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Hybrid Renewable Energy System for Reverse Osmosis Desalination Unit: A Review

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ABSTRACT

In order to fulfill the rising demand for water, particularly in areas with a lack of freshwater resources, reverse osmosis (RO) desalination has emerged as a popular desalination technique. The environmental impact of carbon emissions from conventional fossil fuel energy sources is lessened by its integration with renewable energy sources (RES). This system is called hybrid energy system (HES). HRS-RO desalination system is being optimized primarily to lower overall system costs and energy requirements and to ensure system dependability. This paper presents investigation of the hybrid energy system- HES-RO desalination system's optimization based on ideal system operation, ideal system sizing, and ideal thermodynamic analysis. Hybrids desalination techniques were taken into consideration alongside RES. Discussions on the review's key results and suggestions for additional research were offered. The most significant studies showed that of energy (COE) of HES is between 0.179 $/kWh and 0.272 $/kWh, LPSP is 0.1397and Renewable fraction (RF) of 92.

1. Introduction

Energy and water are interdependent sources that have varying effects on each other. Desalination consumes energy, which is often obtained from fossil fuels [1], to produce fresh water. Water is also necessary for the extraction and refining of fossil fuels [2]. Due to the greenhouse gas (GHG) emissions from these procedures, as well as from burning fossil fuels to provide energy for desalination, the ecosystem is severely harmed. Desalination-related emissions are predicted to reach a total of 0.4 billion tons of CO_2 equivalents annually by 2050 [3]. As a result, the increasing demand for clean water would significantly harm our environment as well as trigger the depletion of fossil fuels [4].

Due to the fast variations in fossil fuel prices; that desalination depends on them as the primary energy source, these prices have an impact on the process economic viability [5, 6]. Therefore, it is crucial to use renewable energy sources for desalination in order to meet our needs for clean water in the future while minimizing the negative impacts on the environment [2, 7].

All desalination methods require some type of energy to operate. As conventional energy sources have various limitations, including negative environmental consequences, the current trend favors the use of renewable energy sources to power desalination plants [8]. Due to of the high energy requirements of the thermal desalination process and the resultant environmental effect of the traditional energy sources used to power the thermal techniques, the membrane process driven by renewable energy sources has become increasingly prominent. Figure 1 illustrates the contribution of different desalination processes to the global production.

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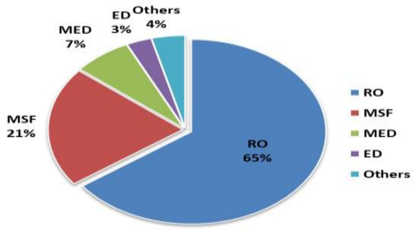

Figure1: Contribution of desalination processes to global production, [9]

Figure 1 depicts that Reverse Osmosis (RO) desalination is more widely used than other desalination methods.

Desalination plant electricity can be supplied by renewable energy sources, which are a dependable, sustainable, and clean option. Two renewable energy sources with enormous potential on a global scale are wind and solar power. These resources can be used to power desalination procedures in desert, semi-arid, and coastal regions that are experiencing a severe water shortage to their adequate capacity [10, 11]. The installation prices of these resources have significantly decreased, which has increased both the installed capacity and the energy generated by these sources [12]. As a result, in-depth research has been done on using these renewable resources to power desalination plants [13].

The size, location, feed pressure, and features of the desalination plant, as well as the estimated cost of producing fresh water, all influence the choice of RES for desalination. The intrinsic qualities of low intensity and intermittency of various RES are the constraints of their application. Integration with the grid, hybridization, and the use of energy storage devices like batteries can all help to mitigate or even eliminate these issues.

