Solar Mining Technology Options – Techno-economic-ecological datasheet

Concentrated Solar Power

Parabolic Trough with storage

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Figure 1: Parabolic Trough plant [1]

I. Description of technology

The Parabolic Trough technology can be seen as the most mature concentrated solar power (CSP) technology. In 2015 approximately 84% (3960 MW_{el}) of the worldwide CSP plants in operation are parabolic trough power plants [2]. Chile has a 10 MW_{th} parabolic trough plant in operation (Minera Centinela, ex El Tesoro, Solar thermal plant), one project is currently on hold (170 MW_{el} Enerstar María Elena ISCC) and four projects (Pedro de Valdivia 1-4) totalling 360 MW_{el} have been announced [3]. In general, a parabolic trough plant consists of four major system components: the solar field array, a thermal storage, auxiliary co-firing unit and a conventional thermal power block system (heat recovery steam generator (HRSG), steam turbine and generator). The solar field is composed of rows of parabolic shaped mirrors, which reflect the incoming sunlight onto a receiver tube in the focal point. The receiver tube collects the reflected sunlight and heats up a heat transfer fluid (HTF). Normally the HTF used is a synthetic oil mixture (e.g. Diphenyl oxide / biphenyl). This HTF can either be used to store the generated heat in a storage unit (e.g. molten salt tanks) or to feed a conventional thermal power block to produce steam and generate electricity. The thermal storage system consists of a cold tank and hot tank which are used to charge and discharge the system. The tanks are filled with a nitrate salt mixture ($KNO_3/NaNO_3$) that allows operating temperatures ranging between 300°C and 400°C. In the power block unit of parabolic trough plants steam parameters of 400°C and 100 bar pressure can be achieved.

➔ Proposal of a *SolarMining*-CSP-technology option for the mining industry in Chile

In the arid resource rich regions of Chile an important synergy potential between solar energy and mining exists. Given the intensive energy use of the mining sector, this potential is highly relevant for achieving the country's goal in terms of energy costs, emissions and competitive and sustainable mineral extraction. This paper shows the potential emission savings when electricity from a concentrated solar system powered by typical Calama solar conditions supplies mining operations. The concentrated system modelled, based on [10], has 50 MW_{el} of rated capacity plus 1640 MWh_{th} of storage capacity and a diesel co-firing system which ensures operation in times of lower irradiation. Assuming a plant lifetime of 30 years and an interest rate of 10% lead to a saving around to 96% of gCO_{2eq}/kWh, while a 165 USD/MWh_{el} of levelised cost of electricity. Such a concentrated solar power plant demands 11.4 kg/GWh_{el} of copper distributed into its different components.

