20th European Symposium on Computer Aided Process Engineering – ESCAPE20
S. Pierucci and G. Buzzi Ferraris (Editors)
© 2010 Elsevier B.V. All rights reserved.

Life Cycle Assessment of a High Temperature Molten Salt Concentrated Solar Power Plant

Vincenzo Piemonte[1], Marcello De Falco[1], Pietro Tarquini[2], Alberto Giaconia[2]

[1]*Department of Chemical Engineering Materials & Environment, University of Rome "La Sapienza" via Eudossiana 18 00184 Rome-Italy*

[2]*ENEA (Italian National Agency for New Technologies, Energy and Sustainable Development), Casaccia Research Centre, via Anguillarese 310 00123 Rome-Italy*

Abstract

The well-known world energetic matter, mainly due to the worldwide growing energy consumption gone with a reduction of oil and gas availability, and to the environmental effects of the indiscriminate use of fossil fuels in our economy, is leading to the development of clean innovative technologies for the reduction of GHG emissions and the creation of a more sustainable economic structure worldwide. But, realizing and installing renewable energy plants have an environmental "footprint" that has to be evaluated to quantify the real impact of renewable technologies on the environment. Nowadays, the most important tool to evaluate this impact of a product is the Life Cycle Assessment (LCA). To this aim, several impact categories are defined; among these the most important are the Global Warming, the Abiotic Depletion, the Eutrophication, the Acidification, the Land Use and the Human toxicity.

The aim of this work is to present a Life Cycle Assessment of an innovative solar technology, the Molten Salt Concentrating Solar Power (CSP) plant, developed by Italian Research Centre ENEA and able to produce clean electricity by using solar energy. The Life Cycle Assessment was carried out by means of the SimaPro7 software, one of the most used LCA software in the world. It is worth assess that these types of software are an indispensable tools for leading LCA studies. In the second part of the study the environmental performance of the CSP plant was compared with these of conventional oil and gas power plants.

Keywords: LCA, Concentrated Solar Power Plant, Renewable Energy, Conventional Power Plant.

1. Introduction

The well-known energetic issue is stimulating the development of clean innovative technologies for the reduction of GHG emissions and the creation of a more sustainable economic structure worldwide. The exploitation of renewable energy sources for heat and energy production is commonly considered the most promising way to reduce the impact of human activities on environment, since clean energy technologies allow using no-fossil derived energy, without producing pollutants and GHGs. On the other hand, realizing and installing renewable energy plants have an environmental "footprint" due to the utilization of construction materials, transport, maintenance, final disposal, etc. It is extremely important evaluating this impact for renewable plants, and LCA is a crucial tool to understand how reducing technologies environmental footprint.

Among renewable energy technologies, those exploiting solar energy seem to be the most applicable thanks to the huge and diffuse solar energy availability. The present work is focused on an innovative solar technology, the Molten Salt Concentrating Solar Power (CSP) plant, developed by Italian Research Centre ENEA.

CSP plant (Figure 1) basically consists of a solar collector field, a receiver, a heat transfer fluid loop; a suitable heat storage system is also required to maximize the “capacity factor” (i.e. productivity) of the solar plant, and to provide solar heat at the desired rate regardless the instantaneous solar radiation availability and fluctuations [1]. The mirrors of the solar field concentrate the direct solar radiation on the solar receiver set at the focal point. The heat transfer fluid removes the high temperature solar heat from the receiver and it is afterwards collected into an insulated heat storage tank to be pumped, on demand, to the heat users where it releases its sensible heat. Finally, the heat carrier fluid is stored into a lower temperature tank ready to restart the solar heat collection loop. A proper dimensioning of the heat storage system allows to drive the process in continuous.

Recently, some molten nitrate mixtures at temperatures up to 550°C have been positively tested as convenient, cost-effective and environmental friendly heat transfer fluid and storage medium for CSP plants [2,3].

The high temperature molten salt sensible heat is used to generate high pressure steam to be sent to a steam turbine Rankine cycle for the production of clean electrical energy.

