INNOSOL – ENVIRONMENTAL ASPECTS OF THE OPEN VOLUMETRIC RECEIVER TECHNOLOGY

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1. Introduction

In the year 2009 the first research solar tower power plant with open volumetric receiver technology was set into operation in Juelich (Koll et al, 2009). Already during the construction period data concerning construction efforts and components were collected in a detailed quantity structure within the framework of research activities of the "Virtual Institute of Central Receiver Power Plants – vICERP"[1]. On this basis, a calculation of the environmental impacts resulting from the construction and commissioning phase (LCA – life cycle assessment; cradle to gate approach) according to ISO 14040/14044 (DIN 2006a, DIN 2006b) was carried out. In a second step, the results were investigated towards the most effective optimization approaches in order to achieve a reduction of environmental impacts. This analysis pointed out that the reduction of the used unalloyed steel amounts for the mounting structure (heliostat) and the reinforcement steel (tower) or their (partial) replacement with environmentally expedient materials offer the most effective approaches to reduce the environmental impacts of the solar tower construction (Hoffschmidt und Fricke, 2010).

In the research project "InnoSol" a complete LCA for a scaled up power tower realized in a site with appropriate radiation has to be conducted including operation and dismantling phase. Based on the LCA results of a reference plant planned technological concept changes and innovative components will be evaluated. In the first part of the study the solar only reference plant was designed and will be assessed. In the second phase innovative components and concept changes currently under development will be implemented in the life-cycle wide LCA model.

So far the Solar-Institut Jülich and its partners defined the design conditions for the reference plant and started the design layout and the life cycle assessment modeling.

2. Design conditions of the 10 MW Solar Tower

2.1. Site selection

Following the internationally promoted realization of solar power plants in the North African region (ISE et al., 2011) the selected site for the solar thermal tower power plant is located in Algeria. The selection of a suitable location was influenced by geographical, administrative, infrastructural and meteorological conditions. The selected location Bechar is sited on 31°N latitude. Bechar's railway connection to the port of Omar offers good freight transport conditions. Easy access to an international airport and expressway is given as well. The solar irradiance of about 2570 kWh/m²a offers good meteorological conditions for the operation of a solar thermal power plant. The risk of earthquakes is very low so extra construction requirements for the tower are not necessary.

2.2. Design of the water steam cycle

The water steam cycle is designed as a two pressure step cycle. The feed steam temperature is at 520°C with a pressure of 80 bar at nominal load operation. The nominal power of the reference solar tower power plant is just under 10 MW_{el}.

2.3. Heliostat type

For the reference plant the heliostat field was designed with the facetted glass metal heliostat type GM 100.

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The technical characteristics of this heliostat has been examined precisely on the Plataforma Solar de Almería, reliable information about characteristics, material weights and prices were used from various publications (Weinrebe, 2000), (Ulmer, 1998), (PSA, 1997).

2.4. Construction type tower

The tower of the solar thermal power plant is designed as a reinforced concrete construction. The local competences are high for this type of construction, the material can be provided by the regional industry. A tower with a pure steel structure would have to be imported completely as the regional industry cannot provide sufficient preciseness in the element production. The transport of the huge steel tower elements could cause high transport efforts and thus higher total costs. For locations with high risk of earth quakes a steel structure tower although could be the better choice. A rough layout will be done for both tower types to be able to assess the influence of the construction type of the tower on the LCA results.

2.5. Operation strategy

In the project "InnoSol" the environmental aspect of innovative solar tower plant developments is assessed. Due to the future oriented character of these plant concepts the operation strategy in a simplified approach reflects the prospective requirement of load follow operation expected for solar thermal plants. According to the Desertec idea (bin Talal et al., 2007) and the assumption of a 15% share of German power supply in 2050 in "Leitstudie 2010" (Nitsch et al., 2010) the electricity price index PHELIX of the European Energy Exchange EEX in 2010 were used to classify four time periods within 24 hours with three different power targets of 50%, 75% und 100% of the nominal power level (Fig.1).

