low cost and in a sustainable way	Economic research, A thorough mathematical model for the PV system was created using information from the literature. Surprisingly, the model can forecast the cost of a PV system in terms of capital cost and energy cost per kWh based on input data such as solar irradiation, daylight duration, and technical specifications of an actual solar module	input data of solar irradiation, duration of daylight and technical specification of a real solar module	The planned solar farm should be placed in a bright and well-lit position to reach an electricity cost of 0.1 €/kWh or less and to compete with the cost of power from other sources. The suggested model's cost is consistent with the International Renewable Energy Agency's (IRENA) 16 most current estimates for solar power costs, which range from 0.05 to > 0.20 USD/kWh depending on area. The IRENA research provides for a comparison with Mohammed bin Rashid Al Maktoum's current and cost-competitive solar park in the UAE, which has a projected capacity of 1 GW for 2020 and will be able to generate power for 5.85 USD/kWh (IRENA, 2016)
[23]	2017	USA	The purpose of this article is to analyze the total returns for investors that invest primarily in PV and ES-based PV systems using a return on investment (ROI) economic analysis.	economic analysis A Microsoft Excel tool is provided for computation of the ROI	(1) a home without a PV system or an ES	A 7kW PV system without ES is the most cost
[24]	2019	Saudi Arabia	This dissertation illustrates the big picture of the Kingdom of Saudi Arabia regarding the current status of power generation, consumption, and the expected increase in power demand & supply, as well as availability and assessment of the most effective renewable energy resources	a techno-economic analysis of a gridconnected solar PV-wind hybrid system, Simulation	the duration of the project Capital costs	A 7kW PV system without ES is the most cost
[25]	2016	South India	This paper carries out a techno-economic analysis of various sizing combinations of systems with solar photo voltaic, wind energy and stored energy in batteries for production of drinking water from a brackish water source.	Simulation, Economic analysis	Online Solar Radiation Meter, meteorological data	From the results obtained by simulation, we can see that addition of capacities of PV panels or wind turbines or storage capacities does not help in reduction of the cost of energy. But, when the capacities are supplemented with solar PV and wind turbines, we find that we are able to meet the load requirements at lower energy costs. This is mainly because of the fact that when there is no solar insolation after day hours, the wind gets stronger. This complements each other and supplies energy at lower costs.

[26]	2016	Saudi Arabia	To introduce the KAPSARC Cost Calculator for estimating the efficacy of using solar power as an energy source for desalination.	Comparative	The costs of four different solar-powered desalination techniques are compared withthree baseline scenarios: RO grid-powered, MSF cogeneration and MED cogeneration	The findings show that Saudi Arabia's present policy of adopting thermal desalination technology only makes economic sense with the current regulated fuel prices. Raising fuel prices to market levels will encourage the use of more energy-efficient RO, lowering the total primary energy used for desalination.
[27]	2021	Australia	In order to create a case study for Winton in Queensland, we incorporated relevant meteorological data in our simulations. Furthermore, the research investigates the viability of including a thermal desalination technique that uses waste heat from the power block to produce clean water from wastewater. Finally, this paper investigates the optimal ratio of concentrated solar thermal and photovoltaic power generation in terms of Levelized Cost of electricity and water production.	Simulation, Economic analysis	Meteorological data, cost of electricity, cost of renewable energy	After comparing the LCOEs of the CST system and the hybrid PV + CST system, it was determined that the hybrid system is more convenient, attaining a lower LCOE due to the cheap cost of power generation by PV technology without batteries. Although PV power generation is less expensive, the lack of batteries restricts maximum PV production to 30% of total system electricity generation. The optimum power generation ratios are 27.5% and 72.5% by PV and CST systems, respectively; it essentially has the same LCOE as employing a greater PV electricity output, but it creates more clean water due to the additional CST system operation.
[28]	2015	Faisalabad, Pakistan	To assess the design and economics of an off-grid PV system using the life cycle cost technique to deliver the needed electrical energy for a modest family residence in the climatic conditions.	The economics evaluation using life cycle cost (LCC) analysis of the complete system has also been carried out	14.8 kW cycle cost and unit electricity cost have also been calculated to be PKR. 31,963	They conclude that the unit cost of power generated by an off-grid PV system is cheaper than the unit cost of regular grid electricity supplied to residential areas.
