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# Solar polygeneration for electricity production and desalination: Case studies in Venezuela and northern Chile

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ABSTRACT

In this study, a polygeneration system incorporating concentrating solar power (CSP) integrated with a desalination plant is investigated. Parabolic trough collectors (PTC) and multi-effect distillation (MED) technologies are considered, and a transient system model has been simulated using the TRNSYS software. Two alternative desalination integration options and two potential locations in Venezuela and Chile with electricity and freshwater supply problems were selected and studied. Chile has also set a 20% target for non-conventional renewable energy production by 2025; therefore a polygeneration system coupled with desalinization plant is aligned with the needs of both countries. The results show that the CSP polygeneration plant can provide electricity and freshwater to more than 85,000 inhabitants at a reasonable cost; however the costs and feasibility depend principally on the irradiation, the location of plant with respect to the sea, and the specific conditions of each country. With the projected costs expected to decrease, it could be feasible to develop a CSP polygeneration plant in either country. For the Chilean case, LEC and LWC can be reduced to competitive prices if the initial PTC investment cost could be reduced by 15% for the Chilean case, and by 25% for the Venezuelan case.



## 1. Introduction

World global energy demand is increasing and historically has been met by the exploitation of fossil fuels, which provide more than the 85% of global energy needs [1]. As the link between greenhouse gas emissions and Climate Change has been strongly confirmed, each country has an obligation to reduce the production of these gases [source]. Latin America predicts sustained growth in its energy consumption [2] and confronts the challenge of undertaking sustainable development. Furthermore, water and electricity scarcity in various parts of each country is a real concern.

Venezuela is a country of marked contrasts; the country is an exporter of energy due to crude oil production [1,3] however over 60% of electricity generation comes from hydroelectric sources [4]. In recent years there have been problems with thermo-electrical generation and increasing demand, which has caused power cuts in some regions. There is also a lack in supply of freshwater, mainly in coastal areas. However, in these zones (Margarita Island and Paraguana Peninsula), the DNI (Direct Normal Irradiation) of Venezuela is high (approximately 2,000 kWh/m$^2$yr). Chile is an importer of energy [1], with an increasing electricity demand. The country has mandated sustainable development via the non-conventional renewable energy (NCRE) law [5], which states that 20% of electricity generation by 2025 should be produced by NCRE sources. Additionally Chile has a high water demand and water scarcity in the north of the country due to mining [6]. Nevertheless, in the north of Chile, the irradiation is the highest in the world, with DNI of more of 3,000 kWh/m2yr [7,8].

In addition to reducing greenhouse gas emissions, it is necessary to increase the intensity of the processes, hence the concept of polygeneration is proposed, which allows one to obtain several products from one source of energy. These processes try to take advantage of the residual products or to diminish the energetic

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losses to optimize the use of energy. With intelligent integration of solar energy, this resource can be used to generate electricity, clean water, process heat, and other products [9]. Concentrating solar power (CSP) technology has undergone technological improvements and consequently interest has increased in recent years. Several integration options with CSP technology have been studied in order to obtain various products like water, industrial process heat, air conditioning and refrigeration [10].

### 1.1. CSP technology

Using CSP to produce electricity at the commercial level is limited to parabolic trough collectors (PTC) and solar towers. PTC is a technology that has expansive commercial development, with a 80% market share [11,12]. This technology consists of a parabolic-shaped mirror that focuses the DNI to a receiver tube, located in the center of the parabola. The heat transfer fluid (HTF) is circulated and heated via this concentrated light [11]. These plants use thermal energy to power thermodynamic cycles, primarily a Rankine cycle. A heat exchanger transfers the thermal energy of the HTF to generate steam [13]. Installed plants in southern Spain such as Andasol, Palma del Rio, Termosol and also the SEGS plants and Nevada Solar One in USA use this technology [14]. Recently, PTC plants have incorporated thermal energy storage (TES), which aims to increase the hours of operation of the plant in the absence of irradiation. The technology that has had the largest commercial impact has been molten salt [15]. In Fig. 1, a basic scheme of a PTC plant with TES is shown.