The aim of this work is to evaluate the performance of the proposed CSP plant from an environmental point of view by the use of a the Life Cycle Assessment Methodology which is based on calculations and analysis of effects to environment, human health, socioeconomic factors and climate change.

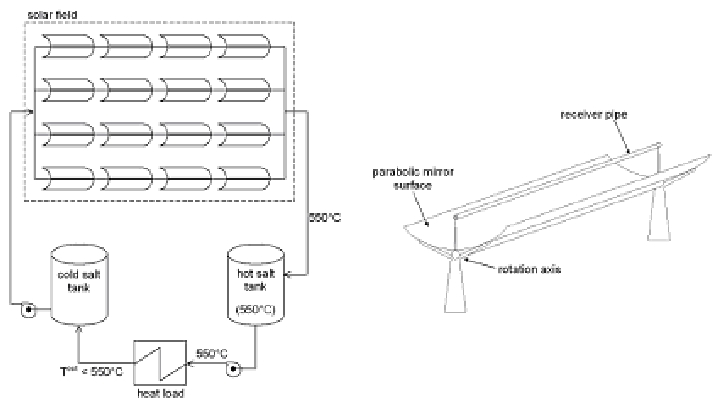

Figure 1: Simplified scheme of a single solar trough collector section (right) and a power plant with two-tank molten salt storage (left).

2. LCA methodology, software & Data base

The "Life Cycle Assessment", methodology allows to evaluate a set of interactions that a product or service has with the environment, considering its whole life cycle that includes the preproduction points (extraction and production of raw materials), production, distribution, use (including re-use and maintenance), recycling and final disposal. So the objectives of the LCA are to evaluate the effects of the interactions between a product and the environment, helping to understand the environmental impacts directly or indirectly caused by the use of a given product.

In compliance with ISO 14040 and 14044, the Life Cycle Assessment is achieved through four distinct phases: first you need to make the description of the system under consideration, the evaluation methods used and the purpose of study (Goal and Scope). The second phase includes products manufacturing (including extraction and production of raw materials, production and distribution of the final product) and its final disposal system. For each process, the emissions into the environment (air, water, soil) or more generally the cost in environmental terms (including, if possible, a need of water and land) must be taken into account. This phase is called Life Cycle Inventory (LCI). The third phase is called Life Cycle Impact Assessment (LCIA) and provides for the determination of a wide range of categories of environmental impact (global warming, abiotic depletion, Eutrophication, Acidification, etc..). The last phase consists in the analysis of the results obtained from the assessment of the individual categories of environmental impact; in this phase the processes of normalization and weighting must be carried out to obtain global results (overall impact indices), which are often used to compare the environmental impact of two products.
If the analysis is performed directly on the categories of environmental impact, such methodology is called "Mid-point approach." A viable and valid alternative is represented by the “End-point approach "or" Damage-oriented approach. "
In general, the LCA can be conducted by assessing the environmental footprint of a product from raw materials to production (Cradle to gate), or to be extended to the whole product life cycle, including its disposal (Cradle to grave).
In this work the LCAs have been performed by using the Eco-Indicator 99 methodology which develops an "End-point" approach: the typical impact categories aforementioned are normalized and grouped in three damage categories: Damage to Human Health, Damage to Ecosystem Quality and Damage to Resources [4]. Furthermore the International Panel for the Climate Change (IPCC) and the Cumulative Energy Demande (CED) methods were also used to estimate the global warming and the total energy requirements.
The software used for the realization of the LCA studies reported in this work is SimaPro7. The LCI of the CSP plant has been realized on the basis of the construction data directly provided by the ENEA centre, while the LCAs of the conventional oil and gas power plants have been performed by using data included in the Ecoinvent v.2.0 database. The data relate to international scenarios, which cover the entire industrialized world.
From how reported above it is evident the contribution of computer simulations to the LCA realization and therefore to the environmental assessment of the process plant considered in this study.