[29]	2019	Tripoli, Libya	The purpose of this study is to determine the economic feasibility of a 100 m3/day saltwater reverse osmosis desalination facility.	Quantitative Analysis	Desalination using the PV-RO system cost 7.77 €/m3, whereas the RO-Solar Rankine system cost up to 12.53 €/m3.	Economic research revealed that employing an On-Grid PV power system to power the facility had the optimum benefit-cost ratio in both monetary and environmental aspects. Compared to either using Grid or Off-Grid PV
[30]	2017	Dhahran, Saudi Arabia	To perform an economic and environmental feasibility study of switching theelectrical power supply of a small building from electrical grid into renewable energy provided by solar photovoltaic module	Quantitative Analysis	4 cents/kWh to 8 cents/kWh on the viability of the proposed PV systems was evaluated	there were three scenarios considered in the findings. The emission of GHG will be in reduction by 50%.

[31]	2020	Iran	To find an optimal configuration that can meet the electricity demand and be satisfactory from both an economic and environmental point of view	Quantitative analysis usingHOMER software simulation criteria and MCDM (multi-criteria decision making) methods.	cost of energy for a standalone system with a reformer was calculated to be 0.164 to 0.233 $/kWh, while the on-grid system cost of energy was 0.096e0.125 $/kWh.	Using solar, wind, and biogas is the most affordable method and adding fuel cell to this configuration would increase,
[32]	2018	Gwakwani, South Africa.	To present an optimal hybrid energy system to meet the electrical demand in a reliable and sustainable manner for an off-grid remote village.	quantitative analysis	were 1, 0.8, 0.6 and 0.4 kW	Based on this research analysis both battery and diesel generator systems achieved the same objective function of backing up the PV system at periods of supply shortages
[33]	2017	Masirah island, Oman.	To investigate the technical and economic feasibility of a hybridenergy system integrated to the existing diesel off-grid/isolated power system	qualitative analysis	capacity of 20.3 MW with net available capacity of 16.7 MW	The finding shows diesel, solar PV and wind generator hybrid system presented the most economic viable hybrid system
[34]	2020	Xining, China	proposes on a technical and economic evaluation of a stand-alone wind-fuel cell (FC)-battery hybrid energy system for a residential house	Description of the simulation tool, Site description, and load data, System configuration, and System components.	The optimal PV/battery/FC system has an initial cost of $6,763,000, an annual operating cost of $82,312/yr, a total NPC of $7,815,223, and a levelized COE of $1.553/kWh.	It is observed that the optimal wind-battery hybrid system is more economical than the wind-FC-battery system.the most economically feasible system is the wind-FC-battery hybrid system. However, when the FC capital cost multiplier value is greater than 0.7, the wind-battery system is the most economically feasible one.
[35]	2011	kualaperlis, Malaysia	presents the optimizationdesign of photovoltaic power system for desalination process ofseawater , reliableand low power consumption of distillation process is selected forthis off-grid power system.	Quantitative analysis	The load demand is constant throughout the year at 19.2 kWh/day, system output can generate at least 19.431 kWh/day	to benefit rural areas where are still lacking of fresh water supply. It will develop to increase thethe efficiency of this system and reduce its operating cost
[36]	2020	Morocco	It assesses the conditions at which solar Photovoltaics (PV) and Concentrated Solar Power (CSP) would be competitive with a grid (mainly fossil) driven desalination plant.	literature review (simple model that assesses the final cost of desalinated water is computed. Second, the cost related to energy consumption is calculated for different power supply options to assess the impact of energy provision on the final cost of water)	the calculated LCOS is found to be equal to 0.3 $/kWh (< 0.5 $/kWh.	To demonstrates at first that desalination, with the last up-to-date technologies, is affordable at an acceptable cost of around 1 $/m3 (range of 0.98 $/m3 and 1.14 $/m3 depending on the power supply option). In addition, the results show that the selling price of desalinated water

[37]	2019	China	to find the optimal configuration for an off-grid, renewable energy reverse osmosis desalination (RO) system	Quantitative analysis	LCOE 0.527 USD/kWh and the corresponding levelized cost of water 3.585 USD/m3 , which were about half of the 7.9 USD/m3	photovoltaic panel tilt angle over a range from 15° to 40°. The LCOW was less than half of the 7.9 USD/m3 currently paid by residents in the area.
