ENVIRONMENTAL IMPACT ANALYSIS OF CONCENTRATED SOLAR POWER PLANTS IN MOROCCO

Leila ABOU EL KOUROUM, Lahcen BAHI, Anas BAHI
Laboratory of Applied Geophysics, Geotechnics, Geology of Engineers and Environment, Mohammedia School of Engineers, Mohammed V University, Rabat, Morocco

ABSTRACT

Many countries all over the world have started to massively introduce renewable energy sources as clean alternatives to conventional energy sources. These technologies are expected to reduce pollution and dependence on fossil fuels. Indeed, the objective of introducing these alternative energy sources is to switch to more sustainable ones that would not compromise the capability of future generations to meet their own energy requirements. However, not many studies have been conducted to illustrate the impact of those renewable energy sources on the environment. Therefore, it is necessary to study their impact taking into consideration all stages of the life cycle of the power plant: the extraction of raw materials, construction of components, installation, operation and maintenance of the plant; and the end of life including waste management. This study focuses on one renewable energy source, which is Concentrated Solar Power (CSP). The approach used is a life cycle analysis of a CSP power plant located in Morocco using a software (OpenLCA) and supported by studies performed from the literature review. The results show that the phase that has the most impact on the environmental performance is the extraction and manufacturing phase followed by operation and maintenance phase. In addition, the environmental category that is most impacted by the technology is the land transformation. The land and soils are significantly impacted and become prone to erosion, temperature change and biodiversity change. Still, the impact is less significant that the adverse environmental impact that arises from conventional energy sources. Moreover, the calculated energy payback time for this case is 15 months, which is considerably less than the energy payback time required from other power plants. Areas of future research have been identified to be able to mitigate the impact of CSP power plants on the soils and to decrease the impact of the material extraction and manufacturing phase on the environment.

Key words: Concentrated Solar Power, Environment, Life cycle analysis, Renewable energy
1. INTRODUCTION

The population growth all over the world has led to a significant increase in energy demand and prices. In addition, fossil fuels availability is limited and the CO2 emissions generated have a negative impact on the environment. As a solution to this problem, several countries have started to invest in renewable energy sources. CSP is a technology used to generate electricity by converting the direct solar radiation into a very high temperature heat that is used in a heat engine cycle to generate electric power. CSP is a promising technology in regions with high direct normal irradiance and can be a reliable source of power in peak loads in sunny regions by 2020 and of base load by 2025 to 2030 [1].

There are four types of CSP technologies: parabolic dish systems, parabolic trough collectors, linear Fresnel reflector and solar power tower. The technology chosen for this study is the parabolic trough collectors (PTC) that consists of a number of curved reflectors that focus the sun radiation in the absorber tube situated in the focal line of the parabola (Fig.1). The reflector as well as the absorber tube follow the movement of the sun all day to collect the maximum radiation [2]. The heat transfer fluid used can be either molten salts or thermal fluids, while a direct steam generation system can also be used. PTC are installed in a very large area of land and require a high amount of water for cooling and condensing operations, around 3000 L/MW h [3].

Since the emissions generated from CSP power plants operation are negligible compared to burning fossil fuels, the emissions from its life cycle could be important. In order to evaluate the impact of a CSP power plant on the environment, the consequences of all components and activities of the project from construction to waste on the natural environment are analysed. The life cycle assessment (LCA) is used for that purpose and examines the environmental impact of important components beginning with the extraction of raw materials, manufacturing, construction, operation, and then the end of life which includes disposal, reuse and recycling. The environmental categories taken into consideration in this study are: climate change, human toxicity, terrestrial acidification, freshwater eutrophication, marine ecotoxicity, natural land transformation, water depletion and fossil depletion.
2. DESCRIPTION OF THE POWER PLANT

Morocco depends essentially on fossil fuels (coal, oil and natural gas) for the operation of its power plants to generate electricity. Currently, 96% of the country’s energy supply are imported [5]. However, Morocco has an important potential of renewable energy sources, especially solar energy, that could be used to save the country from importing the majority its energy needs. The country has areas that receive more than 5 kWh/m² /day of solar irradiance which is the equivalent of more than 3000 h/year of sunshine [7].

In fact, Morocco is part of the Mediterranean Solar Plan (MSP) to develop 20 GW of renewable energy generation in the Mediterranean region by 2020, along with other 42 countries in Europe, Middle East and Africa. For the development of the MSP and part of the Moroccan Solar Plan, Morocco aims to decrease its energy dependence by installing a large solar power plant of 580 MW [8]. The solar power station analysed is a fictional yet realistic configuration of a solar plant based in Morocco, it contains CSP with PTC and has a capacity of 50 MW. It contains 600 solar collector, and operates on a base of a Rankyne cycle with molten salt storage (Fig. 2). It is located near the region of Ouarzazate city, which has a strong direct normal irradiance of about 2420 kWh/m² (Fig. 3) [6].

