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Economic Analysis of Off-Grid Reverse Osmosis Desalination: A Case Study in Chabahar, Iran

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ABSTRACT

Accessing fresh water in Chabahar, Iran's only oceanic port, poses significant challenges due to both geographic and infrastructural constraints. Situated along the Gulf of Oman, Chabahar faces acute water scarcity, making the deployment of a water desalination system an attractive and necessary solution to meet the city's growing water demands. Among available technologies, reverse osmosis (RO) desalination stands out as an efficient and widely adopted method for seawater purification. However, the successful implementation of such a system requires careful consideration of its power supply, especially given the lack of a reliable local power infrastructure. This paper presents a comprehensive techno-economic analysis of an RO water desalination system tailored for Chabahar's unique conditions. To address the energy needs, various distributed generation (DG) options are evaluated to ensure continuous and cost-effective electrical supply to the desalination units. System design and optimal component sizing are conducted using the HOMER software, which allows for detailed modeling under different operational scenarios. The technical findings are then integrated into a financial analysis using COMFAR software, enabling assessment of investment feasibility, operating costs, and long-term sustainability. Notably, real-world regional data are incorporated throughout the analysis to enhance the study's practical relevance and applicability, offering valuable insights for policymakers and planners.

1. INTRODUCTION

Water scarcity has become a critical global issue, essential not only for sustaining ecosystems but also for supporting economic, social, and environmental stability [1]. Only about 3% of the Earth's surface water is considered drinkable, and approximately 25% of the global population—across nearly 80 countries—lacks access to adequate fresh water [2]. As population growth and the expansion of industrial, tourism, and agricultural sectors

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increase water demand, desalination technologies are gaining prominence [3]. With an average annual rainfall of just 250 mm compared to the global average of 800 mm, Iran ranks among the world's drought-prone countries [4].

Currently, around 66% of global desalinated water is produced using membrane-based processes, while 34% relies on thermal methods. The feedwater sources include seawater (59.8%), saline groundwater (21.2%), and a smaller share from surface and wastewater [3]. A crucial consideration in desalination projects is the cost comparison between desalinated water and the actual consumer price. Seawater desalination typically requires between 7–14 kWh/m³, which is significantly higher than the 2–6 kWh/m³ required by membrane processes [5].

A study in [6] proposed hybrid photovoltaic (PV) and wind turbine (WT) systems for reverse osmosis (RO) desalination, projecting a production capacity of 2,374 million cubic meters per day by 2030. Taking into account operation, maintenance, energy supply, and water transport, the estimated cost per cubic meter ranges from 0.59–2.81 euros, with an initial investment of approximately 9,790 billion euros. Another approach combines RO and multi-stage flash (MSF) technologies alongside electricity generation, while also assessing techno-economic challenges, including predicted CO_2 emissions. Under the Kyoto Protocol, carbon penalties are estimated at $25–85 per ton. For instance, a 100 MW system operating at 60% capacity could deliver about 120,000 cubic meters of water per day in the UAE, with heat for MSF provided by a heat recovery steam generator (HRSG) and auxiliary boilers. However, MSF systems generally have lower efficiency compared to RO [7].

In Egypt, a 60,000 m³/day RO plant was developed on the Mediterranean coast, powered by the national grid and diesel generators, though emission penalties were not included in the analysis. National grid subsidies, which influence internal rate of return (IRR) calculations, were factored into power and sale price adjustments [8]. In Cyprus, a similar RO system was evaluated, considering capital investment, operations and maintenance, and energy costs, with water quality and equipment lifespan identified as major cost factors [9]. In Libya, an economic assessment compared two RO configurations: hybrid PV/grid and hybrid diesel generator/PV systems, with the PV/grid option favored due to lower emissions and costs [10]. However, extending the grid to remote locations like Chabahar, Iran, is economically unfeasible, and local wind speeds (~5 m/s) limit the use of wind turbines.

This paper proposes an off-grid RO desalination system, focusing on its economic viability. The comparative analysis between PV and diesel generator supply is conducted using HOMER software for technical and preliminary economic evaluations, while COMFAR software is used to analyze IRR, net present value (NPV), and other financial metrics.

The paper is organized as follows: Section II details the RO desalination system and energy requirement calculations; Section III presents the technical and economic feasibility results for the case study; and Section IV offers concluding remarks.

