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Water consumption in solar parabolic trough plants: review and analysis of the southern Spain case

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ABSTRACT

The purpose of this paper is to highlight water consumption as a key design parameter in determining the most convenient cooling system and selecting the most appropriate location for Solar Parabolic Trough (SPT) plants. Considering the importance of water in guaranteeing environmental sustainability, a review of water consumption parameters is presented, and water consumption in the SPT plants that are in the planning stages for southern Spain are analyzed as examples. The selected region for the present study, is exposed to high horizontal solar irradiance, undergoes large seasonal weather fluctuations (prolonged droughts) and is located far from the coast (determining the site's topography and soil availability). These characteristics demonstrate that water consumption is one of the decisive factors for the construction of new solar plants in similar locations worldwide, in addition to other considerations such as capital cost or plant efficiency. Currently, most SPT plants are based on the Rankine cycle via a conventional steam turbine generator, which implies the requirement of a cooling system using water. In this paper, all current cooling technologies are reviewed and the required water consumption is analyzed. The impact of plant consumption on the area of SPT plant location is analyzed as well. This paper also discusses the socio-economics and environmental effects of an implemented cooling system. In addition, this paper presents different technical alternatives for minimizing water consumption for cooling and the effects thereof on the rest of the key parameters in the development and construction of a new SPT plant.

Contents

1. Introduction

The aim of this article is to review and highlight importance of water consumption in a Solar Parabolic Trough (SPT) along with other parameters such as technology, economical investments and

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Nomenclature

DNI	Direct Normal Irradiance
HTF	Heat Transfer Fluid
IC	Investment Costs
LCOE	Levelized Cost of Energy
NPV	Net Present Value
OC	Operation Costs
SPT	Solar Parabolic Trough

Symbols

C_e	Specific heat capacity of air (kJ/kgK)
C_v	Latent heat of water vaporization (kJ/kg)
C_w	Specific heat capacity of water (kJ/kgK)
m_w	Mass flow of evaporated water (kg/s)
V_a	Volumetric flow of air put into circulation (m^3/s)
V_w	Volumetric flow of evaporated water (m^3/s)
Q_t	Total power heat dissipated (kW)
Q_w	Dissipated thermal power, absorbed by the evaporation of water evaporation process (kW)
ρ_a	Air density (kg/m^3)
ρ_w	Water density (kg/m^3)
ΔT	Temperature change experienced as a result of air circulation (°C)

reduction in Greenhouse Gas (GHG) emissions. All of these aspects must be identified as clear constraints during the decision stages before, during and after the development and implementation of any new SPT power plant. The beneficial effects of renewable energy in terms of reducing GHG emissions has been extensively investigated [1]. However, limited studies have focused on other environmental parameters such as the one discussed in this paper: water consumption and usage in certain areas that can be affected by power plants based on solar energy.

In fact, plant location, cooling system size and technology underlying a new SPT power plant should be evaluated during the design, sizing and development phases of a project because these parameters have an effect on water consumption and thereby on the environment. Before the implementation of a SPT plant in a selected location, it should be considered that local water resources are in use for human consumption, leisure, industry and agriculture. The implementation of a new SPT plant will be an additional drain that could harm the resources commonly used for these pre-existing activities, placing the sustainability of the local area at risk. From technological point of view, cooling system is a crucial component of water consumption in a SPT plant. However, the technology used for electrical power production will also affect water consumption during the plant life cycle. This paper reviews Rankine technology plants because they are the most common type of SPT power plant constructed and under construction.

To analyze the water problem, this study will use the SPT power plant construction projects in southern Spain [2] as a reference, where water consumption represents a significant problem due to resource scarcity. The main objective of these projects has been, according to Spanish Government, to promote zero-emissions systems, generally called "green energy" systems, to minimize environmental impacts. The location, Spain, was considered for the case study because of high solar radiation intensity in the area with limited water supply.

Horizontal solar irradiance is the key parameter considered for construction of SPT plants. As indicated by maps of horizontal solar irradiance (Fig. 1) and the locations of existing SPT plants and plants planned for the mid-term (Fig. 2), all of the plants are located in areas of high irradiance. On the other hand, water resources in these areas are critical, a crucial factor for SPT plant development in Spain. Section 2 analyzes the available water resources and the expected impact of the SPT plants in these areas.

As a general example, a typical 50-MWe SPT plant needs a plant layout of approximately 200 ha and an adequate electrical infrastructure. High- and medium-voltage power lines must be located nearby to connect the plant to the distribution network. Soil availability and a uniform orography of the location are critical to maximizing solar irradiation and are directly related to efficiency and improving efficiency and improving economic parameters of the SPT system. Consequently, SPT plants are often located in areas with high solar irradiation where water is a scarce resource. Water consumption is distributed among the different activities in these areas; hence, water resources are in direct competition with other potential uses and activities, such as agriculture, industrial or leisure activities, that may be developed in the same area.

Based on these considerations, this article highlights the importance of using a cooling system technology that reduces water consumption. The paper reviews the most important plants in Spain, used as case studies, and analyzes the fact that power generation must be considered another element of local development and not an activity in competition with other water resource uses.

Spain is in the process of implementing SPT plants as a strategic plan to exploit excellent solar irradiation conditions, especially in the southern part of Spain. In Sections 2 and 3, we describe the current hydrologic status and that expected for upcoming years for the selected areas where the SPT plants will be located. In Sections 4 and 5 different cooling systems in SPT plants using Rankine cycles are reviewed and compared. Section 6 analyzes the implementation of SPT plants in Spain and in Section 7 an analysis of plants from the point of view of water consumption is performed.

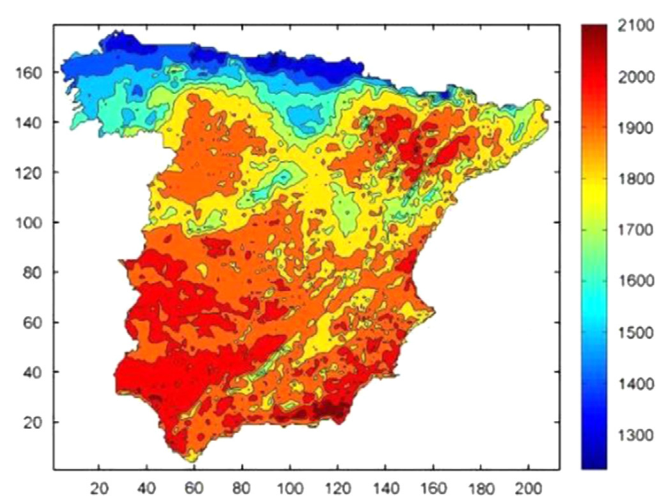

Fig. 1. Horizontal solar irradiance in Spain (kWh/m^2).