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Research article

Sustainable design of a thermosolar electricity generation power plant in Burkina Faso

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ABSTRACT

Research towards renewable energy sources is of great relevance in the pursue of environmental impact reduction and to decrease the dependency on fossil fuels. In high solar irradiation locations, the use of Concentrating Solar Power technologies might be a good alternative in front of other power sources.

This study presents how multi-criteria methods such as the weighted technical analysis are useful to select the best heat transfer fluid to be used in a relatively small Concentration Solar Power plant in the Burkina Faso. To do so it analyzes three aspects, the technical performance of thermal fluids, their environmental impact and their price, giving them different weights to confer more or less relevance according to the idiosyncrasy of the region.

To do the technical analysis, this study simulates the heat gain and temperature increase of four heat transfer fluids while passing through a solar parabolic trough. The environmental impact factor is evaluated following the life cycle assessment methodology and the economic factor compares their price in the market.

Results show that Dowtherm A is the best choice for Burkina Faso and Marlotherm is the worst, but these results change considerably if the comparison is done in the USA, where the environmental factor gains relevance in contrast to the economic factor.

1. Introduction

The International Energy Agency (Solar Paces, 2017) indicates that the primary energy demand will increase at a 1,5% rate until 2030, being fossil fuels such as natural gas, petrol and coal the principal power source representing an 80% of the total energy consumption. To confront this situation, the XXI International Conference on Climate Change agreed to reduce the global greenhouse gas (GHG) emissions to limit the global world warming below 2 °C in 2100 (Paris Climate Change Conference, 2015). As the consumption of energy is essential for the production of goods, and electricity plays an important role in it, the reduction of GHG emissions might be achieved with the incorporation of renewable energy power sources.

Globally, planet Earth receives approximatively 170 PW of solar radiation in the higher limits of the atmosphere, where 30% is reflected to space and the rest is absorbed by seawater, earth surface and clouds. This radiation is more than enough to think of a developed society using technologies based on solar capture. It is said that 25% of energy necessities could be provided by Concentrating Solar Power (CSP) technologies by 2050, which imply a reduction of 2.100 million tons of CO_2 (Greenpeace International, 2009). Unfortunately, the higher costs of implementation, their relatively new technological advances and the low financial capability and resources of many countries with high potential to incorporate them, keep their entrance slow.

Burkina Faso is a good example. Having an 87% of the energy system based on fuel and a transmission and distribution grid with 14% losses (World Bank, 2014), its potential to reduce the GHG emissions in the generation of electricity is enormous. Additionally, there is still a huge amount of the population living in remote or dispersed villages without access to electricity. But access to electricity is not the only shortage its population has, water is also a scarce and valuable good. Burkina Faso has a particular climatology with a 3 months rainy season followed by a long period of drought that directly affects the quality and quantity of water. In fact, as it happens with electricity grid, access to treated and purified water is far from being warranted in relatively isolated settlements (Amante et al., 2016).

In views of this situation, the research group in the department of project and construction engineering in the UPC designed and build a pilot portable water treatment plant that can work either manually or electrically powered. This purification water plant uses the residual

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Fig. 1. Prototype of the water purification plant.

waste cake from the production of Moringa Oleifera oil as a coagulant/flocculants that captures and eliminates the suspended organic solids and disinfects water (López-Grimau et al., 2013). Fig. 1 presents an image of the actual prototype of the water treatment plant that has electric pumps and electro-valves to work in automated mode but it can also work manually with the manual pump and the manual activation of valves.

This water treatment plant needs a source of power to run automatically. A previous study analyzed its energy consumption and indicated that renewable energy power sources, particularly those coming from the sun, where the most favorable alternative (Amante-García et al., 2017).

Within this framework, this study analyzes the possibility to consider CSP with Parabolic Trough Systems (PTS) to power this water treatment plant and the nearby villages, being CSP the most extended thermosolar technology with an implementation close to 90% against other similar alternatives (Deutsche Gesellschaft für Technische Zusammenarbeit, 2010). To achieve an effective introduction, CSP require, among other factors, high solar irradiation in relatively flat locations. In fact, two of the countries with higher installed CSP plants in the world are located in Africa (CSP World, 2015), (National Renewable Energy Laboratory, 2015).

Burkina Faso satisfies most of the requirements for the implementation of CSP plants, as the country has a flat orography with grasslands and small mountains (the top peak is 750 m high). Moreover, the solar irradiation indices are quite high in comparison to other places in the world (European Commission, 2017).

In this context, a cooperation project in one of the most impoverished countries in the world, as Burkina Faso is classified in the position 183 in the Human Development Index ranking (Human Development for Everyone, 2016), the price of components and materials acquisition to build and use the CSP plant is of great relevance.

Therefore, this study analyzes the technical, economic and environmental advantages to use a CSP plant in Burkina Faso to cover the electricity needs of rural settlements and a water purification plant.

The technical analysis is carried out simulating the behavior of four Heat Transfer Fluids (HTF) (Therminol VP1, Therminol 66, Dowtherm A y Marlotherm SH) through a 600 m solar parabolic trough (made of a number of solar collector modules) in a small CSP plant in the Burkina Faso. This study takes into consideration the seasons around the year and three solar irradiation incidence angles to determine their efficiency along the Heat Collecting Elements (HCE) using the software Solidworks Education Edition 2017®. The environmental impact analysis is done following the life cycle assessment using the SIMAPRO software. The economic analysis compares the prices of these four HTF.

Finally, using multi-criteria tools, this study presents which of these four HTF obtains the best qualification to be used in a CSP plant in Burkina Faso.

2. Methodology

In the first place, this study presents the situation and characteristics of Burkina Faso's solar radiation. The annual global Direct Normal Irradiation (DNI) from various sites is higher than 1.800 kWh/m2/year, which seems to be adequate to install a CSP in the country.

The designed water purification plant has a peak power consumption below 5 kW and a total daily consumption of 11.178 kWh (Amante-García et al., 2017) to treat 8.000 liters of water. Considering that local necessities might need more water, needing a bigger water treatment plant in consequence, and that in low income countries the energetic necessities of population are not guaranteed, the installed power plant should cover the energy demand of the treatment plant (or plants) and the nearby population needs.

Small CSP plants are capable to generate 1 MW power with a solar field of around 3 or 4 hectares, like the pilot plant in Gurgaon, New Delhi (NREL, 2014) that produces hot (350 °C) vapor at 42 bar to run a turbine generator that produces electricity with 600 W/m^2 of DNI and a solar field of 8.000 m^2. However, fields may be bigger and capable to