2. CASE STUDY

In this study the population of Chabahar is considered, consequently the water demand and the needed power to desalinating of water is calculated. The calculations are as follows.

2.1. water Demand Calculation

The maximum daily factor in different regions, maximum hourly factor of population and domestic consumption standard are taken into account to calculate water's daily usage capita. The industrial, agricultural, commercial and public usage of water re-neglected. The daily usage capita of each person is just about 125 liters. The daily usage could be calculated by (1) [11].

$$Daily\ usage = \left[\left(C_1 * C_2 * capita\ usage\ per\ person\right)\ +\ losses\right] * population \tag{1}$$

In which C_1 denotes maximum daily factor in different regions and C_2 denotes maximum hourly factor of population which are 1.5 and 1.4 in Chabahar respectively. Hence the population of this city is 264051 [12], daily and annually demands are estimated about 70 thousand and 25 million $m^{3,}$ respectively.

2.2. Desalination system introduction

The most common desalination system is the reverse osmosis because it requires low construction area. The specifications of RO is shown in Table 1. In which the installation and annual O&M costs are 0.22 $/m^3 and 1 $/m^3. To supply the daily use of fresh water, 289 units with the capacity of 240 m^3/day are to be needed.

Table 1. Specifications of Reverse Osmosis Desalination

Characteristic	Commentary
Price	$ 103,681
Capacity	240,000 liters per day
Desalination Method	Reverse Osmosis
Membrane Type	Marine Filmtek (USA)
Number of Membrane	24
Chassis Material	Stainless Steel
Chassis Dimensions	2*2*10
Pump Type	Vertical Multistage

This study's aim is to get metal flow and distributions of equivalent stress on some special sections such as longitudinal and transverse sections under processing tube tension-reducing.

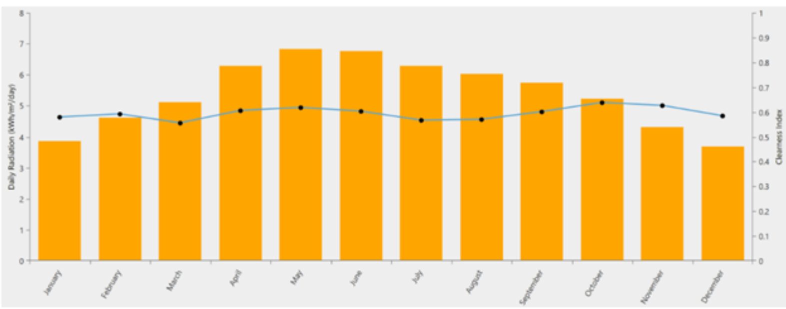
2.3. POWER USAGE CALCULATION

In this study two separated scenario are considered. These scenarios are explained below.

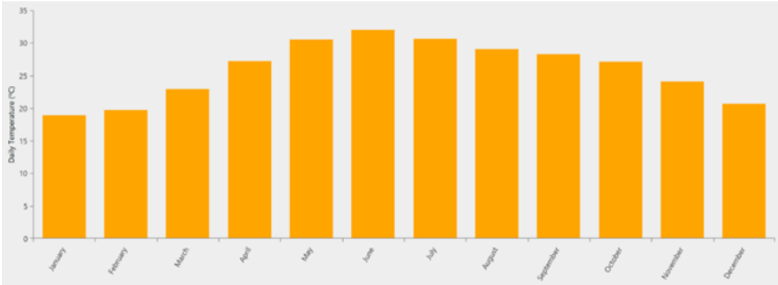
2.3.1. First scenario (PV)

In this scenario the system is not fed by connecting to the power grid and it just depends on PV systems. According to the system reliability and 24/7 operation, a battery is necessary for charging during daytime and being discharged after sunset. The mentioned city is located on 25.3 latitude and 60.6 longitude.

Monthly average radiation, cleanness indexes and temperatures that was gathered by NASA during 24 years (1983-2005) is shown in Figure 1. The related information of the PV, battery and inverter can be seen in Table 2.



(a)



(b)

Fig. 1. (a) Monthly average radiation and cleanness indexes (b): Monthly average temperatures

Table 2. Information of the PV, Battery and Converter

	PV	Converter	Battery
Capital	1000($/kW)	400($/kW)	283($/unit)
Replacement	800($/kW)	400($/kW)	283($/unit)
O&M	10($/year)	10($/year)	0.1($/hour)
Life Time	25 years	15years	3285.1 kWh

2.3.2. Second scenario (Diesel Generator)

In this scenario the system is not fed by connecting to the power grid and it just depends on diesel generator systems. The related information of diesel generator and fuel is shown in Table 3. According to the emission which diesel generators make, the penalty and the cost of emission should be considered. The penalty factors are shown in Table 4 and emission factors in Table 5.