[38]	2019	Abu Dhabi	To show how Abu Dhabi can implement a sustainable desalination scheme by looking at the recent developments in both the desalination and energy	quantitative analysis	a Levelized Cost of Water (LCW) analysis is conducted for a proposed 90,000 m3/day	thermal desalination technologies consume at least 10% more fuel than RO-based desalination technologies. Sustainable desalination of seawater regarding a clean energy resource and economical technology option is a must for Abu Dhabi to meet its vision 2030 targets
[39]	2018	Turkey	To evaluated the operations of seven different (off-grid) power systems (wind-photovoltaic-diesel-battery) used to satisfy the electrical energy demand of a small-scale reverse osmosis system	quantitative analysis	The LCOE value for the wind system with the battery defined as case 2 was calculated to be $0.975/kWh levelised cost	analyses indicated that potable water production with the proposed hybrid power system is economically feasible for the site
[40]	2020	Iraq	to investigate the thermo-fluid aspects of such a system with a view to ascertain the drivers to enhance its thermal performance and productivity. surface area of the concentrated energy collector, solar intensity, oil tank insulation, salinity, water depth,mass flow rate and connection types between the oil tank	quantitative analysis	8.6 US$/m3, while that value reached 9.74 $/m3	Distillate productivity is profoundly influenced by the operating parameters (salinity, HTF flow rate, number of stages) and weather conditions (radiation intensity, ambient air temperature). Optimum flow rate of HTF is 1.65 L/min that produces the highest distillate
[41]	2002	Egypt	feasibility study of water desalination in these areas using photovoltaic energy as the primary source of energy	thermal and membrane process	the cost of producing 1 m3 of fresh water using the small PV powered RO water desalination systems is 3.73$.	It is found that the cost of producing 1 m3 of fresh water using the small PV powered RO water desalination systems is 3.73$. This cost is based on using a small system that is operating during the daylight only. If the system size and the daily period of operation are increased, the price of producing fresh water will be decreased in these regions.
[42]	2020	Brazil	To presents the techno-economic feasibility of using small-scale PVRO systems	quantitative analysis	At a levelized cost ranging from 1.44 to 1.65 US$/m3	The model predicts that a 10 m3/day proposed system capacity can produce water at a levelized cost ranging from 1.44 to 1.65 US$/m3. This is enough to sustain the basic water needs of 250 people for 2 days.

[43]	2011	Mrair-Gabis, Libya	introduce a cost-effective substitute to expensive grid extensions in isolated areas	simulation and economic estimation	levelised cost at 0.25$, 0.5$ and 0.75$ diesel prices. At 0.25$ diesel price, 6.7 kWh/m2 and 4.6kWh/m2	find that Wind energy on the other hand does not seem to be cost-effective in the sensitivity analysis because the wind potential is limited, n to the economic and practical diesel generator drawbacks, considering the diesel emissions make the renewable options more feasible
[44]	2019	Athens, Greece	to determine the optimum technical and economic system, by minimizing the total system installation and operation cost for 20 years lifetime, which then compared in economic terms with the water transportation practice	qualitative and simulation	levelised a cost of 425 €/membrane. this cost was selected at 0.065 €/m3	shows that the application of a photovoltaic powered seawater reverse osmosis desalination unit that incorporates water storage, a small capacity battery bank and an energy management system, is technically feasible to produce fresh water
[45]	2012	Jordan	Aims to detail the project's photovoltaic system design and size, highlight some findings and measurements, and offer a brief economic analysis.	simulation and economic estimation	1000 kg/m3. 9.81 m/s2. 30 m3 /day 40 m = 11772000 Joules/day = 3.27 kWh/day f 5.5 kWh/m2 per day we retrieve the required size of the PV array of 11.6 m	For the provided project, an economic analysis has been performed. Despite the greater initial investment costs, the study clearly reveals that PV cells are substantially cheaper than diesel generators.