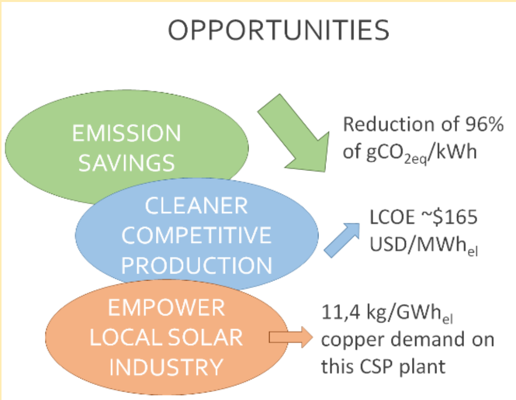

Figure 2: Opportunities in CSP

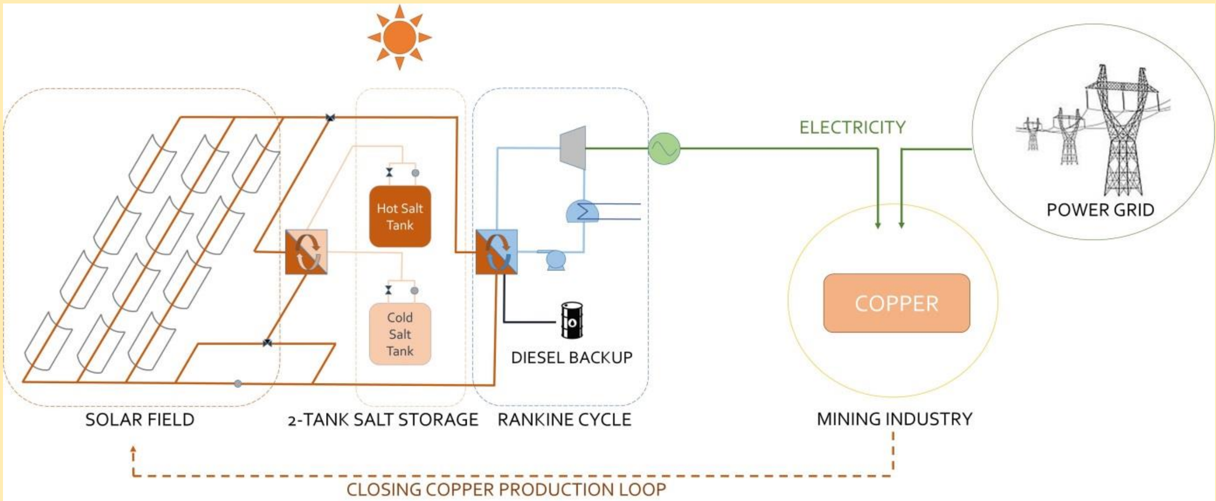

Figure 3: Schematic description of the proposed integration of a CSP plant into the mining industry

II. The technical performance

In this section the assumptions and datasets used to calculate the energy yield of a parabolic trough power plant with storage at a characteristic plant location in Chile are described.

Location. The investigated power plant site is located in vicinity to the Chuquicamata copper mine, north of the city of Calama in the Antofagasta region. The open pit mine operated by state-owned enterprise Codelco is one of the largest open-pit copper mines in the world [4]. The arid climate of the Atacama Desert which is characterised by a high solar irradiance makes this location interesting for solar technologies. This opens an option to integrate this technology into the existing electricity consuming mining processes.

Weather data. To estimate the electricity yield of a parabolic trough plant with storage detailed information of the direct normal irradiance (DNI) in at least hourly time resolution at the power plant location need to be used. Moreover, the year-to-year variability of the solar resource should be considered by using a typical meteorological year (TMY) or to calculate exceedance probabilities (e.g.:P50, P90) of a long-term dataset. Thus the financial risk of a solar energy project is minimised [5] [6].

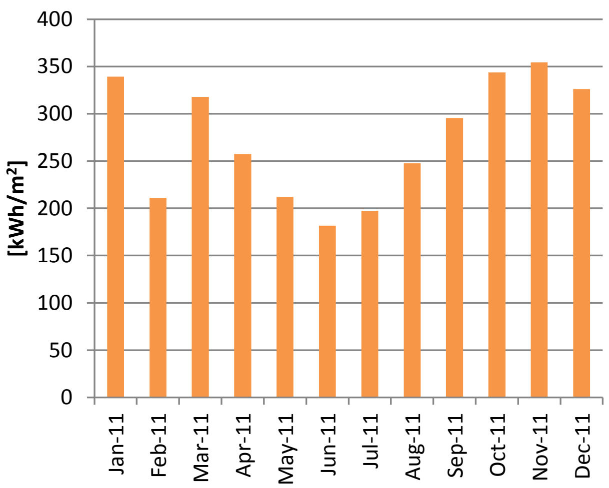

Figure 4: Monthly direct normal irradiation (DNI) for Calama/Antofagasta Region in 2011

Due to the lack of long-term measurement data of solar radiation, weather data of the recently started and publicly available wind and solar measurement project "Campaña de medición del recurso Eólico y Solar" of the Department of Energy of Chile was used, which offers wind and solar ground measurement data at a 10-minute time resolution [7] [8]. The dataset of the measuring station at Chuquicamata goes from May 2010 to December 2012. As the measurement year 2012 shows significant gaps (measurements from March to October are missing) the only full consecutive year of weather measurements in 2011 was taken as a characteristic year for the calculations. Figure 4 shows this monthly direct normal irradiance (DNI) along the reference year of 2011. According to this dataset, the annual direct normal irradiance was calculated to be at 3280 kWh/(m^2*a), which corresponds to reported values of NREL (2015) [9].