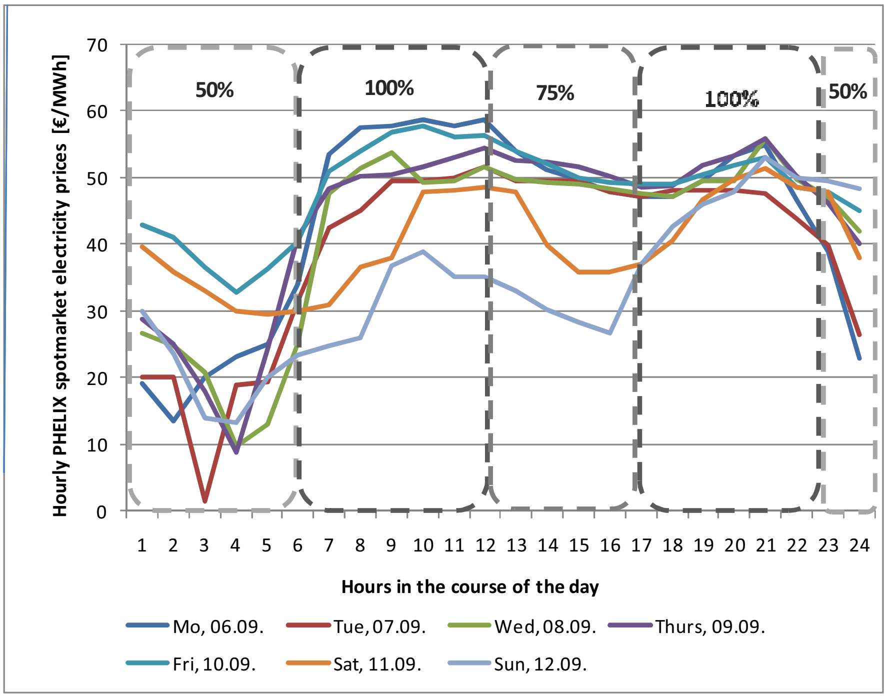

Fig. 1: Defined time periods with load targets laid over the hourly PHELIX prices of a week in September 2010

2.6. Storage capacity

The heat storage of the reference power tower plant is a ceramic structure following the construction principle in the demonstration plant in Juelich. For the operation mode described in section 2.5 a storage capacity of 8 hours of nominal load was defined.

2.7. Feed-in tariff

The German feed-in tariff currently does not contain an approach to couple tariffs to market prices. For that reason the herein used feed-in tariff is based on the tariff principles of the Spanish Real Decreto 661-227, tariff for Central Receiver Power Plants, group b.1.2, regime B. For the layout calculations of the InnoSol plant concepts the following tariff amounts were defined: the tariff consists of a basis price of 0,23 €/kWh plus a market price related bonus between 0.05 and 0.07 €/kWh. The bonus level is connected to the time periods, 0.05 €/kWh for the 50%, 0.06 €/kWh for the 75% and 0.07 €/kWh for the 100% load period.

3. Design layout reference plant

3.1. Approach for layout optimization

For the power plant design the optimal layout of the main solar components – tower height, solar multiple and heliostat field design, receiver size – was calculated by simulating the respectively attainable electricity production using a thermodynamic model and applying the result in an economic optimization approach.

Cost estimations for the optimization program were realized based on literature data and experience. To take cost changing into account, elder cost information from various sources was updated to 2010. The adjustment of currency value was done using the inflation rates of US Dollar. The material price movement was included using the Producer Price Index of the mainly relevant materials and subcomponents. The cost estimation comprises costs of main solar and conventional components, engineering, installation, capital cost, operation, maintenance and personal costs.

Based on the simulation results for the yearly electricity output and the feed-in tariff the attainable economic revenue of certain design variations was calculated.

Finally the calculation of the resulting net present value from investment costs, taxes, yearly operational costs, interest rates and revenues allowed identifying the optimal design solution.

3.2 Results

Optimal tower height was determined with 160m. The optimal heliostat field size amounts to 1600 heliostats. The receiver surface optimum was identified with 152m^2. These results are only valid under the above described boundary conditions and for the specific plant design.

4. LCA modeling

4.1. Method

The Life Cycle Assessment (LCA) is conducted according to ISO 14040/14044 (DIN EN ISO, 2006a, 2006b). Based on the investigated skeleton data (amounts of material masses, energy use, processes etc. used for the construction, operation and deconstruction phase) the Life Cycle Inventory (LCI) results are calculated using the commercial LCI database ecoinvent V2.2 (Frischknecht et al., 2007). The assessment of the investigated Life Cycle Inventory is done using the CML method of the University of Leiden, Netherlands (Guinee et al., 2001) in the version 2000 baseline V2.04 as implemented in the ecobalancing software SimaPro.

