



# Techno-economic analysis of MED and RO desalination powered by low-enthalpy geothermal energy



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## HIGHLIGHTS

- Techno-economic analysis of RO and MED using low enthalpy geothermal energy
- A cost model was developed for estimation of the LCOW of each scheme.
- RO is more cost-effective than MED when driven by the same geothermal source.
- Sensitivity analysis conducted to study the effect of several parameters on LCOW
- Quality and utilization efficiency of the geothermal resource affect LCOW the most.

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## ABSTRACT

Utilizing low enthalpy geothermal resources in various applications, including desalination, has triggered continuously growing interest in the past decade. This work offers a preliminary techno-economic evaluation of coupling a low-enthalpy geothermal resource, commonly found in regions such as the Arabian Gulf countries, and a suitable desalination technology. The desalination processes chosen, multiple effect distillation (MED) and reverse osmosis (RO), were designed as integrated energy–water systems and were compared and assessed in terms of their levelized cost of water produced. It was found that geothermal RO could potentially be a more cost-effective option for seawater geothermal desalination in the Gulf Cooperation Council (GCC) countries, based on our model results. A number of parameters, which can potentially alter the results of the analysis, were chosen to investigate their effect on the LCOW of the proposed schemes. These parameters include feed water quality, operational lifetimes of both the geothermal and desalination systems, quality of the geothermal resource, cost of well-drilling and finally, reinjection temperature of the utilized geofluid. By varying their values, the robustness of our initial model results was assessed.

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## Nomenclature

Symbol	Description	Units
A	Heat transfer area	m <sup>2</sup>
$\alpha$	Correction factor of pressure	
$\alpha_{\text{reinj-wells}}$	Ratio of reinjection to extraction wells	
$A_s$	Specific heat transfer area	m <sup>2</sup> /m <sup>3</sup>
B	Brine stream of the desalination plant	
$C_{\text{BOIL}}$	Cost of boiler	USD \$
$C_{\text{CAPEX(IND)}}$	Amortized indirect capital expenditure of the desalination plant	USD \$/y
$C_{\text{CAPEX(D)}}$	Amortized direct capital expenditure of the desalination	USD \$/y

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	plant	
$C_{\text{CH}}$	Specific cost of chemicals	USD \$/m <sup>3</sup>
$C_{\text{el}}$	Specific cost of electric energy	USD \$/m <sup>3</sup>
$C_{\text{INS}}$	Annual cost of insurance	USD \$/y
$C_{\text{l}}$	Annual cost of labor	USD \$/y
$C_{\text{MEM(RO)}}$	Annual cost of membrane replacement	USD \$/y
$C_{\text{p}}$	Specific heat capacity of geothermal water	kJ/kg °C
$C_{\text{SP}}$	Annual cost of spare parts' replacement	USD \$/y
$C_{\text{th(MED)}}$	Specific cost of thermal energy	USD \$/m <sup>3</sup>
$\text{CAPEX}_{\text{EN}}$	Capital expenditure of the energy generation scheme in the year t	USD \$/y
CF	Concentration factor	
D	Distillate stream of the MED plant	
$E_t$	Energy generation in the year t of operation	kWh
ERD	Energy recovery device	
GCC	Gulf Cooperation Council	
GOR	Gained output ratio	
$h_{\text{geo}}$	Enthalpy of the geofluid at the top of the wellhead	kJ
HPP	High pressure pump of the RO	

(continued on next page)

**Nomenclature** (continued)

$h_{reinj}$	Enthalpy of the geofluid at reinjection point	kJ
LCOE	Levelized cost of energy	USD \$/kWh
LCOE-th	Levelized cost of thermal energy	USD \$/kWh-th
LCOE-el	Levelized cost of electricity	USD \$/kWh
LCOW	Levelized cost of water	USD \$/m <sup>3</sup>
LMTD	Log mean temperature difference	°C
$m_{geo}$	Flow rate of geofluid	kg/s
$n$	Lifetime of energy generation scheme	years
$n_{effects}$	Number of stages	
$N_{unsuccess}$	successful drilled wells	
$N_{wells}$	Number of total required geothermal wells	
$n_{well}$	Lifetime of the geothermal wells	years
OPEX <sub>EN</sub>	Operations and maintenance expenditure of the energy generation scheme in year t	USD\$/y
ORC	Organic Rankine Cycle	
P	Pressure	bar
$P_{BOIL}$	Pressure in the boiler	bar
$Q_{BOIL}$	Required power for the boiler	kW
$Q_{req}$	Required thermal heat for energy and/or desalination	kWh
$Q_s$	Specific energy consumption	kWh/m <sup>3</sup>
$Q_{water}$	Annual nominal production of the plant	m <sup>3</sup> /y
$Q_{well}$	Extracted heat per geothermal well	kWh
r	Discount rate	%
S	Salinity	ppm
$T_b$	Top brine temperature	°C
$T_{geo}^{in}$	Inlet temperature of the geofluid,	°C
$T_{geo}^{out}$	injection temperature of the geofluid	°C
$T_s$	Temperature of motive steam	°C
$T_v$	Vapor temperature	°C
U	Heat transfer coefficient	kW/m <sup>2</sup> /°C
$U_{BOIL}$	Heat transfer coefficient of the boiler	kW/m <sup>2</sup> /°C
$W_{net}$	Net power of the ORC	kW
X	Steam quality	%
Greek symbols		
Symbol	Description	Units
$\delta_{geo}$	Rate of annual degradation of the geothermal field	%
$\eta_I$	1st thermodynamic law efficiency	%
$\lambda$	Availability of the desalination plant	%
$\lambda_{tech}$	Technical availability of the geothermal wells	years
$\lambda_{unsuccess}$	Percentage of unsuccessful drilling	%
$\lambda_v$	Latent heat of evaporation	kJ/kg
Subscripts		
b	Brine	
BOIL	Boiler	
EN	Energy generation scheme	
f	Feed water of the desalination plants	
geo	Geothermal	
i	MED effect	
MED	Multi-effect distillation	
p	Produced water	
RO	Reverse osmosis	
t	Year of operation	
well	Geothermal wells	

