Can Concentrated Solar Power + Desalination Solve Rising Energy and Water Prices? An Australian Site Feasibility Study

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Introduction

Droughts and water shortages due to climate change are becoming a re-occurring problem worldwide. Water scarcity usually occurs in the same regions with sufficient direct normal irradiance (DNI) resources, which provides suitable conditions for combining solar technology and desalination. Australia is one of the few regions with a high DNI and suffers from droughts and scarcity of freshwater resources [1]. The total annual rainfall in Australia was 347 mm between 2019 and 2020, well below the average of 457 mm (1900 – 2020) [2]. In addition, although Australia has abundant groundwater resources, only 30% is potable (containing less than 1500 mg/L of total dissolved solids) [3]. Thus, sustainable desalination of seawater can become a national strategy for meeting Australia's growing water demand.

Solar thermal combined with desalination (D) provides an exciting new prospect for the renewable energy market, since it can provide clean energy and drinking water. A recent opportunity is to integrate the thermal desalination process with the CSP power cycle, using waste heat energy [4]. However, the waste heat temperature of CSP plants using the steam Rankine cycle is too low (30°C) and cannot reach the temperature (70°C) required for the multi-effect distillation (MED) operation [5]. Therefore, CSP turbines should be operated at higher back-pressures to reach sufficient saturation temperatures for integration, but this off-design condition would reduce the plant thermal efficiency of CSP by about 15%. The supercritical CO_2 (sCO_2) Brayton cycle provides higher energy efficiency and higher turbine discharge temperature compared to the steam Rankine cycle. Also, the sCO_2 cycle uses a single-phase working fluid, which makes its turbomachinery have a smaller footprint, about 10% of the Rankine steam cycle. In addition, since the main compressor of the sCO2 cycle operates near the critical point of CO_2 (30.98◦ C and 7.38 MPa), it makes its compression work much less compared to that of other Brayton cycles [6].

This work aims to develop effective methods to assess the viability of a site for hybrid concentrated solar power (CSP) with a sCO_2 cycle as the power block and MED desalination plants in Australia. A scoring system was created to rank the viability of the sites and validated by CSP-D's techno-economic model to ensure that the selected sites had a payback period of fewer than 25 years and met the scoring system's ranking.

Methodology

The technical and economic feasibility of establishing the CSP-D plant at the identified geographic location was analyzed using a MATLAB script developed by the co-authors [4].

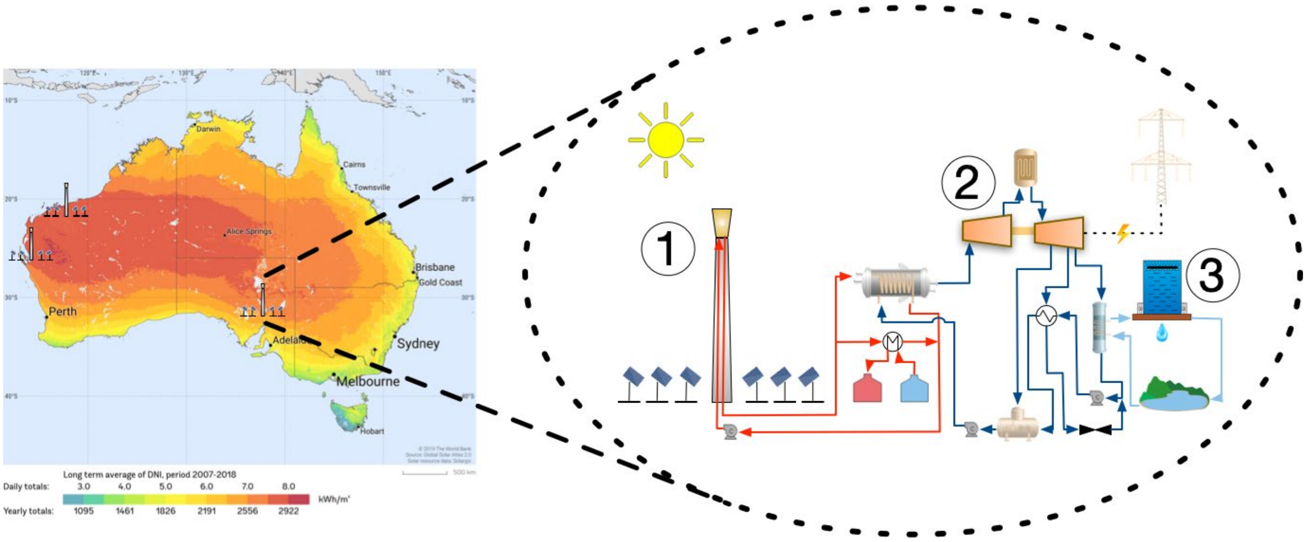

Figure 1. The schematic diagram for solar tower concentrated power plant with sCO_2 cycle coupled with multi-effect distillation plant using waste heat

Figure 1 illustrates the CSP plant configurations that consists of: (1) a solar tower receiver, (2) a sCO_2 cycle as the power block, and (3) a MED plant that is driven using the waste heat from the sCO_2 power block. The Levelized cost of water (LCOW) and electricity (LCOE), annual energy capacity, and payback period (PB) were investigated at each site to determine the best site for CSP-D in Australia. The CSP-D plant technical conditions are presented in Table 1.