Plant configuration. The calculation of the energy yield was performed by using the CSP performance model of Telsnig (2015) which simulates the system performance of the solar power plant based on an hourly control logic [10]. The parabolic trough plant simulated has a rated capacity of 50 MW_{el} and includes a thermal storage with a total storage capacity of 1640 MWh_{th} resulting in an overall capacity factor of 75% (approximately 6500 full load hours per year). A diesel-fuelled co-firing system ensures system operation in times of lower irradiation during the day to avoid part-load states. The total share of co-firing during the year is limited to 2%. Figure 5 shows the resulting system performance during a characteristic winter and summer day in Calama.

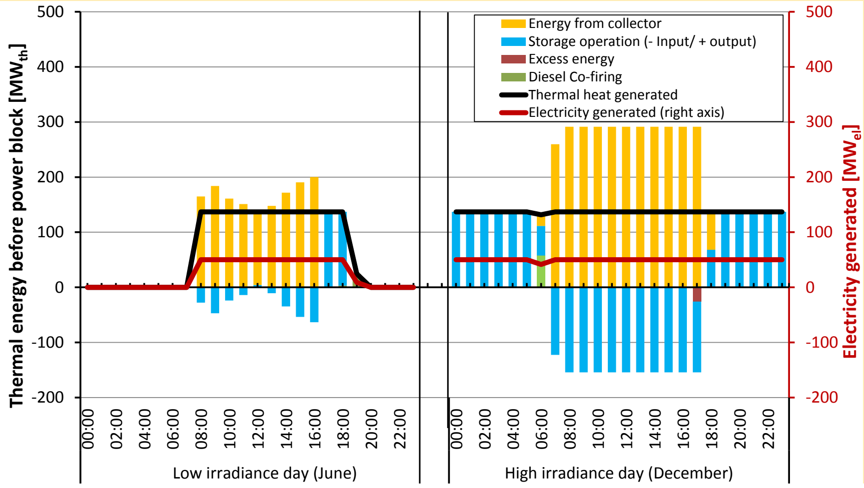

Figure 5: System performance of a parabolic trough plant at a low (left) and high irradiance day (right) for Calama, Antofagasta Region

III. The ecological performance

Methodological approach. To quantify the environmental impacts of the proposed '*SolarMining*' technology options a Life Cycle Assessment (LCA) is performed. The LCA is carried out in close accordance with the general principles and the framework of the international standards ISO 14040 and ISO 14044 [11] [12]. This framework comprises four phases:

- the goal and scope definition
- the inventory analysis
- the impact assessment
- and the interpretation of results

Goal and scope definition. The scope of this analysis is to quantify the environmental impacts of a parabolic trough plant with thermal storage used to provide electricity for copper mining. Moreover, it is investigated to which extent the production cycle of the mining operation can be closed by evaluating the resource requirements for copper in the parabolic trough plant. The reference value or 'functional unit' to which all inputs and outputs are related is defined at 1 kWh_{el}. The system boundaries of the LCA include all major system components of the power plant. The investigated life cycle stages range from the construction of the power plant components to the decommissioning and disposal of the materials at the end of the lifetime. The geographic reference is Calama/Antofagasta Region in Chile and the time reference is 2015. The lifetime of the power plant is defined at 30 years. The data quality requirements were met by using actual solar measurement data in a high temporal resolution. This was based on the estimation of the energy yield of the plant and through the use of a detailed life cycle inventory lists of the different system components of previous LCA studies [10].