The development of CSP has been undertaken in the last decade, mainly in the technology of PTC and solar towers. Since 2007, there has been a steady growth in the installed capacity of CSP, due to the growth of technology in Spain and the USA [12]; this development has allowed production costs to be reduced. In the roadmap for CSP by the International Energy Agency [16], a scenario is presented in which the cost will continue to decline; by 2020–2030, the cost will be competitive with the cost of conventional energy sources.

### 1.2. Desalination technology

Since the mid-20th Century, desalination technology has seen improvements in the efficiency and installed capacity of plants [17]. Desalination technologies at the large scale are divided into two major types: thermal action and permeable membrane. The main thermal technologies are: multi-stage flash (MSF) and multi-effect distillation (MED), while the principal membrane technology is reverse osmosis (RO). The approximate market share is roughly 50% for thermal and 50% for membrane [17]. Nowadays, MED distillation covers 12% of the market of thermal desalination [18]. The process is carried out in several stages (from 2 to 16) in which the pressure is controlled. The process consists of heating the seawater in the first stage with an external heat source at 70 °C, whereby part of it evaporates. The steam of the distilled water is transferred to a heat exchanger for the next stage and is used as heat source for the succeeding stage. This process continues in each of the stages [18]. Electricity is used to power pumps for different fluids and vacuums. The benefits of using a low temperature in the first stage are that there is less fouling outside of the tubes, which allows this technology to be combined with other processes such as thermal and mechanical compressors steam to improve its GOR (Gain Output Ratio) [17]. Another advantage is that it requires minimal maintenance and operating staff, little pre-treatment of seawater, and simple post-treatment due to the good quality of the freshwater produced (approximately 10 ppm of salinity) [18]. Although the MSF technology has been further developed in recent years, there has been a renewed interest in this technology because it has a lower thermal energy consumption and low maintenance.

### 1.3. Literature review

There are few studies of solar energy in countries with tropical weather, but these studies reveal that India is one of those countries with a higher degree of research and development. First, Fernandez-Garcia et al. [10] mention that potential sites for PTC application typically have more than 1,700–2,000 kWh/m$^2$yr DNI, and existing technologies contribute to the direct or indirect heat production for a heat engine. They also mention that the technologies used in the previous studies for desalination with CSP integration are RO, MSF and MED. Purohit and Purohit [11] studied the technical and economic possibilities for CSP implementation in India. They took PS-10 and Andasol-1 projects in Spain and simulated them in different locations in India, with the result that CSP projects are economically feasible in the northwest of the country (particularly in the states of Rajasthan and Gujarat). Preliminary results can be used to identify areas for CSP project development. Note that these regions have more than 1,700 kWh/m$^2$yr DNI, and are classified as desert. The locations classified as having tropical weather have lower irradiation, and economic analyses were unfavorable. Moreover, Janjai et al. [19] performed an analysis for CSP implementation in Thailand where irradiation values are between 1,350 and 1,450 kWh/m$^2$yr, indicating that there was a potential for PTC technology, obtaining an LEC (levelized energy cost) of 0.30 USD/kWh, a plant factor of 20%, and with high state incentives

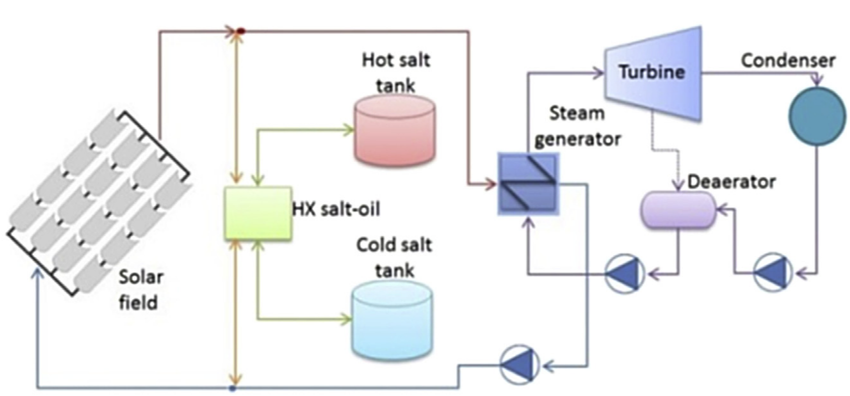


**Fig. 1.** PTC plant with TES configuration.