4.2. Structure of the LCA model

The LCA structure closely follows the structure of the real plant design in the modelling of the three life cycle phases (construction, operation and deconstruction). Therefore the environmental impacts can be related directly to the mainly influencing components or processes within each life cycle phase.

A detailed parameter set up of components, material masses, transport efforts, energy amounts and other processes needed during the life cycle allows a quick and easy model adaptation in case of components or concept changing (Fig.2).

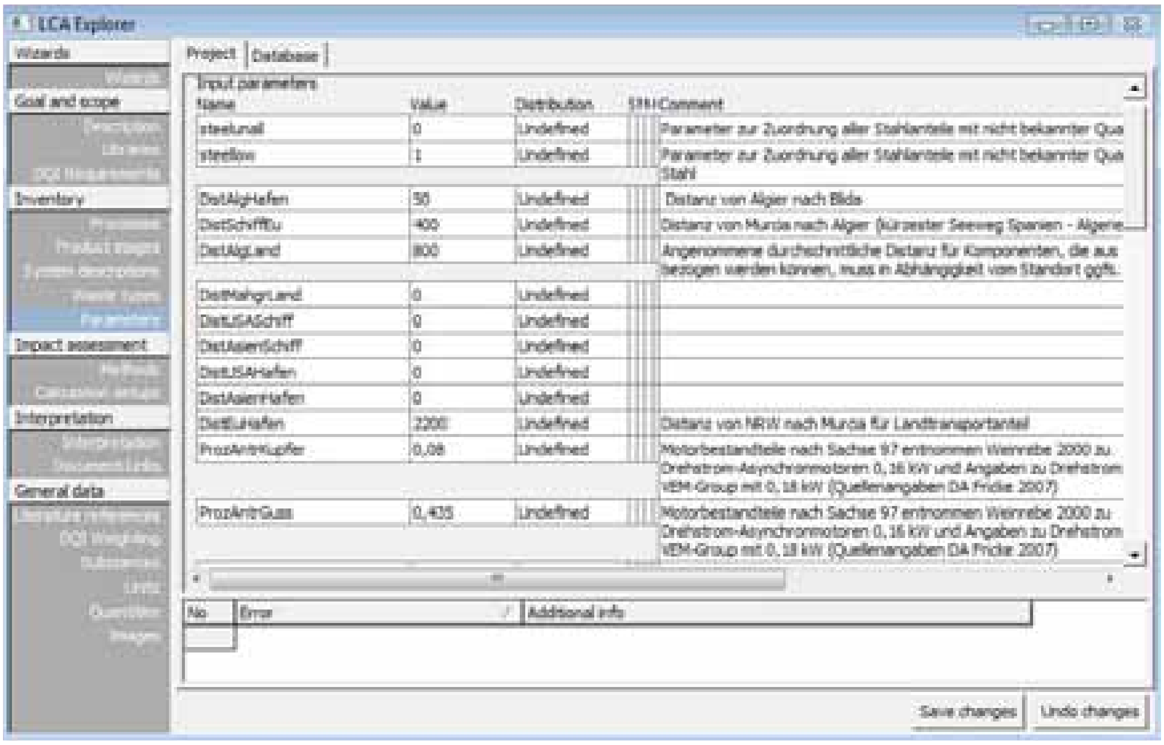

Fig. 2: Section of the realized parameter set up

The intended comparison of the LCA results of the reference plant with the ones of innovative plant concepts in the second project phase will be realised via parameter variation. In the same way the comparison of the results based on different waste management scenarios can be done with little effort by means of parameter variation. An example for the graphical results of a comparison of parameter variation is shown in Fig.3. In the diagram the results for the construction input of a solar tower with a nominal power of 1,5 MW_{el} (red) is compared with the a rough estimation of the construction input for a scaled up plant with a nominal load of nearly 3 MW_{el} (yellow).