1.1. Hybrid RES for desalination

The hybrid system enhances system dependability by compensating for the weaknesses of each RES, hence enhancing system economic efficiency and environmental impact [14]. When a conventional energy source is paired with a renewable energy source, such as wind or solar, the conventional energy source compensates for the renewable energy source's intermittency and high cost, while also assuring environmental conservation [15,16]. In contrast, depending on the geographical location and accessibility of renewable energy sources, several types of renewable can be combined to improve cost efficiency and overall system performance [17,18]. Renewable energy sources can be used with energy storage technologies such as capacitors, batteries, and hydrogen storage to address the issues of intermittent irradiation and changing wind speeds [19, 20]. An evaluation of hybrid energy applications for developing countries reveals that using diesel as an alternative is more expensive than using a hybrid system, and integrating hybrid renewable options can be implemented more quickly than expanding existing grid infrastructure [21].

The component sizing and energy management strategies in hybrid systems can be exceedingly challenging. Small-scale saltwater desalination facilities, especially those located in off-grid locations may benefit from the proper optimization of hybrid systems because they can be more dependable and cost-effective.

Numerous HES combinations have been recorded for reverse osmosis (RO) desalination, including PV/Diesel generator[26], PV/ WT/Diesel generator[27], PV/WT [28], PV/WT/BG/ Diesel generator [29], PV/WT/Battery[30], PV/WT/Battery /Diesel generator[31], PV/ Bat/Fuel cell [32], and PV/WT/Biomass/FC [33]. Energy demand, renewable energy sources, weather, astronomical conditions, and project economics are the main determinants of hybrid system combinations [34,35].To accomplish many goals, such as fulfilling dependable load demand, saving fuel, and lowering CO_2 emissions while keeping a minimum cost of energy (COE), the HES must be sized optimally [36,37].

The three tested parameters that were used to determine the economic viability were Net Present System Cost (NPC), Cost of Energy (COE), and Water Cost. However, because the operation of the renewable component of the hybrid systems does not produce any emissions, the concern for ecological improvement has been restricted mainly in the emission from nonrenewable generators. However, emissions that are linked to various stages of their life cycle, from manufacture to disposal, are referred to as lifecycle emissions [38]. A PV/WT/DG-based hybrid power-driven ROD system with a battery bank is shown conceptually in Figure 2. A bidirectional inverter is also included to change direct current to alternating current or vice versa. PV modules, which provide the majority of the electricity, are connected to the DC bus by a battery bank. The AC bus is connected to the diesel generator, wind turbine, and RO desalination equipment. When there is a shortage, the battery bank releases the excess portion of the generation. Typically, the generator is employed as a source of emergency power. In the RO unit, sea water is desalinated before being eventually distributed to the community in response to demand [39].

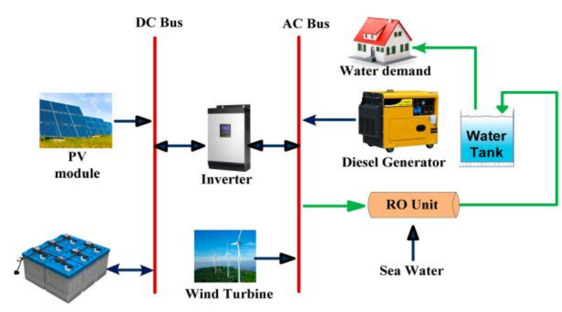

Figure2: RO desalination process with RE-based hybrid system [39].

2. Review of Hybrid RES for desalination

To achieve the sizing optimality of HESs, a variety of optimizers have been utilized. Examples include various met heuristic evolutionary algorithms [40], linear and nonlinear programming [41,42], artificial neural networks [43], numerical iterative methods [44], and different commercially available software tools [45,46].A PV/Bat/RO system with fuzzy cognitive maps for variable load control for 200 m^3 freshwater production was designed by Kyriakarakos et al. [50] in one of these works. PSO was used to optimize the component sizing. Drinking water production was significantly enhanced via variable load management, going from 41% to over 54%.PSO was used to optimize the component sizing. Drinking water production was significantly enhanced via variable load management, going from 41% to over 54%. For the RO desalination, Wu et al. [51] created a PV/Bat/DG- based HES and used a powerful heuristic Tabu search method to optimize the system. They claimed that when compared to harmony search (HS) and simulated annealing (SA), the Tabu search method yields better results. Additionally, they varied the fuel price, interest rate, and capital cost to examine the sensitivity.