Table 1: CSP-D plant design conditions [4, 7]

Solar Plant Conditions	**Value**	**Power Block Conditions**	**Value**
Solar multiple	2.4	Net power output	50 MW_e
Thermal storage	10 hours	Turbine inlet temperature	550°C
Heat transfer fluid hot temperature	574°C	Maximum pressure	20 Mpa
Heat transfer fluid cold temperature	290°C	Main compressor inlet pressure	7.69 Mpa
MED Conditions	**Value**	Recompression fraction	0.31
Steam temperature	70°C	Air cooler specific power	5% of the net power generation
Gain output ratio	10.36		

A free, open-source geographic information software system (QGIS) was used to perform a site-specific analysis in conjunction with all the constraints of developing a solar thermal power plant and desalination [8, 9]. Spatial data was obtained from an Australian Government database that provides environmental information as part of collective public policy, including Electricity Infrastructure, Surface Hydrology National, National Heritage List Spatial Database, Commonwealth Heritage Listed Areas, Collaborative Protected Areas Database, Australia - Ecological Communities of National Environmental Significance Distributions, National Vegetation Information System, and Digital Elevation Model (DEM) of Australia derived from LiDAR 5 Metre Grid [10]. The DNI Map of Australia is provided by Solar GIS [11]. The siting feasibility screening steps involved first creating layers that met the identification constraints using the raster calculator in QGIS (Table 2).

Table 2 Constraint Layers for CSP-D site selection [8]

Layer	**Feasibility Constraint Applied**
Electricity infrastructure map	Within 50km of an existing substation
DNI	Greater or equal to 2000 kWh/m^2
Surface hydrology	There must be an intersection with a surface hydrology
Sensitive areas	Avoid national heritage, aboriginal heritage areas, flood sensitive areas, and high-density cyclone areas

A list of constraints was established to ensure that the selected site had the potential for a CSP-D plant and that its payback period would not exceed 25 years. The initial Zone analysis screened out areas that met DNI >= 2000, had surface hydrology, was within 50 km of the substation, was free of high-frequency cyclones, could have a 20 km buffer from the regional center, and had a 50 km buffer zone around major cities. Table 3 provides a scoring system from 1 to 5, where the total score is divided by the number of factors to achieve a final score of 5.

Table 3 CSP-D site scoring system

Score	**0**	**1**	**2**	**3**	**4**	**5**
DNI (kWh/m^2)	1500	1800	2100	2400	2700	3000
Distance to a transmission line (km)	100	75	50	25	10	5
Distance to water source (km)	600	500	400	300	200	100
Land slope percentage (%)	10	4	3	2	1	0
Distance to heritage area (km)	0	5	10	15	20	25
Distance to load (km)	500	400	300	200	100	50
Level of community acceptance	0%	15%	30%	50%	75%	90%
Density of vegetation	High	Most	Moderate	Some	Rare	No

Preliminary Results

The red area in Figure 2 (a) is the area that satisfies all the constraints listed in the cross-model, identifying the feasible areas for the establishment of a CSP-D plant in Australia. Five areas were then selected based on the cross-modelling results (Figure 2 (b)), including Carnarvon (zone 1), Karratha (zone 2), and Geraldton (zone 5) in Western Australia (green circles), the Port of Augusta (zone 3) in South Australia, and Walgett (zone 4) in South East of Australia.