Inventory analysis. The life cycle inventory (LCI) analysis involves the data collection and estimation of all inputs and outputs of the investigated product system. We used the life cycle inventory data and parameterised LCA model reported in Telsnig (2015) and adjusted it to Chilean conditions, taking into account changes of the sizing of the different power plant components and transport distances. Transport distances for the construction phase of the power plant were assumed as 220 km which represents the road distance between the harbour of Antofagasta and Calama. Transport distances of the materials to a disposal or recycling facility were assumed to be 100 km. Data of the LCA database ECOINVENT V2.2 was used to consider emissions of pre-processes and raw material extraction [10] [13]. The emissions resulting from co-firing of diesel in the co-firing system of the power plant were calculated by the assumption that 2% of the plant's electricity production is delivered by co-firing, which is reported as the minimum co-firing rate in current CSP plants [14]. The emission factor for diesel was obtained from IPCC (2006) and accounts for 72.6 gCO_{2eq}/MJ_{diesel} [15]. Auxiliary electricity is generated within the CSP plant.

Life Cycle Impact Assessment (LCIA). The material and energy demand which is outlined in the LCI are used to calculate the environmental impacts during the LCIA. The LCIA involves the connection of the inventory data with appropriate impact categories and category indicators. In this assessment, we want to quantify the impact category "climate change" which is calculated by its indicator "Global Warming Potential (GWP)". As a second impact category the "depletion of mineral resources" is assessed by quantifying the amount of copper used for the different sections and services of the power plant. In this way an estimate is given to what extent copper production cycles can be closed by implementing solar technologies in the copper mining processes. Results show that the GWP during the life cycle of the investigated parabolic trough plant with storage ranges between 15 gCO_{2eq}/kWh_{el} and 30 gCO_{2eq}/kWh_{el} (upper limit at a 2% diesel co-firing rate). This means a significant reduction potential of GHG emissions in comparison to the emissions caused from electricity provided from the Southern Electricity Grid (SIC) or Northern Electricity Grid (SING) which are reported with 379 gCO_{2eq}/kWh_{el} and 725 gCO_{2eq}/kWh_{el}, respectively [16] (see Figure 6).

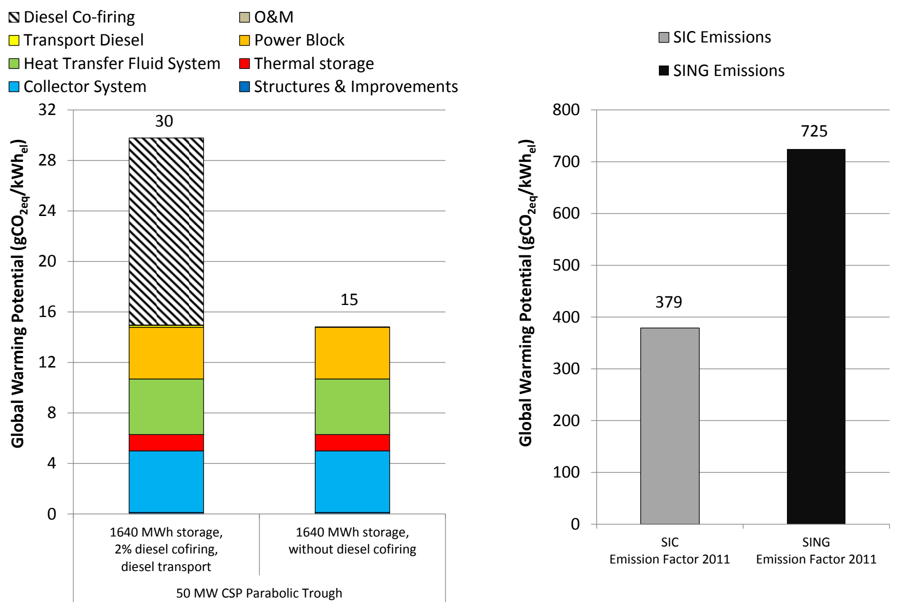

Figure 6: Global Warming Potential of a parabolic trough plant with storage (left-hand side) and GWP emission factors from the SIC and SING electricity mix (right-hand side).

