What Factors are Most Important in Determining Payback Period on Concentrated Solar Power + Desalination Plants: A Sensitivity Analysis

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Introduction

Water shortages are caused by increasing water demand and inadequate water supply. Desalination (D) represents an effective method to add water supply, but it comes at the price of additional environmental impact due to the high CO_2 emissions associated with the energy required to run desalination plants. For example, it is estimated that the carbon footprint for fossil-fueled-powered seawater reverse osmosis (i.e., one of the most commonly used desalination technologies) is 2.91 kg CO_2/m^3 [1]. Thus, to meet the Paris Agreement targets in locations that face persistent or periodic water shortages, the dependency on fossil fuel inputs for desalination plants must be reduced. This can be achieved through investment in alternative renewable energy sources should be considered. Both wind power (3.3 US c/kWh for onshore wind and 7.5 US c/kWh for offshore wind) and solar photovoltaic (PV) (4.8 US c/kWh) currently have competitive generation costs compared to fossil fuel electricity (5.4 – 16.7 US c/kWh) [2]. However, these technologies are intermittent (with capacity factors of 17% and 39% for solar PV and wind, respectively [2]).

In contrast, concentrated solar power (CSP), with sufficient thermal storage, can achieve higher capacity factors to drive a desalination process. Further, a strong (beneficial) negative correlation exists between high direct normal irradiation (DNI) and times of drought (e.g., water supply constraints) [3]. However, care must be taken to ensure CSP+D plants achieve good outcomes since numerous factors impact their economic feasibility. For a start, several process configurations are available in CSP-D, including a low-temperature multi-effect distillation (LT-MED) driven via the waste heat energy from the CSP plant, or a reverse osmosis (RO) unit that consumes a portion of the electricity generated by the CSP plant to power the high-pressure pumps [4]. Initial studies by the co-authors suggest that the estimated payback period for a cogenerated CSP-D plant is between 15 and 18 years [5]. However, the risk to the financial viability of CSP-D projects needs to be analyzed, depending on the effect of reconciling different variables on net present value (NPV) and payback period (PB).

In order to assess which of the parameters has the most effect on financial viability, this study makes a sensitivity analysis of PB and NPV. Five different classes of variables were considered: (1) geographical site conditions (e.g., DNI, plant distance from the seawater source, and elevation above sea level), (2) weather conditions (e.g., seawater and ambient temperature), (3) equipment infrastructure costs (e.g., solar field cost, thermal energy storage cost, power block cost, desalination and water pipeline costs, and operational costs), (4) investment conditions (e.g., discount rate, insurance rate, interest rate, and plant lifetime), and (5) market conditions (e.g., electricity and water tariffs). For the first time, this work explores how global market trends and unpredicted weather patterns can affect the feasibility of such a cogeneration plant.

Methodology

For this study, Karratha in the North Western Australia region was considered (see Table 1 for site conditions) [6]. In addition, this site was selected as it is away from national heritage areas, flood-sensitive areas, and high-density cyclone zones.

Table 1: Karratha, Western Australia, site conditions

Average daily direct normal irradiance	7.955 kWh/m^2/day [7]
Distance from the coastline	20 km

Elevation above sea level	300 m
Land slope	Less than 3%
Distance to transmission line and load	Less than 10 km

The performance of the CSP-D plant was modelled using an in-house MATLAB code published by the coauthors [8, 9]. The net power output of the CSP-D plant was 50 MW_e. The payback period (PB) and the net present value (NPV) were considered. PB is defined as the number of years required to recover the original cash investment (Eq. (1)), while the NPV is defined as the current value of the future payment stream for the entire CSP-D project, as shown in Eq. (2) [10].

$$PB = \frac{(LCOE \times W + LCOW \times Dist) \times n}{(PPA \times W + WPA \times Dist) \times FC} \tag{1}$$

$$NPV = \sum_{t=1}^{n} \frac{Z_t}{(1+r)^t} - Z_{inv} \tag{2}$$

where PPA and WPA are the power (US$/kWh) and water (USD/$m^3$) purchase agreements, respectively, n is the operating year, and FC is the plant availability. LCOE and LCOW are the levelized cost of electricity (US cents/kWh) and water (US$/$m^3$), which incorporate the plant operational period, and the annual insurance rate. Z_t is the cash flow at the number of periods (t) and r is the discount rate (%).

For the 5 different variable groups mentioned previously, a variance of 10% in each input variable was applied to rank the parameters that have the most effect on the plant's feasibility. A risk analysis is then performed for the high-impact input parameters (summarized in Table 2).