Zhao et al. [52] examined an off-grid and grid-connected configuration of a renewable-based PV/WT system with compressed air storage for a sea water RO system. According to the study, COE for an on-grid system was 0.12 dollars per kWh and for a stand-alone system it was 0.34 dollars per kWh.In order to satisfy house load in three different locations, El Boujdaini et al. [53] optimized a PV/WT/DG/bat system with the PSO algorithm and obtained the best COE of 0.57$/kWh, RF 29%, LPSP 3.9%, and dump energy 15,000 kWh. In a related study, Sanaye and Sarrafi[54] suggested a novel PV/WT/LPG system that incorporated artificial neural network (ANN) with PSO optimization to provide a remote family with the power, cooling, heating, and clean water needs. They claimed that this technique cuts the run time by 10% and can prevent the emission of 73,361 kg of CO_2 a year. Reverse osmosis desalination (ROD) plant with a hybrid PV/WT/Bat configuration was studied by Zhang et al.[55].

To reduce the life cycle cost, the HES is changed using an SA-chaotic search technique. Das et al. [56] evaluated a hybrid renewable energy system to deliver power as well as drinkable water. The evaluation considered the ROD system's Energy Efficiency (EE), which resulted in a Cost of Energy (COE) of 0.234 $/kWh, the establishment of 1.64 new work positions, and an annual generation of 24,038 kWh. Similar to this strategy, Mokheimer et al. [57] created a hybrid PV/WT/Bat arrangement with a continuous RO load of 1 kW. The mathematical model was replicated using MATLAB software, and the results were then compared to HOMER. The energy and desalination costs were determined to be 0.672 $/kWh and $3.693-$3.812/m^3, respectively.

Ghaithan et al. [58] optimized a hybrid PV/wind system to supply power to the RO desalination system, resulting in annual emissions of 90,899 kg CO_2-eq and a COE of 0.0557 $/kWh.

Khanet al. [59] investigated the expansion of domestic and worldwide desalination plant capacity, focusing on Saudi Arabia's potential for renewable energy. The study provided a detailed examination of the evolution and technology advancements in PV-RO, Wind-RO, and hybrid PV-Wind-RO systems during the last three decades. The study also investigated the use of several optimization and sizing software tools comparing existing software tools for HRES-RO desalination. Economic analyses demonstrated a significant reduction in water production costs with the use of hybrid PV-Wind-RO systems.

Table 1(a & b) displays a variety of relevant research works. Numerous researches have investigated the use of various renewable energy resources to power desalination processes.

Table 2 (a & b) presents another number of pertinent studies for RO desalination plants.

Table 1-a: Previous research work relevant studies

Ref.	Configuration	Methods	Out come
[39]	PV/WT/DG/Bat	(NSGA) (PSO) (SSA)	Cost of energy (COE) is 0.179 $/kWh life cycle emissions (LCE) is 0.169 kg/kWh, excess energy (EE) is 402 kWh/yr
[33]	PV/WT/Biomass/ FC	GA	Cost of energy (COE) is 0.1967 $/kWh, Emission is 0.745 kg/kWh damage to human health is7.89 $\times 10^{-2}$
[83]	PV/WT/DG	MOMVO	Cost of energy (COE) is 0.272 $/kWh LPSP is 0.1397 Renewable fraction (RF) is 92
[27]	PV/WT/DG/ Battery	HOMER	Cost of energy (COE) is 0.308 $/kWh Net Present Cost (NPC) is 152,672$ Renewable fraction (RF) is 90%
[29]	PV/WT/BG/HT/ DG/Battery	HOMER	Cost of energy (COE) is 0.107 $/kWh) Net Present Cost (NPC) is 538,765$ Renewable fraction (RF) is 93.9%