The assessment of the copper demand for the different sections and services of the CSP plant identifies the power block (49%), the collector system (22%), the thermal storage system (15%) and the heat transfer fluid system (13%) as main copper containing components. Especially the wiring and e.g. transformers, generators, compressors electrical components require larger shares of copper. The copper demand of all other components and services in the pre-processes of the life cycle or of the raw material extraction is negligible. Based on this assessment a specific copper demand for solar energy generation with a parabolic trough plant of 11 kg/GWh_{el} was calculated.

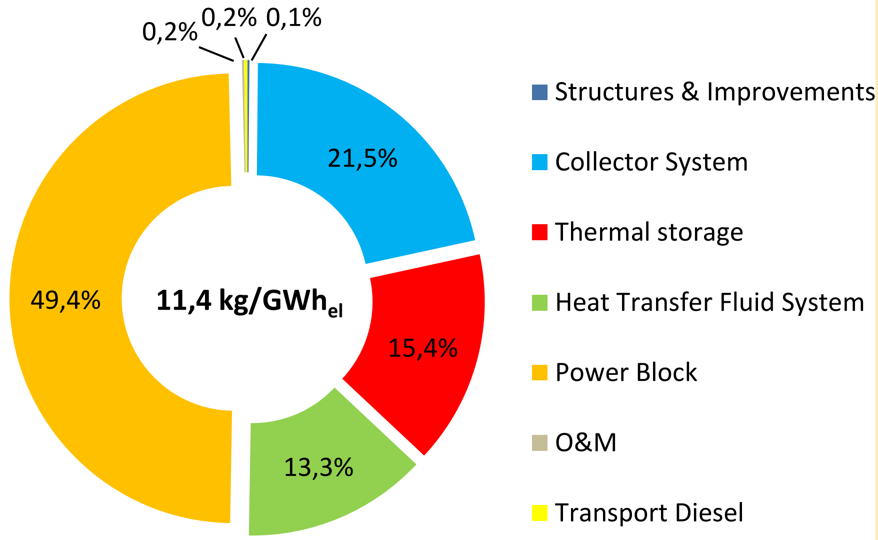

Figure 7: Copper demand of different components of a CSP parabolic trough plant

IV. The economic performance

The economic assessment is performed by calculating the levelised costs of electricity (LCOE) of the parabolic trough power plant according to the methodology described in IEA/NEA (2010). A stable interest rate of 10% and a plant lifetime of 30 years was assumed. All costs are given in US Dollar ($US\$_{2010}$), 1 US$ corresponding to 508 CLP. Based on the configuration a total land area requirement of 200 ha was assumed.

The investment costs were estimated from Telsnig (2015) and include the specific investment costs for the main power plant components, subdivided into investment costs of the solar field, the power block and the molten salt storage. Moreover EPC costs (engineering, contracting and procurement) and owner's costs are considered in this calculation.

Operating costs include fixed operating costs (FOM) considering the overall manpower and insurance costs during operation and variable operating costs resulting from the co-firing of diesel in the co-firing system of the power plant.

Technology		CSP Parabolic Trough with Storage
Technical data		
Location		Calama/Antofagasta
Aperture Area Solar Field	[m^2]	600000
Land Area (Estimate)	[ha]	~200
Capacity	[MW_{el}]	50
Storage capacity	[MWh_{th}]	1640
Storage concept		2-tank indirect molten salt
Full load hours	[h/a]	6500
Co-firing fuel		Diesel
Diesel demand	[TJ/a]	59
Economic data		
Specific investment costs	[$US\$_{2010}/kW_{el}$]	8874
FOM	[$US\$_{2010}/kW_{el}/a$]	68
VOM	[$US\$_{2010}/kW_{el}/a$]	34
Interest rate	[%]	10%
Lifetime	[a]	30
LCOE	[$US\$_{2010}/MWh_{el}$]	165

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For more information see: http://www.ier.uni-stuttgart.de/forschung/laufendeprojekte/index.html

http://serc.cl/solar-mining/

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