Table 2 Future variation range and fixed variation range of selected input parameters

		Future variation range (2025)		Fixed variation range	
Variable	Base	Min	Max	-10%	10%
DNI (kWh/m^2/day) [7]	7.955	7.40	8.51	7.16	8.75
Seawater temperature (°C)	26.73	26.93	27.73	24.06	29.41
Discount rate (%) [11]	5.50	2	7.50	4.95	6.05
PPA (cents/kWh) [12, 13]	27.43	25	30	24.687	30.173
Operational year (y) [14]	25	30	40	22.5	27.5
Solar field cost ($) [2]	150	136.83	164.35	135	165

Preliminary Results

Figure 1 shows that the DNI is the most influential parameter among all input variables, as might be expected, while the impact of the PPA price shows the second highest intensity. Other input parameters, including the plant's lifetime, interest rate, and installed cost of the solar field, follow in the merit order, respectively, and have a greater impact on system performance than other input parameters, such as the pipeline cost, ambient temperature, and operational expenditures.

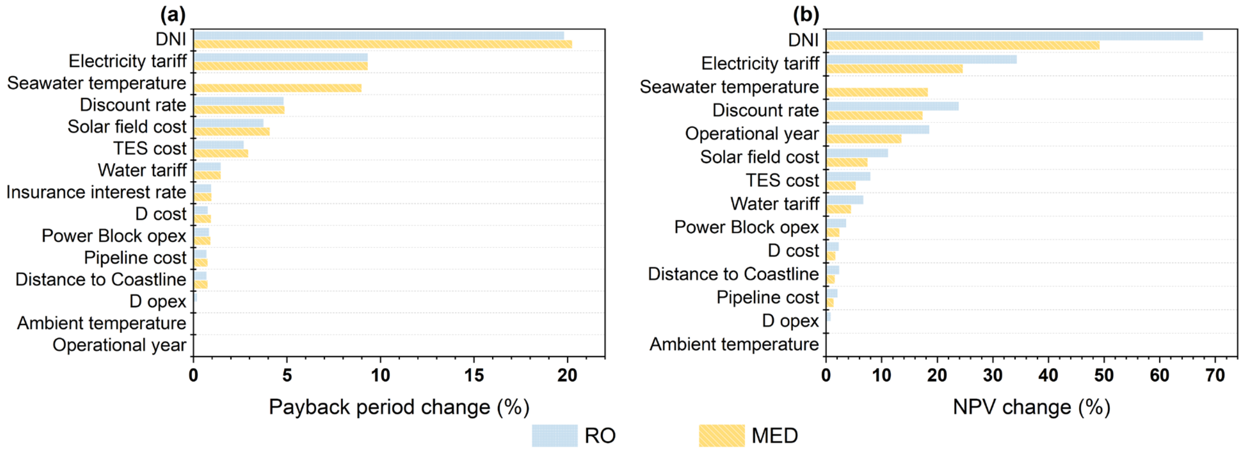

Figure 1. Sensitivity analysis results for (a) payback period and (b) net present value

The ranking of the effects of the input parameters on PB and NPV is similar for both CSP-MED and CSP-RO configurations, while the NPV trend indicates that CSP-RO is more sensitive to the input variation. CSP-MED has greater economic feasibility because this configuration uses waste heat (free energy input) from the CSP unit; thus, having lower operating costs. Furthermore, seawater temperature has a greater impact on the CSP-MED configuration compared to CSP-RO, since MED uses seawater to condense the last-effect permeate vapor.

Figure 2 shows the difference between the change in NPV and PB with a fixed variation range (±10%) and the estimated future variation range (presented in Table 3). The possible future fluctuation ranges of PPA, solar field cost, and DNI are similar to the fixed variation range in the conventional sensitivity analysis, but the estimated variation ranges of discount rates and the plant's lifetime are different.