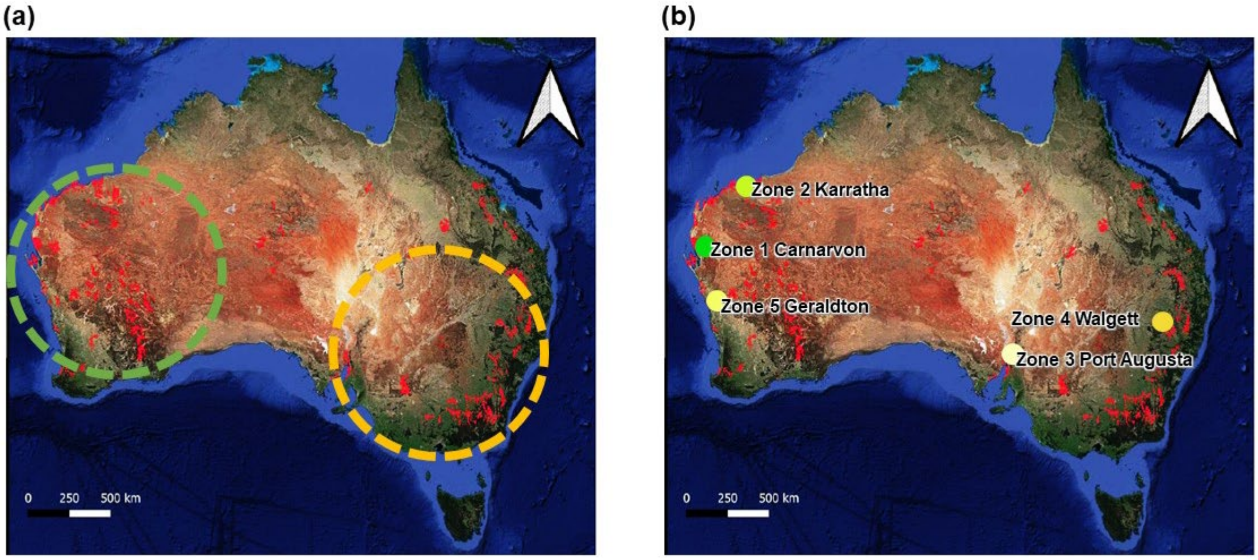

Figure 2 (a) Results of zone analysis, (b) Final 5 zones identified for CSP construction in Australia, the green circle shows the zones in Western Australia, and the yellow circle shows the zones in Southern Australia and eastern Australia

Table 4 shows the techno-economic results for each of the 5 zones shown in Figure 2. The LCOE and LCOW for each site are the determining factors for a viable site. All zones are at or near 25-year payback and have the potential to optimize the site further to find a site with a better DNI and closer to a feedwater source. Note that Zone 4 is the only case that relies on inland brackish water desalination and has a significantly higher LCOW due to high pipeline infrastructure costs resulting in a payback period of nearly 30 years.

Table 4 Techno-economic results for CSP-D for 5 selected zones in Australia

Site number	1	2	3	4	5
LCOE (Cents/kWh)	7.91	7.91	9.39	9.54	8.46
LCOW ($/m^3)	0.91	1.63	0.22	6.39	3.77

Annual energy (GWh/Year)	268	267	227	216	240
Payback period (Years)	21.3	21.5	24.5	30.6	25.4
Site score (average out of 5)	3.5	4.8	3.9	2.5	3.8

Zone 1, located in Carnarvon, WA, has the fastest payback period of all the identified areas. One advantage of this site is that it can be connected to neighboring substations to distribute power and thus satisfy the energy requirements of Carnarvon. However, there is currently no high-voltage transmission network connecting Carnarvon to the rest of Perth, resulting in a lack of market demand for electricity in the area. In addition, as zone 1 is located near Ningaloo Reef, the site may have issues such as heritage and environmental sensitivity concerns.

Karratha (Zone 2) is a mining town in the northern part of Western Australia. Since Karratha is located at the edge of a high cyclone frequency zone, which just satisfies the constraints so that it is not excluded in the analysis. The final site is located in a mining operation isolated from the rest of Western Australia and has a mini-grid with multiple substations. The early environmental and social assessment scoring system from Table 3 indicates that Karratha has the highest CSP-D exploitability with a score of 4.8/5.

Port Augusta in South Australia has previously been an area of interest for CSP-D. The Port Augusta area is located approximately 14 kilometers from the city center and is close to the cities of Port Augusta and Adelaide. This allows the CSP-D, established at this location, to have a sufficient market for hydroelectric demand. The LCOW in this region is the lowest of all regions at $0.22/m^3, suggesting that the desalination component of the region will be key to supporting a viable project.

Walgett (Zone 4), located in New South Wales, suffered a severe water crisis in 2019, which led the government to encourage desalination technology in the region through grants. However, the area is approximately 110 km from the city center and requires a long pipeline to transport brackish water. With further government support in this area over the next few years, and the expected increase in water prices (which will improve the economics of the project), the area's viability may increase. Current simulations indicate that the area has a payback period of more than 30 years and a pre-assessment system score of only 2.5/5, well below the other four areas.

Geraldton (Zone 5), a regional city north of Perth in Western Australia, has a calculated payback period of 25.4 years for a CSP-D plant. The Geraldton area is located approximately 28 km from the city center. The pipeline path to the coast has little variation in elevation within a short distance. The main benefit of this location is that the transmission network is connected to the Perth grid, indicating that there will be a greater demand for electricity.

In conclusion, CSP+D can be a solution for rising energy and water prices in Australia. According to the preliminary results, Western Australia has the highest number of selected sites with the best development score ratings and payback periods. The results show that four of the selected zones meet within the 25-year payback period, which means the screening approach and the scoring system are feasible. With continued optimization of technology and the areas identified, CSP-D developments could help drive a rapid transition to renewable energy-based technologies in Australia.

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