Table 1-b: Previous research work relevant studies

Ref.	Configuration	Methods	Out come
[31]	PV/WT/DG/Battery	HOMER	Cost of energy (COE) is 0.164 $/kWh Net Net Present Cost (NPC) is 3.12$
[62]	PV/WT/DG/ Battery	HOMER	Cost of energy (COE) is 0.107$/kWh Net Present Cost (NPC) is 502,662$
[82]	PV/WT/DG/Battery	HOMER	Cost of energy (COE) is 0.145 $/kWh Net Present Cost (NPC) is 207,676$
[84]	PV/WT/DG/Battery	HOMER	Cost of energy (COE) is 0.107 $/kWh Net Present Cost (NPC) is 502,662$ Renewable fraction (RF) is 93.1%
[81]	PV/WT/DG/Battery	HOMER + GA	Cost of energy(COE) is 0.404 $/kW h Net Present Cost (NPC) is 473,013$

Table 2- a: Number of pertinent studies for RO desalination plants

Ref.	Performance and description of the system
[71]	• An examination and evaluation of renewable energy sources were conducted to power a reverse osmosis desalination facility situated in a remote area, Sail El Hasaa, Jordan, with a daily capacity of up to 100 m3 facilitated by the HOMER software. • The hybrid systems PV/DG/WT/B were estimated to be NPC 376,124USD and COE0 242USD. The preliminary capital outlay and annual expenses amounted to 153,651 US dollars and 17,209 US dollars per year, respectively. The system under consideration exhibited a renewable fraction of 84%.
[72]	• A methodology founded on the principles of experimental design was introduced for the purpose of sizing and optimizing a hybrid renewable PV-Wind system that supplies a reverse osmosis (RO) water desalination process. • A meta-model (hybrid spline) reflecting the system's restrictions and aims was investigated utilizing an experimental design tool. The established meta-model was then used to optimize with a bi-objective genetic algorithm. • The optimization process involved the use of two objective functions: the loss of power supply probability (as a reliability indicator) to show dissatisfaction levels in water production, and the embodied energy (as an environmental indicator) to evaluate the energetic cost (in MJ) and assess potential environmental impacts throughout the life cycle. • The optimal sizing of the system through meta-models, as opposed to using a dynamic simulator, yielded promising outcomes by significantly reducing CPU times (from multiple days to just 13 minutes).
[73]	• The cost-effectiveness and energy requirements of reverse osmosis (RO) desalination technology were reviewed; it was used to bring fresh water to Arar City in northern Saudi Arabia, providing an average of 1000 cubic metres of water per day. • The techniques combined two well-established methodologies, particle swarm optimization and bat algorithm (BA), with a novel approach: social mimic optimization. • The results indicated that the BA proved to be the swiftest and most precise optimization methodology for addressing this design challenge when compared to the other two optimization methods. • The investigation demonstrated that the cost of producing freshwater came to $0.745/m3.