3. LCA Results

In the table 1 are reported some preliminary aggregated data relatives to the construction of a CSP plant for a continuous energy production of about 400 kWe for 300 days/year (i.e. 2880 MWhe/year). A biomass furnace was also considered to provide a plant back-up energy of 1.58 MWth, required to balance protracted cloudy periods. The LCI data are directly provided by the Italian research centre ENEA.
The LCA was performed considering the most important materials used for construction as well as the energy requirements for construction, while transport was implicitly included in energy consumption. Materials used was expressed per MJ produced electricity over its life time, assumed 20 years. In order to perform a LCA cradle to grave the disposal of the building was also considered.

The most important LCA results for the CSP plant are summarized in table 2. It is worth noting that the high value assumed from the impact categories is mainly due to the environmental contribution of the building materials production. In effect the production of 1 kg of stainless steel is associated with an emission of 3.93 kg of $CO2_{eq}$.

Table 1: Raw materials, energy demand and land use for the CSP plant building

Raw material	**Amount**	**Raw material**	**Amount**
Concrete (kg)	334973	Mineral wool (kg)	6474
Steel (kg)	384000	Biomass (kg)	746048
Stainless steel (kg)	116284	**Energy Demand**	
Glass (kg)	62239	Solar radiation (MJ/year)	70006154
Plastics (polypropylene) (kg)	28000	Electricity (Italian mix) (MJ/year)	9027
Sodium nitrate (kg)	877241	**Land use**	
Potassium nitrate (kg)	584827	CSP plant (m^2)	36000
Zinc (kg)	116423	Biomass growth (m^2)	750000

Table 2: Main LCA's results for the CSP plant

Impact category	**Value/year**
Global warming 100a ($kgCO2_{eq}$)	141788.4
Ozone layer depletion 25a ($kgCFC\text{-}11_{eq}$)	0.012
Human toxicity 100a ($kg1,4\text{-}DB_{eq}$)	91302.9
Acidification ($kgSO2_{eq}$)	730.376
Eutrophication ($kgPO4^{3-}{}_{eq}$)	72.801
NOx ($kgNOx_{eq}$)	686.385

In the second part of the LCA study, the environmental performance of the CSP plant was compared with respect to those of an oil power plant and a gas power plant characterized by the same productivity of the CSP plant considered in this work.
The results of the LCAs comparison are reported in figures 2 and 3 in terms of cumulative energy demand and climate change evaluated at 100 years, respectively. From the pictures is evident that the CSP plant requires a high quantity of renewable energy (from solar, biomass, water), while fossil energy duty is about 80% less that that required from a gas power plant and 90% less that that required from an oil power plant. These findings agree with a much lower emission in terms of $CO2_{eq}$ (measured as Global Warming Potential) reported by the CPS plant with respect to these of the oil and gas power plants (figure 3).
In the figure 4 it is also reported the comparison of the three power plants considered in this work by using the Eco-indicator 99 methodology in terms of damage categories. The figure clearly highlights the lower impact of the CSP plant both for the damage category “Resources” and “Human Health”, while its impact for the “Ecosystem Quality” is substantially comparable with that of the oil power plant and slowly higher that of the gas power plant.
From an overall point of view the figure 4 suggests that the CSP plant is always preferable to the oil power plant (its impact is lower than that of the oil power plant for all the three damage categories). On the contrary the comparison with respect to the gas power plant must be further elaborated by means of the mixing triangle technique [5]. From figure 5 it is evident that the gas power plant is preferable to CSP plant only for very high values of ecosystem quality macro-category, that is only if we assign a very low importance to the resources depletion and to the human health.