![Figure 2. Direct solar radiation in Morocco](image)

The configuration of the studied solar power plant is listed in Table 1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Ouarzazate, Morocco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>50 MW</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>30 years</td>
</tr>
<tr>
<td>Number of collectors</td>
<td>600</td>
</tr>
<tr>
<td>Field area</td>
<td>150 hectare</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>6 hours</td>
</tr>
<tr>
<td>Annual water consumption</td>
<td>160,256 m³</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>35000 MWh/year</td>
</tr>
<tr>
<td>(maintenance/operation)</td>
<td></td>
</tr>
<tr>
<td>Direct irradiance</td>
<td>2420 kWh/m²</td>
</tr>
</tbody>
</table>
3. MATERIALS AND METHODS

The Life Cycle analysis was conducted to analyse the environmental performance of a CSP power plant and to identify the environmental categories that are mostly impacted throughout the lifecycle of the CSP plant. The LCA model was performed using openLCA software and was backed up by studies and models in literature review [10-15]. The functional unit used in this case is 1 MW.h. The LCA methodology and configuration, including the system boundaries is illustrated in the flowchart in figure 4. The system includes all parts of the CSP power plant, during the principal phases that consist of:

- The extraction of raw materials, construction and installation.
- The use, operation and maintenance.
- End of life, dismantling and waste management.

The assessment of the impact includes the extraction of raw materials, the construction and manufacturing of components, the transport of different parts, the installation, and finally the end of life which includes waste management [9]. Concerning the life cycle inventory of the CSP plant, the following elements were taken into consideration [10]:

- Solar field: including materials to construct the solar collectors (mirrors, frame and base), heat collection elements, controls and tracking system.
- Heat transfer fluid system
- Storage: salts, foundations, insulation, circulation pumps, heat exchangers and piping systems.
- Power block: systems of the Rankine steam cycle (turbine generator ….).
- Facilities that include roads, building, parking lots and treatment centers (water).
4. RESULTS
The life cycle is analyzed for the selected impact categories in the principal phases that could be consolidated as follows: 1. extraction and manufacturing, 2. construction, 4. Operation and maintenance, 5. Dismantling and disposal, normalized to the overall life cycle results. The impacts are: climate change, human toxicity, marine ecotoxicity, terrestrial acidification, natural land transformation, freshwater eutrophication and fossil depletion. The results are illustrated in figures 5 and are comparable to other values published by other authors. The results illustrated are also lower than those obtained in case of electricity generated from some other energy sources [11,12].
According to figures 5, the phase that generates the most environmental damage is the extraction and manufacturing phase, due to the use of materials such as steel, molten salt, heat transfer fluid and copper. Conventional energy sources are also required in the manufacture of the system as it is the main source of energy in the manufacturing industry. This is followed by the operation and maintenance, due to the use of the electricity grid for the maintenance. The other stages of the life cycle show relatively low environmental impact such as the end of life phase and the construction phase. However, the CSP power plant consumes high quantities of water, especially during the operation phase, which can be problematic for plants in fields located in the south with high solar irradiance but low water availabilities.

Moreover, the results of the study illustrate that land transformation is the most environmental category impacted by the CSP power plant. This results match the information found in the literature review which consider that soils drastically change when such technology is constructed [16]. In fact, the soil near the collector fields is disturbed and the vegetation and inherent biological soil crusts is destroyed. The sand becomes loose and disposed to erosion. The existence of the solar collector has also an impact on the energy balance of soils and has an important impact on the soil temperature [16].

In addition to the previous analysis, the energy payback time is a significant parameters to evaluate the effectiveness of the CSP plant. The energy payback time is the time necessary for the CSP power plant to recover the amount of energy it has employed in its construction process [13]. The energy payback time is calculated using the following equation [14]:

\[
\text{Energy payback time} = \frac{\text{CED}_c}{\text{E}_{\text{net}} \cdot \text{g}} \cdot \text{CED}_0
\]

Where CEDC is the primary energy demand for the manufacture of the power plant, E_{net} is the net electricity produced per year and g is is the utilization grade of primary energy source to produce electricity.

According to the values taken for the studied CSP plant, the energy payback time is 15 months. This amount of time is significantly less than the time required for other energy sources on the market.

5. CONCLUSION
This study shows that the life cycle analysis of a CSP power plant can be evaluated for characteristics impacting the environmental performance. For the illustrated CSP power plant

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\text{Figure 5. Impact of CSP power plant on the identified environmental characteristics}
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configuration, it can be concluded that: the most impacted environmental categories are the land transformation and fossil depletion. Indeed, the solar plant has a significant impact on the the local environment, especially on the soil. The solar collectors have an impact on soil erosion, soil temperature and the biological soil crusts. Moreover, the most impacted phase of the life cycle is the raw materials extraction and manufacturing of the different parts.

More studies can be conducted in the future concerning the economic and social assessment of the CSP power plant, in order to obtain the full sustainability evaluation of the technology. Also, solutions can be identified to decrease the risks on the impacted soils and to mitigate the impact of the materials extraction and manufacturing of components phase by using recycled elements and choosing materials that would require less energy to be manufactured.

REFERENCES


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