[74]	• In Cape Town, South Africa, a mathematical optimization model was developed to power a reverse osmosis desalination unit using traditional grid infrastructure and a diesel generator in conjunction with a photovoltaic energy-based system. • The model was tested using three different case situations and the Time of Use Demand Response (TOU DR) program. ▪ Case 1 consisted of a system powered solely by the grid. ▪ Case 2 involved both the grid and a diesel generator. ▪ Case 3 combined the grid with a diesel generator and photovoltaic energy. • The results showed that Case 3 resulted in a significant reduction in carbon emissions, totaling 751,766 $kgCO_2$-e and 648,315 $kgCO_2$-e after implementing the DR program, as well as the lowest annualized cost of services ($1,158,801 with TOU DR). • Case 3 exhibited a lesser degree of susceptibility, as its cost-variation proportion was notably lower compared to that of Case 1 and Case 2.
[64]	• The usage of an Artificial Neural Network (ANN) for power management in a reverse osmosis desalination unit driven by a VP/WT/B hybrid renewable energy system was investigated. • The primary goal of the ANN power management system was to ensure the smooth distribution of generated power from these sources over a 24-hour operational cycle, taking into account wind speed and irradiation fluctuations, as well as the RO unit's constraints and specific water requirements, using MATLAB/Simulink.
[68]	• The investigation aimed to create a renewable energy system capable of supplying the electricity demands of a large-scale reverse osmosis desalination plant (1500 m^3/d). It also entailed finding the most efficient sizing and evaluating the technical, economic, and environmental viability of various off-grid power solutions. • The results of the HOMER Pro software-based optimization process demonstrated that the suggested photovoltaic/wind/diesel/battery/inverter system outperformed other solutions. It showed possible reductions of 60.7%, 73.7%, 62%, and 81.5% in net present cost, renewable fraction, energy cost, and carbon dioxide emissions as compared to the current diesel system. • The optimal scenario included 451 kW of solar panels, 25 wind turbines, a 250 kW diesel generator, 352 battery storage units, and 358 kW of system converters.
[79]	• The research was centered on determining the optimal performance of various off-grid resource combinations in Egypt for powering a small desalination plant with a capacity of 1 m^3/h. ▪ The initial choice involved integrating a photovoltaic solar panel, wind turbine, diesel generator, and battery. ▪ The HOMER program simulated an alternative solution that included the same components. • The results showed that the first option had an electrical power cost of 0.2252 $/kWh and a matching water cost of 1.10 $/$m^3$, whereas the second option had reduced costs of 0.1216 $/kWh and 0.56 $/$m^3$, respectively.
[63]	• A hybrid wind and solar photovoltaic power plant with optimal capacity was recommended to power a desalination facility. • A case study on Gran Canaria Island revealed the best Distributed Renewable Energy Systems (DRES) for a desalination plant that produces 5600 m^3/day and injects 5.88 GWh/year of power into the grid. • A hybrid solar PV and wind generation system with electrochemical storage was offered as a possible alternative to reduce the Levelized Cost of Electricity (LCOE)

