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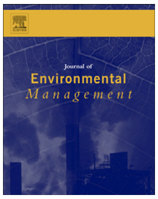

Short communication

Concentrating solar power plants versus groundwater resources in Mediterranean areas of Spain: The environmental dilemma

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ABSTRACT

Concentrating solar power plants (CSPPs) are considered to be particularly respectful of the environment but under Mediterranean climate where surface water scarcity is a key issue, these types of electrical plants usually require groundwater for their cooling towers and use the same aquifers to discharge their salinized effluents. This study analyses de Spanish case, where fifteen out of the fifty active CSPPs use groundwater directly, four discharge their effluents to infiltration ponds and forty-three to surface watercourses most of which recharge underlying aquifers. The volume of water withdrawn and discharged varies greatly among similar plants. The salinity of the effluent exceeds 2.5 times that of the withdrawn water in half of the plants and it may alter the current or potential use of the water turning it unsuitable for drinking or even for irrigation. There is a risk that the impact on groundwater can be extended to related ecosystems such as wetlands. This can become a serious environmental problem, but specific impacts on groundwater are often overlooked in environmental impact assessments of CSPPs and no research on the matter has been reported so far. Other legal and political implications of CSPPs are further discussed.

1. Introduction

The Framework Convention on Climate Change (UNFCCC) held in Paris on 30 November 2015, acknowledged the worrying increase in atmospheric CO_2 worldwide, and described it as “an urgent and potentially irreversible threat to human societies and the planet” (United Nations, 2015). This forum sent out a request to all countries to work together to reduce greenhouse gas emissions. Various mitigation measures were also proposed, with particular emphasis on the need to restructure the global energy system and recommending the replacement of fossil fuels with renewable energies such as concentrating solar power (CSP).

CSP is considered a viable and effective alternative to fossil fuels, particularly in arid regions (Pitz-Paal et al., 2013; Xu et al., 2016) and developing countries (Damerau et al., 2011; Metz et al. 2007). Concentrating solar power plants (CSPPs) seem to offer the maximum safeguards for the environment as they emit the lowest amount of CO_2 per unit of energy produced compared to fossil fuel plants (Trieb et al., 2014). Based on this kind of data, authorities and environmentalists (Greenpeace, 2016) proposed the construction of CSPPs as an opportunity to drive sustainable development and environmentally-friendly energy production. In fact, the amount of installed CSP systems has grown exponentially since 2007 (Xu et al., 2016). Although the current profitability of CSPPs is questionable, they are eventually expected to become competitive with fossil fuel-based plants and could even achieve production costs on a par with natural gas by 2020. The balance of costs with coal-fired plants will arrive between 2020 and 2030 (Pitz-Paal et al., 2013; Trieb et al., 2014).

The best locations for CSPPs are areas with high direct solar radiation (Xu et al., 2016) mostly located in arid or semi-arid regions, which often require the use of groundwater to ensure the necessary constant water supply. Due to the absence of surface water, the power plants must discharge the salinized effluent they produce either directly or indirectly to the same aquifers that supply them. These aquifers also supply industry, agriculture and even the population. However, these issues are hardly ever considered when analyzing the environmental impact of CSPPs.

The aforementioned processes affect not only the quality and quantity of the groundwater available in aquifers, but in the case of small aquifers may also have a significant impact on other

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parameters such as the groundwater flow pattern and even local water levels.

In comparison with other technologies, the amount of water used by CSPPs is far from negligible, ranking as top consumer among renewable sources (IEEE Spectrum, 2008; Macknick et al., 2012). According to some studies (Fenercom, 2012; Macknick et al., 2012), compared to other generation technologies with cooling systems, CSPPs consume a greater volume of water than conventional plants with equivalent energy production. According to these sources, a CSPP needs between 3000 l/MWh and 3500 l/MWh (similar to a nuclear plant), whereas coal-fired plants need around 2000 l/MWh, and combined cycle plants with natural gas less than 1000 l/MWh. This is attributable to the lower cycle efficiency in CSPPs related to lower operating temperatures (Otieno and Loosen, 2016). In CSPPs, 95% of the water is used for cooling and 5% for mirror or heliostat cleaning (Xu et al., 2016; http://spectrum.ieee.org).

In the qualitative study by Otieno and Loosen (2016), the risk of depletion or disruption of water resources was ranked with the highest risk by six CSP experts even after mitigation, particularly due to the possibility of local climate changes. Direct environmental impacts of CSP also include atmospheric pollution from life cycle fuel combustion, possible impact on biodiversity, land area required, visual and audial impact, material and energy consumption and potential of a fire hazard when using synthetic oil as a heat transfer fluid (Hernandez et al., 2014; Lilliestam et al., 2012). Related research on environmental impacts of CSP technologies across different areas and scales is currently demanded (Hernandez et al., 2014; Macknick et al., 2012; Rudman et al., 2016). Furthermore, no research on the specific impact of CSPPs on groundwater resources has been reported yet.