Table 3. Information of Diesel Generator

Capital cost	500($/kW)
Replacement	500($/kW)
O&M	0.045($/year)
Life Time	15000 Hours

Table 4. Emission Penalty ($/ton)

Characteristics	Quantity
Carbon Dioxide	10
Carbon Monoxide	3.5
Particulate Matter	543.2
Sulfur Dioxide	328.3
Nitrogen Oxide	409.8

Table 5. Diesel Generator Emission Factor & Fuel properties

Characteristics	Quantity
CO (g/lit fuel)	16.5
Particulates (g/lit fuel)	0.1
Fuel Sulfur to PM(%)	2.2
NOx (g/lit fuel)	15.5
Carbon Content(%)	88

3. SIMULATION AND RESULTS

In this section HOMER is used for equipment's sizing and the prediction of suitable time of replacement. HOMER minimizes the cost and accurately sizes the equipment with the use of MOPSO[1] algorithm and the consideration of emissions. Results of HOMER software is used for IRR and NPV with the consideration of inflation rate, will be analyzed with the COMFAR software, after pre techno-economic analysis. Whole procedure is shown below (Figure 2).

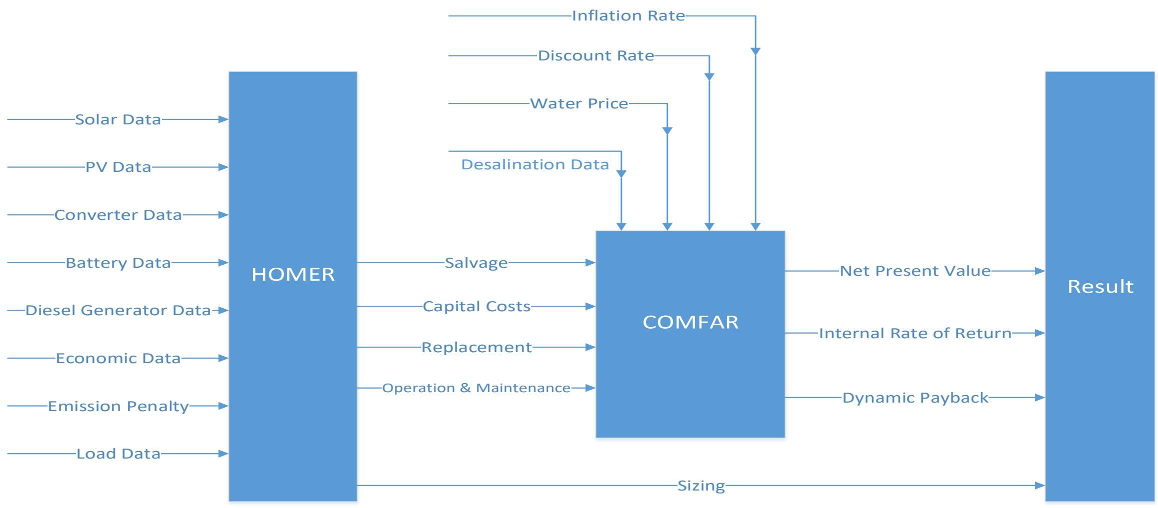


Fig. 2. Procedure's Flow Chart

3.1. Pre Techno-Economic Analysis by HOMER

Both scenarios were simulated in HOMER (Figure 3). If we combine both scenarios in the simulation the results will be calculated for each scenario separately by HOMER. While the data is for Iran, we assume the inflation 10% and diesel 0.4 \$/Liter. Nominal value of capital cost, O&M, salvage and replacement are shown in Table 6 for the first scenario. The inverter will be replaced after 15 years and the battery after 16. Results of the second scenario are shown in Table 7. The generators will be replaced in 2, 4, 6, 7, 9, 11, 12, 14, 16, 18, 19, 21, 23, 24 years from the beginning.