Table 2- b: Number of pertinent studies for RO desalination plants

Ref.	Performance and description of the system
[66]	• Three autonomous hybrid configurations for an autonomous region of Iran were examined. Desalination with solar-wind-battery-RO, solar-battery-RO, and wind-battery-RO. • The major optimization goal of minimizing life cycle costs was used to evaluate alternative renewable energy systems that support reverse osmosis desalination. • The reliability of the hybrid techniques was evaluated based on the possibility of power outages.. • A novel hybrid search algorithm combining simulated annealing and chaotic systems was developed and compared with the original chaotic search and simulated annealing algorithms. • The outcomes demonstrated that the hybrid search algorithm outperformed both the original simulated annealing and chaotic search algorithms.
[67]	• Seven different (off-grid) power systems (wind-photovoltaic-diesel-battery) were tested on Turkey's Bozcaada Island to meet the electrical energy needs of a small-scale reverse osmosis system with a 1 m^3/h capacity. • The HOMER programme was used to conduct techno-economic assessments of the systems. • The results showed that the most efficient system included wind turbines with a 10 kW rated power, a 20 kW PV panel, and an 8.90 kW rated power diesel generator. The power cost $0.308 per kWh, while the water cost $2.20 per m^3**.**
[75]	• The research focused on identifying a cost-effective and sustainable energy-water system situated in a rural community in Australia. • A modeling approach was formulated to be accessible and user-friendly for regional energy and water utilities. • The most cost-effective of the seven energy setups included a hybrid RE-RO system that included grid electricity, a 2.4 MW wind turbine, and a 2.8 MW distributed rooftop solar photovoltaic (RTPV) system to meet the 14 GWh and 1.2 GWh annual energy demands of the community and RO plant, respectively.
[76]	• An optimization technique for developing a solar and wind-powered hybrid reverse osmosis desalination plant was proposed. • Based on the simulation results, the hybrid approach had a relative error of 47.75 percent for the hybrid search algorithm and 4.08 percent for the chaotic search algorithm when compared to the top performing hybrid and simulated annealing algorithms.
[78]	• A hybrid system was developed and optimized to measure the effectiveness of desalinating salty water using hybrid RO-MSF desalination systems. • Various solar wind RO-MSF models were analyzed and evaluated from a technical and economic perspective. • A model was created that may be used in small-scale desalination facilities, with desalinated water priced between $1.35 and $1.84 per m^3 depending on the solar wind RO-MSF model.
[80]	• The optimal size of a hybrid renewable energy system (HRES) that includes a wind turbine, a solar panel, a battery bank, and a reverse osmosis desalination unit was established using single and hybrid optimization algorithms. • Common optimization techniques used included particle swarm optimization, bee swarm optimization, harmony search, simulated annealing, and the chaotic search algorithm. • The results showed that hybrid optimization strategies outperformed the evolutionary algorithms under consideration, with the HRES leading to lower system costs and greater system reliability, hence improving fresh water supply.
[60]	• A photovoltaic/wind turbine system was showcased to power a reverse osmosis water desalination unit for hydroponic cultivation within a controlled greenhouse situated in El-Tor city, South Sinai Governorate (Egypt). • An economic analysis was conducted on two hybrid systems in the study; Photovoltaic/wind turbine (PV/WT) configurations with and without a backup diesel generator, aimed at optimization. • The HOMER software was utilized to model and evaluate the system's performance over a 15-year lifespan, focusing on Net Present Cost (NPC) and Cost of Energy (COE). • Findings indicated that the COE of the PV/WT system was lower compared to the PV/WT/Diesel system, with no capacity shortages observed in the latter configuration.
[70]	• A techno-economic evaluation was presented on different system sizing combinations involving solar photovoltaic, wind energy, and energy storage via batteries to produce potable water from brackish sources. • The hybrid power system design choices were evaluated for the selected location, Kalpakkam in South India. • Different hybrid power system design options were explored for the Kalpakkam site in South India. • The findings suggested that the most efficient configuration for achieving an aim of around 6000 units of electricity per year was a solar capacity of 8 kW, a wind capacity of 1 kW, and a storage battery of 1.5 kW, with an energy cost per unit of INR 12.73. • To ensure greater availability (>50%), a combination of solar 9 kW, wind 5 kW, and storage battery 2 kW was selected to generate around 7500 units per year at a cost of INR 24.29 per unit of energy.
[77]	• A hybrid photovoltaic/wind/hydrogen/reverse osmosis desalination system was simulated and developed in a distant Iranian area to increase fresh water availability and meet load demand. • An efficient meta-heuristic technique utilizing artificial bee swarm optimization was applied to accomplish this objective, revealing that adjusting the maximum loss of power supply probability to 0–10% yielded positive outcomes.
[61]	• Various hybrid designs of wind, photovoltaic (PV), and diesel systems were evaluated for a community in Saudi Arabia's north-east region. • Using the HOMER program, various power generation systems, including diesel alone, wind-diesel, PV-diesel, and wind-PV diesel, were modeled and compared to determine the best option. • The results showed that the diesel-only system was the most cost-effective alternative, with an energy cost of 0.037 US$/kWh and a fuel cost of 0.067 US$/l • The PV-diesel hybrid system with particular capacity was identified as the best cost-effective solution, with a COE of 0.038 US$/kWh.
[85]	• A small-scale hybrid PV-wind-generator unit capable of generating energy and drinking water for 1000 individuals was developed in this research. • Specific test locations included disaster-prone locales such as Nairobi, Kenya, and Nyala, Sudan. • The proposed model consisted of various components including solar PV modules, a wind turbine, a diesel generator, batteries, and a desalination unit.