**1. Introduction**

In the Middle East, water is a precious yet scarce resource that due to its unavailability has to be artificially generated through desalination. Desalination processes are characterized as energy intensive, so with the rise of awareness for fossil fuels' finite reserves and their adverse impacts on global climate, the concept of renewable energy desalination (RED) has been introduced [1–4]. Among the various forms of renewable energy, geothermal energy can be used to cover a constant electricity demand, such as a base load desalination plant, with no energy storage required. The energy output is stable throughout the year and geothermal power plants can be utilized as stand-alone systems or be combined with an intermittent power generating system (e.g. photovoltaic (PV)) [5]. Good candidates for geothermal desalination are countries with available sea/brackish water access and good quality geothermal energy [5,6].

While coupling renewable energy and desalination can achieve environmental friendliness, the challenge, just as it has been with

conventional types of energy, remains: produce and deliver high quality water in the most cost-effective way. A key action in improving the economics of geothermal desalination is understanding the technical features of the system, particularly those that affect the overall efficiency and how they are linked to the costs of the desalination plant [5,7].

**1.1. Geothermal energy sources and utilization**

Geothermal energy is thermal energy stored in a hot fluid, called geofluid (liquid, vapor, or a mix of both) in the Earth's crust [7]. The quality of the geothermal resource varies from site to site and depends on the following parameters: geofluid temperature (typically 50–350 °C), geothermal well depth, chemical composition of the well's rock formations and available geofluid quantity [7]. Geothermal resources are classified according to their temperature (that is, their enthalpy level) as follows: high enthalpy sources with temperature over 200 °C (typically found in volcanic locations and island chains), moderate enthalpy with temperature in the range of 150–200 °C and low enthalpy with temperature under 150 °C [7,8]. The most abundant geothermal resources are of medium enthalpy and are water dominated (as geofluid) systems (called hydrothermal fields). High-enthalpy fields, on the other hand, are steam-dominated [7,9,10].

Reykjavik Geothermal (RG), a leading company in geothermal power development, has assessed the geothermal resources of the Middle East to be within the range of 90–150 °C with a total geothermal potential of 229 GW [8]. Highlighted regions include the volcanic areas around the Red Sea (Yemen & Saudi Arabia) with potential for medium-/high-enthalpy resources for power generation. They also include the sedimentary basins along the Arabian Gulf with potential for large low-enthalpy resources for desalination, cooling and low-temperature steam generation. RG also depicted that many of the potential sites were in coastal areas where seawater desalination plants are commonly located [8].

Geothermal energy can be used directly for heating (e.g., district heating) or indirectly to produce electricity. The mode of harvesting geothermal energy depends strongly on the quality of the particular source. Low enthalpy geothermal sources can be utilized for direct heating where the geofluid is passed through heat exchangers to release sensible heat [7]. High enthalpy geothermal sources can be utilized via steam power cycles (single flash, double flash or dry steam) to generate electricity. Medium and low-enthalpy geothermal sources (i.e., hydrothermal fields of up to 150 °C) can also serve as a primary source of energy to produce electricity through an Organic Rankine Cycle (ORC) [7,9,11,12], as an indirect utilization of geothermal heat. Here, two fluids are constantly circulating in the ORC: the geofluid (primary fluid) that is pumped from the low enthalpy geothermal field and the organic working fluid (secondary fluid) that is going through subsequent thermodynamic changes [10].

**1.2. Geothermal desalination**

In the literature, there have been examples of successful implementation of geothermal desalination. In 1996, a geothermal desalination unit with capacity of 3 m<sup>3</sup>/h fed with brackish geothermal water of 65 °C, was installed and operated in south Tunisia using an innovative desalination process, named Aero-Evapo-Condensation (AEC) [13]. The process allowed the use of geothermal and/or solar energy at low cost with operational simplicity. Later in 2004, a novel project was conceptualized for the Greek island of Milos by Karytsas et al. [14]. They reported a hybrid system, constructed and operated with an aim of generating electricity and producing fresh water through desalination using low enthalpy geofluid as the sole energy source. The hybrid system consisted of a low-enthalpy multiple effect distillation (MED) unit with 80 m<sup>3</sup>/h capacity and a 470 kW ORC power generator unit (thermal efficiency ~7%), both driven by the same low-enthalpy geothermal resource. The main advantage of this system was its self-sufficiency in thermal energy supply and potential self-sufficiency in

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