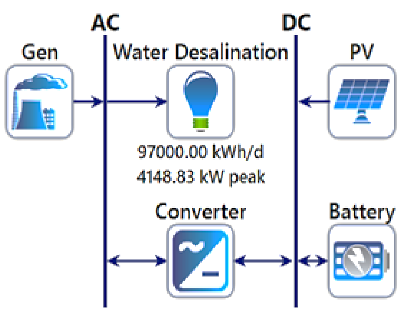


Fig. 3. Simulation of System

[1] Multi Objective Particle Swarm Optimization

Table 6. Nominal Values of equipment in first scenario

	PV	Converter	Battery
Capital	$31,283,682	$3,542,316	$29,574,915
Operating	$312,837	$88,558	$105
Salvage	$0	$118,077	$10,953,671
Replacement	$0	$3,542,316	$29,574,915
Size	31,284 kW	8,856 kW	104,505 kW

Table 7. Nominal Values of diesel generator

Capital	$2,300,000
Operation	$1,813,320
Salvage	$920,000
Fuel	$3,769,066
Replacement	$2,300,000
Emission penalty	$327,386
Size	4,600 kW

3.2. COMFAR Economic Analysis

The results of both scenarios are taken out from HOMER and are put in COMFAR software in addition of the dynamic and static costs which includes the providing equipment for each scenario, installation and operation, maintenance, fuel, penalties for emissions and the system itself (Table 8).

Table 8. Economic Information

Characteristic	Commentary
Water desalination unit purchase	$29,963,809
Annually maintenance	$60,760
Water price	$1
Discount rate	15%
Inflation rate	10%
Project life time	25 years

Figure 4 shows the results of IRR for each individual scenario. IRR is equal to the rate earned by an investor during a commercial investment. IRR will be reached when NPV is equal to zero. Figure 5 shows the investment flow. This Figure shows ROI, dynamic payback and NPV. The provided values in Table 9 are the decision making factors in selecting each scenario.

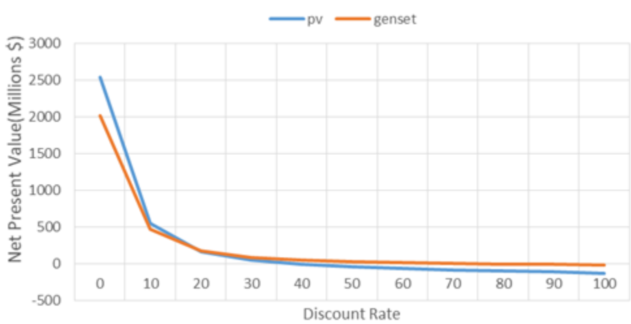


Fig. 4. NPV for each individual scenario

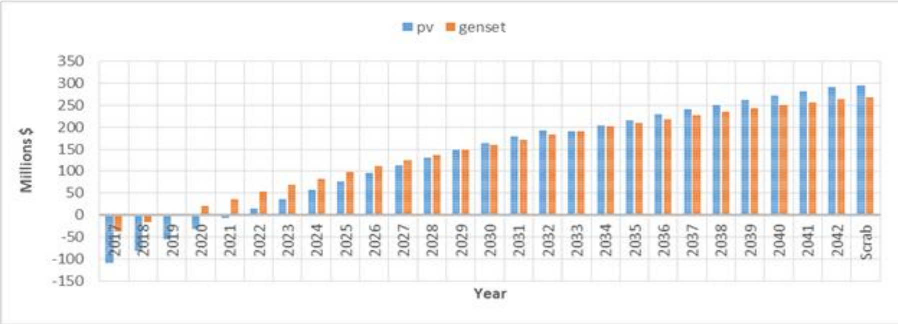


Fig. 5. Dynamic Payback

Table 1. Economic Compression

	First Scenario	Second Scenario
Internal Rate of Return	38.28%	71.55%
Return of Investment	4.66 years	2.26 years
Net Present Value	$295,182,403.67	$268,783,663.63

4. CONCLUSION

In this paper two software including HOMER and COMFAR are used to study techno-economic of the revised osmosis desalination of water in order to decide which power supply to use in Chabahar city, Iran. According to the results of the mentioned software, despite IRR is less in the second scenario, NPV and long term profit in the first scenario is more which makes it more beneficial from economical point of view. More to say, second scenario pollutes more while the first one is more popular to the environment because of its green and clean resource usage. With assuming the reduction of fossil fuels and price volatility, the second scenario will face a lot of difficulties in near future.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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