Different configurations of hybrid renewable energy system used for desalinate 100m^3 of water by Ro desalination unit. Figure 3 and 4 showed that the cost of energy and net present cost respectively with different configurations hybrid systems [62].

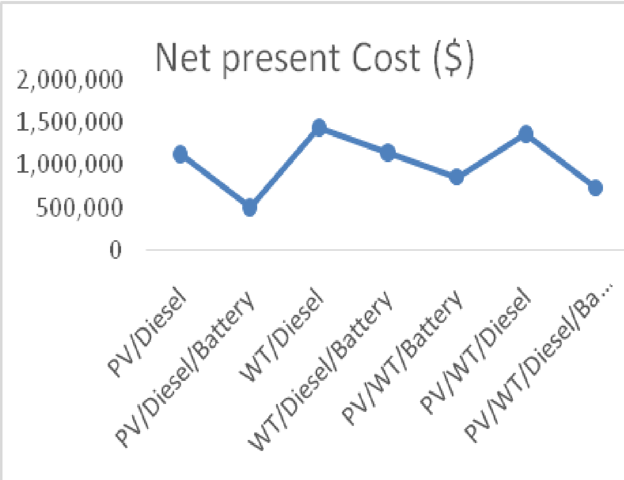

Figure 3: Cost of energy of some hybrid configurations to desalinate 100 m^3 of water.

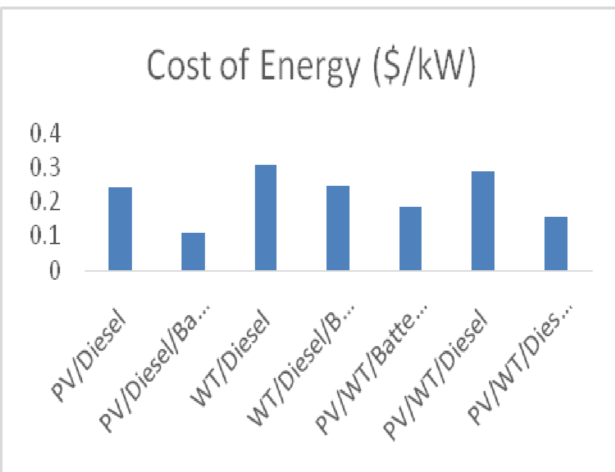

Figure 4: Net present cost of some hybrid configurations to desalinate 100 m^3 of water.

From above figures it is clear that the optimal configuration is PV/Diesel/Battery. This hybrid system has lowest cost of energy and net present cost.

3. Software Tools

It is possible to evaluate the functionality and dimensions of hybrid renewable energy systems using a variety of software tools. Erdinc and Uzunoglu [47] and Sinha and Chandel [48] conducted in-depth analyses of the currently available software packages. The literature mentions several software tools for sizing HRES, including HOMER, Hybrid 2, RETScreen, HybSim, and Hybrids [48]. Table 3 presents a tabular assessment of these instruments' capabilities, advantages, and limitations. Fig. 5 depicts a diagrammatic representation of an HRES-RO system with HOMER inputs and outputs, depending on the application and input-output factors.

Table 3: A comparison of HRES software tools those are available.

Software	Advantage	Drawback
HOMER	•User-friendly and convenient •Provides a setting for self-learning and is simple to understand. •Presents the design and results in a graphical manner. •A whole year of hourly simulation. Compatibility with MATLAB •The impact of temperature on solar PV is also mentioned. • NASA is the only source for a reliable meteorological database and product database	• The Black Box code • Models based on first-degree linear equations are employed. • Daily average data used to represent time series data cannot be used. • There is only a free trial version. The professional edition must be bought.
RETScreen	• Simple to use due to the spreadsheet program's MS Excel foundation. • NASA is the only source for a reliable meteorological database and product database. • Free download limitations disadvantage	•Limited data entry choices • A lack of search, visualization, and graphic feature possibilities. • There is no option to import time series data files.
Hybrid 2	•Lacks Flexibility and Limited Access to Parameters. •User-Friendly. • Uses a GUI for Project Design •Multiple Electrical Load Options. •Many Resource Data File	• The impact of temperature on solar PV is excluded.