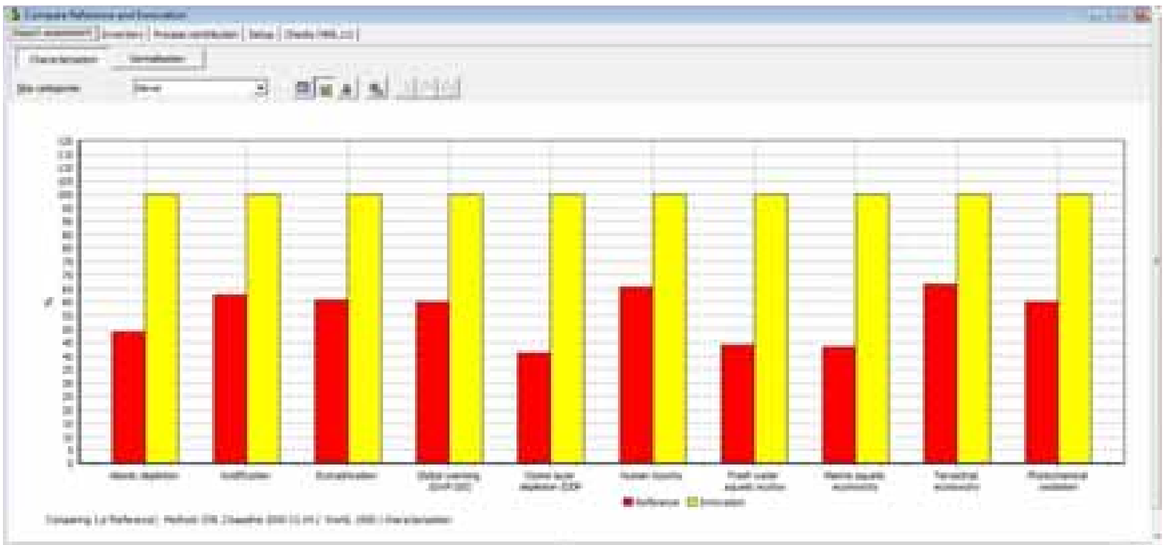

Fig. 3: Example for presentation of results via parameter variation
(Construction phase for different sizes of nominal power)

4.3. Waste scenarios for deconstruction phase

The influence on the LCA results from the construction phase depends strongly on the supposed waste treatments and the estimated recycling rates for the various materials. An assessment of the solid waste management situation in the Maghreb countries published by SWEEP-Net[1] with support of the GIZ[2] clearly points out the existing gap in waste management infrastructure and gives an idea of the expectable structural change in the coming decades (Sherif, 2010). Based on that information a reference and a future waste scenario will be worked out. Additionally a third waste scenario referred to the waste treatment standards of Western Europe will be modelled.

The LCA results for the deconstruction phase based on the different scenarios will be compared. The comparison will highlight environmental problems that could result of an inadequate waste treatment or a disregard of the intended development of the waste management infrastructure in the Maghreb region. The environmental impacts of the deconstruction phase should already be taken into account during concept development of a solar thermal power plant as well as of an innovative energy supply system.

5. Conclusion

The definition of the main boundary conditions and the results of the power plant optimization enable the completion of the quantity structure as the main requirement for the assessment of the environmental impacts. With the adjustment of technical optimum and maximum economic outcome a realistic plant design was carried out.

6. Discussion

The selected operation strategy does not reflect the future load follow operation requirements completely. In future systems of electricity supply solar thermal plants have to close the gap between electricity provided by fluctuating sources (photovoltaic, wind) and the load curve (residual load). Although the simplified approach of adapting the power output to fixed power levels within certain time periods creates more complex requirements for the power application and the operation management. Furthermore the requirement of following specific power levels for defined time periods results in a minimum need of storage capacity and solar multiple. Depending on the feed-in tariff conditions the additional investment can cause higher economic revenue. The focus of this study however lies on the ecological impacts. Here any additional input in solar multiple and storage capacity plus additional electricity use for the storage fan is correlated with additional environmental impacts above average. From this point of view the simplified operation strategy effects more realistic LCA results for plant concepts used in future energy supply systems.

7. Outlook

Based on the layout results the quantity structure of the construction phase will be completed in the coming months. The quantity structure of the operation and deconstruction phase will be accomplished as well. The resulting LCA values represent the basis of comparison for the second phase of the study.

In the second phase of the project innovative components and concept changes currently under development will be implemented in the life-cycle wide LCA model. A comparative analysis of results for the “reference power plant concept” and “innovative concepts” allows the evaluation of the ecological improvement potential. The results are to be used to support the development of an integrated ecological and technical design (ecodesign). Any optimization approach of components or the power plant concept itself could entail unexpected influences on the performance of the entire system. All environmental impacts will be related to the amount of electrical energy. Thus all influences on the entire system caused by implemented innovations will be implicitly included in the comparative analysis of the environmental impacts.

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