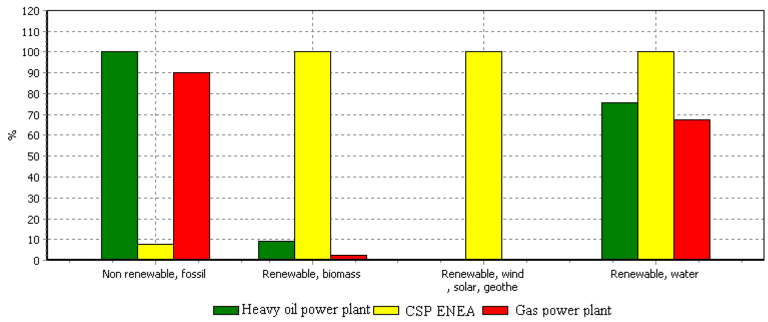

Figure 2: LCAs Comparison in terms of Cumulative Energy Demand (CED)

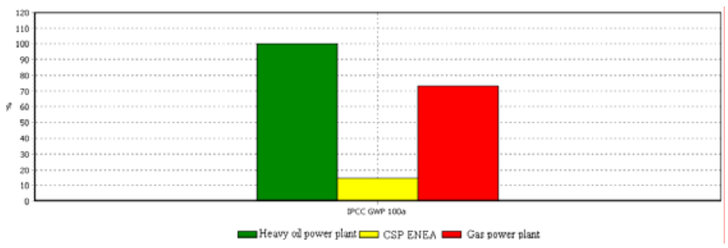

Figure 3: LCAs Comparison in terms of Global Warming 100a (IPCC)

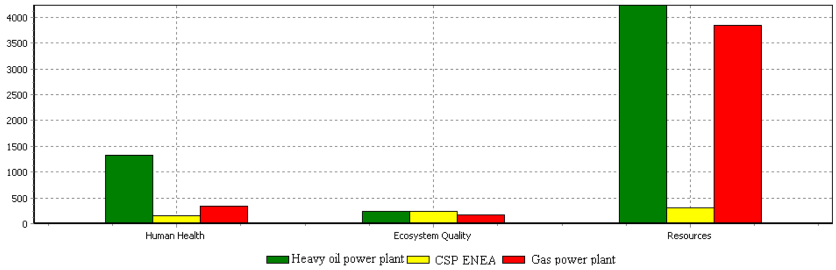

Figure 4: LCAs Comparison by means of the Eco-indicator 99 Methodology: damage oriented approach

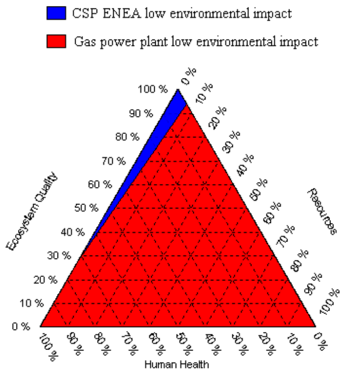

Figure 5: Comparison of the global impact of the CSP plant vs. a gas power plant by using the mixing triangle approach

4. Conclusions

In this work the CSP plant performance was assessed from an environmental point of view by using the LCA methodology. The CSP plant was also compared to conventional power plant (gas and oil) in order to evaluate its reliability. Even if this is only a preliminary study the results are very interesting: by assigning reasonable values to the three damage categories used in the eco-indicator 99 methodology, the CSP plant is always preferable with respect to the conventional power plants. This finding confirms the high potentials of this innovative plant technology.

References

[1] C.J. Winter, R.L. Sizmann, L.L. Vant-Hull, *Solar Power Plants*. Springer-Verlag Ed, New York, 1991.

[2] D. Mills, *Advances in solar thermal electricity technology.* Solar Energy. 76 (2004) 19-31.

[3] U. Herrmann, D.W. Kearney, *Survey of Thermal Energy Storage for Parabolic Trough Plants.* ASME J Sol Energy Eng. 124 (2002) 145-151.

[4] Goedkoop, M., Effting, F., and Collignon, M. 2000. The Eco-indicator 99, A damage oriented method for Life Cycle Impact Assessment, PRé Consultants B.V. second edition.

[5] P. Hofstetter, A. Braunschweig, M. Mettier, R.M. Wenk, O. Tietje, The Mixing Triangle: Correlation and Graphical Decision Support for LCA-based Comparison, Journal of Industrial Ecology, 3(4) 2008, 97-115.