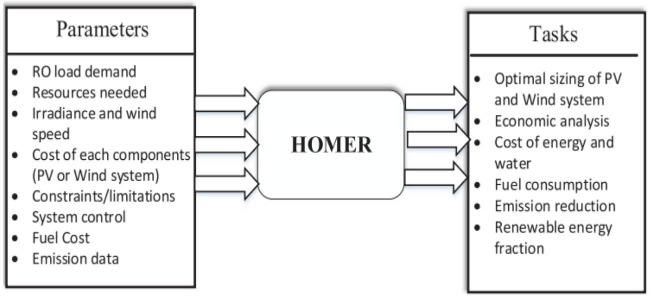

Figure5: Schematic of the application of HOMER for HRES-RO [49].

4. Conclusions

Desalination technology that relies on renewable energy has initiated a novel trend by emerging as a feasible option for freshwater generation. The current evaluation concentrates on both global and local patterns in desalination capacity, along with advancements in technology. The potential use of renewable energy for desalination applications on a small or large scale has also been scrutinized.

This review offers an outline of renewable energy-based desalination, specifically focusing on PV-wind-RO technology, recognizing the prevalence of RO membranes in the desalination process. Various setups and combinations of PV and wind to meet the power requirements of the RO process are described here. The operational efficiency of a RE-based desalination system is determined by various aspects, including the site, energy technology (PV, wind), grid or battery power backup, desalination method, and the RO plant's individual energy usage.

As per an analysis of existing literature, the expenses associated with freshwater production are influenced by variables like desalination plant capacity, solar or wind patterns at the site, TDS levels of the feed water, the type of renewable resource harnessed for power production, and whether the system operates off-grid or is connected to the grid. Additionally, the sizing of the PV, wind, or hybrid power system plays a crucial role in determining the overall unit cost and consequently, the cost of water production. One study showed cost of energy (COE) of HES is 0.179 $/kWh, [39] and another one showed cost of energy (COE) of HES is 0.1967 $/kWh, [33]. Third study showed cost of energy (COE) of HES is 0.272 $/kWh, LPSP is 0.1397and Renewable fraction (RF) is 92, [83].

Finally, it is suggested that a full techno-economic assessment be done for selected distant areas to determine the viability of RO plants of varied capacities powered by renewable energy sources based on daily water requirements. The use of renewable energy sources for water desalination, namely a PV-wind hybrid power system with or without battery backup, offers various advantages.

Conflict of Interest

The authors declare no conflict of interest.

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Nomenclature

ANN	**Artificial Neural Network**
BBS	**Battery Bank System**
COE	**Cost of Energy**
DG	**Diesel Generator**
EE	**Excess Energy**
EMP	**Extended Mathematical Programming**
GA	**Genetic Algorithm**
GHG	**Green House Gas**
HS	**Harmony Search**
HES	**Hybrid Energy System**
HOMER	**Hybrid Optimization Model for Multiple Energy Resources**
HRES	**Hybrid Renewable Energy System**
FC	**Fuel Cell**
LCOE	**Levelize Cost Of Energy**
LCE	**Life Cycle Emission**
LPSP	**Losses of Power Supply Probability**
PV	**Photovoltaic**
PSO	**Particle Swarm Optimization**
NPC	**Net Present Cost**
MSF	**Multi Stage Flash Desalination**
NASA	**National Aeronautics and Space Administrative**
NSGA	**Non-dominated Sorting Generic Algorithm**
PLPSP	**Potential Loss of Power Supply Probability**
RES	**Renewable Energy Sources**
RF	**Renewable Fraction**
RO	**Reverse Osmosis**
WT	**Wind Turbine**
SSA	**Salp Swarm Algorithms**