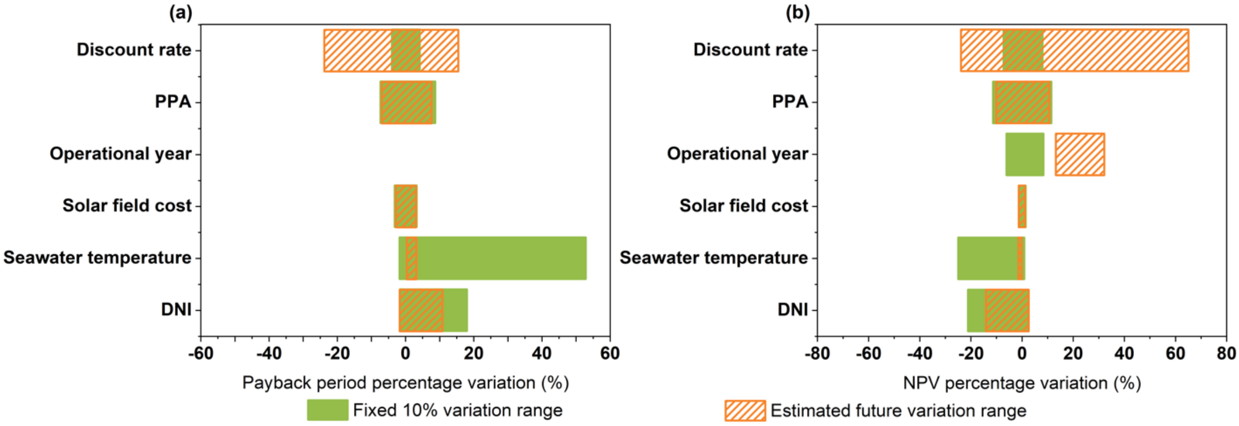

Figure 2. Comparison of fixed variation range (±10%) and estimated future variation range for CSP-MED on (a) Payback period and (b) net present value

The actual project performance fluctuation due to discount rates is much larger than the results of the fixed variation range according to the discount rate estimated for lower, central, and upper bounds by AEMO and AER publicly available documents by Synergies Economic Consulting [11].

In most current simulations, the operating year of the plant is set at 25 years. However, current projections for CSP-D operating years can reach 30-40 years [14]. This increase in the plant's lifetime will not influence the PB of the project, but will increase the NPV due to having more revenue. However, the degradation of plant performance due to the long operational times must be considered.

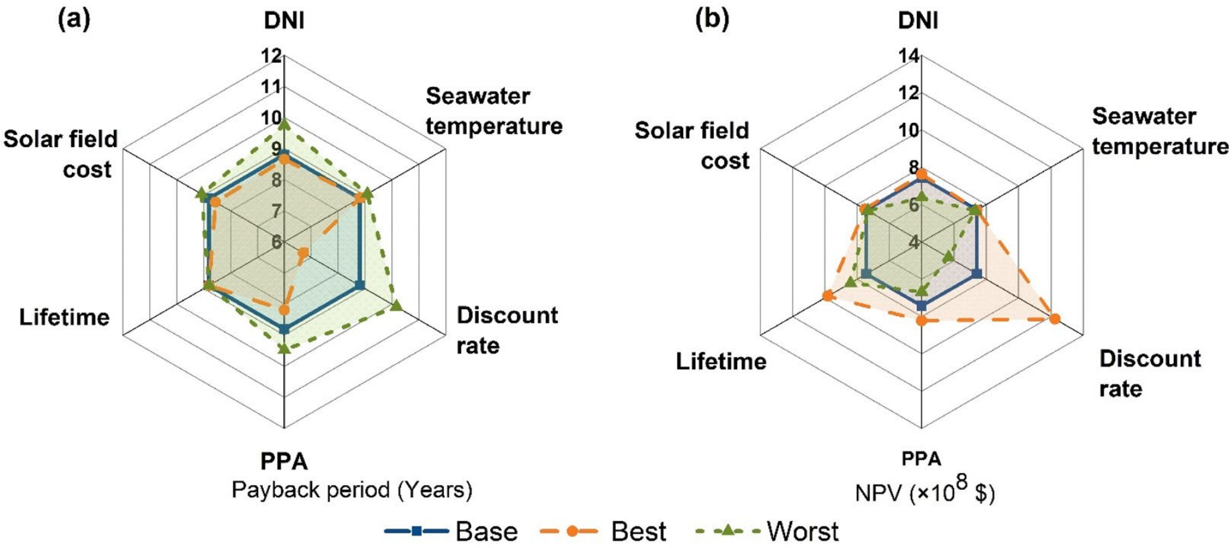

Figure 3. Comparison between base, best, and worst expected future plant performance results for CSP-MED with (a) Payback period (b) Net present value

The best and worse expected future plant performance results are shown in Figure 3. For example, the optimal discount rate was estimated at 2%, while the least discount rate was 7.5%. In contrast, the difference between optimal and least performance DNI was less than 12.5%. The CSP-D performs better in regions with a higher and stable annual average DNI. In addition, the installed cost of CSP tends to decrease according to IRENA's projections. This means that even with the effects of inflation, the cost of the solar field will still fall as technology advances. This allows CSP-D to have a better economic performance in the future.

The PB and NPV affected by PPA ranged from -6.97% to 7.62% and -10.10% to 10.69%. According to the AEMC's report, the current electricity price is forecast to decrease and stabilize at ~25 cents/kWh [12]. However, the forecast considers the increase in the amount of electricity produced by renewable energy sources, which leads to a decrease in the price of electricity. In comparison, fossil fuels are a non-renewable energy source, where their price will continue to rise, resulting in higher costs for conventional power plants. Also, the impact of environmental policies will further affect the cost of conventional power plants, such as charging for CO_2 emissions. This means that environmentally friendly CSP-D will be more competitive in the future.

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