CSPPs are widely developed in Spain. Construction began in 2007 and reached its height in the period 2010–2012, primarily due to a government program of subsidies for this type of facilities. During this period, 74% of currently operating CSPPs were set up. These dates coincide with the launch of the Mediterranean Solar Plan in July 2008 in Paris, whose aim was to deploy an additional 20 GW of renewable electrical capacity for 2020 (Jablonski et al., 2012). Moreover, Spain ranked as the top country in operating CSP in 2011 with over 60% of the total capacity worldwide (Pitz-Paal et al., 2013).

The rollout of new plants in Spain is currently halted as incentives have been cut. However, numerous projects have been approved or are in very advanced stages of processing. In addition, public opinion and most experts continue to be convinced that CSPPs are the best option from an environmental point of view, compared to other methods of electrical energy production. It can be assumed that an upturn in the economy or a rise in the price of oil as well as the development of new technology would reactivate many of the projects currently on hold, which in the case of Spain implies a minimum of 22 new plants.

This work explores the dilemma of how greenhouse gas generation is weighed against the impact on aquifers in the case of CSPPs located in arid or semi-arid areas. It highlights the interrelation between CSPPs and groundwater systems, and the importance of considering this aspect in the planning or approval of new plants. It focuses on the singularity of their location and on the fact that the aquifers act as both source of water as well as sink of saline effluents. The analysis is based on the Spanish plants built in the last 10 years, which can be extrapolated to other Mediterranean countries where this technology is expanding. In summary, the aim is to attempt to prevent errors by alerting to aquifer sensitivity to CSPPs, particularly under arid or semi-arid climates. In addition, it emphasizes the importance of proper control policy of the CSPPs impact on groundwater.

2. Results and discussion

Tables 1 and 2 provide a summary of the location and characteristics of the CSPPs included in the analysis. All the information was taken from public open data sources including academic literature, public agencies reports, official web sites, public environmental impact assessment studies, NGO's and the solar industry itself. Water consumption or salinized effluent discharge data were either gathered from published data, environmental assessment reports or, in some cases, estimated based on the consumption and production of similar facilities. The effluent concentration factor in Table 2 was calculated as the volumetric proportion between the withdrawn and discharged water. In those cases where water requirements are given as an interval in Table 1, the lower limit was used to estimate the concentration factor. It is specified in the Tables whether the data comes from estimations or statements.

Most Spanish CSPPs are located in the southern half, where there are more hours of light and more direct solar radiation (5.1–5.4 kWh/m^2) (ADRASE, 2016). There are 50 solar plants in operation (Fig. 1) of which 44 use Parabolic Trough Collector Technology (PTC), 3 use Fresnel Technology (FT) and 3 use Solar Tower Collector Technology (STC). The main difference between them is that whereas PTC and FT are line-focused technologies focusing the sunlight to a line of receivers, STC is a point-focused technology leading the sunlight to a central point where the receiver is located allowing to reach higher temperatures (500–1000 C°). The maximum power that can be generated by Spanish CSPPs is limited by law to 50 MW (turbine size restriction), and thus most of the plants built (44 out of 50) are specifically designed with that capacity. This limitation implies that all the factors that determine the environmental impact of the plant (occupied area, need for water, volume of effluent, concentration of salts in the effluent and others) are in turn limited. However, to produce a greater quantity of energy, the plants were built so close together that what initially appeared to be an advantage (limited power = limited impact) has become a drawback. Just accounting for the duplicity in common facilities and accesses, as well as inefficient staff management, it appears that two plants producing 50 MW together may have a greater impact than one plant producing 100 MW. Besides this, CSP system is more suitable for large scale applications (>100 MW) because it generates electrical power using conventional turbines (Xu et al., 2016).

CSPPs unquestionably have an initial impact on the territory. In the case of linear systems, they alter the topography as they require a very flat surface to locate the mirrors, necessitating major earthmoving operations that modify the geomorphology and the patterns of water and wind erosion/sedimentation. In addition, these earth movements affect the sedimentation of the water ecosystems and increase water turbidity and the concentration of dissolved solids, salts and metals (Field et al., 2010). The application of chemical herbicides to clear sites before construction can also contaminate aquifers and other water resources (JISEA, 2015).

The average surface area of Spanish CSPPs is around 175 ha. Fig. 2 shows the frequency diagram of the ratio between energy production and surface area. It is worth noting that plants with the same technology and power show wide variations in their surface area, from 110 ha to 270 ha in the case of PTC. For example, a plant such as Casablanca (n°10) produces 0.23 MW/ha, whereas Solnova 1 (n°46) produces 0.43 MW/ha. Mean values are 0.29 MW/ha, although most plants –14 out of 50– produce around 0.25 MW/ha. Access to water sources and sinks, arrangement of evaporation basins and/or infiltration ponds, public regulations, and other land ownership issues may lie at the root of these differences.

CSPPs also consume large amounts of water, particularly in their cooling circuits. A typical Spanish plant uses around 40% of the