Solar Mining Technology Options – Techno-economic-ecological datasheet

Photovoltaics

Open space photovoltaic system

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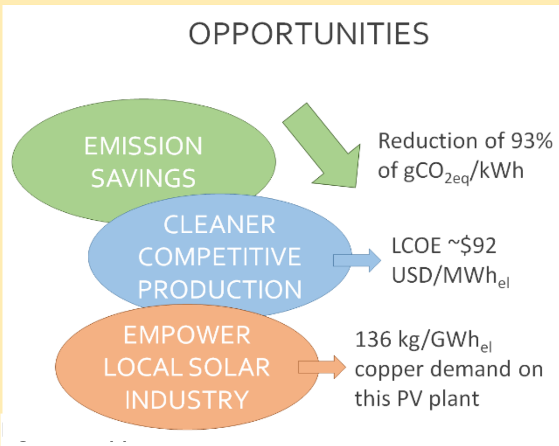
Figure 1: Photovoltaic power plant [1]

I. Description of technology

Photovoltaic (PV) energy systems are used to convert the global irradiance of the sunlight into electricity. Photovoltaic systems are made of photovoltaic cells which are assembled to modules which, and can be combined in a modular way to a PV system. The three main types of photovoltaic cells include wafer-based crystalline silicon cells, thin-film solar cells and emerging PV cells (e.g. concentrating solar PV, organic PV). With about 85% of today's installed capacity crystalline silicon cells show the highest market share followed by thin-film systems at about 15% [2]. In 2014 the worldwide installed PV capacity was more than 150 GW [3]. In 2014 Chile has installed a capacity of 395 MW_{el} of photovoltaic systems leading to a total cumulative PV capacity of 402 MW_{el} [4]. In general, a photovoltaic system consists of several photovoltaic modules, an inverter that converts DC into AC, power control systems, wiring and a tracking system. The energy yield of photovoltaic energy systems can be increased by applying a sun-tracking mechanism to the power plant. Besides systems that are simply placed on open space or rooftops without tracking the sun, PV systems with single axis tracking or 2-axis tracking are realised. 2-axis tracking systems are more rarely applied because of the additional investment costs.

➔ Proposal of a *SolarMining*-PV-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 photovoltaic system powered by typical Calama solar conditions supplies mining operations. The design of the photovoltaic system modelled is orientated along the PV project "Calama Solar 3" [5], assuming a plant lifetime of 25 years and an interest rate of 10%. These lead to a saving of 93% of gCO_{2eq}/kWh, while having a 92.9 USD/MWh_{el} of levelised cost of electricity. Such a photovoltaic power plant demands 136 kg/GWh_{el} of copper, distributed into its different components.



II. The technical performance

In this section, the assumptions and datasets used to calculate the energy yield of a photovoltaic power plant at Calama 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 [6]. The arid climate of the Atacama Desert is characterised by a high solar irradiance. This makes this location highly interesting for solar technologies and opens options to integrate these technologies into the existing electricity intensive mining processes.

Weather data. To estimate the electricity yield of a photovoltaic system, detailed information of the global irradiance 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 [7] [8].

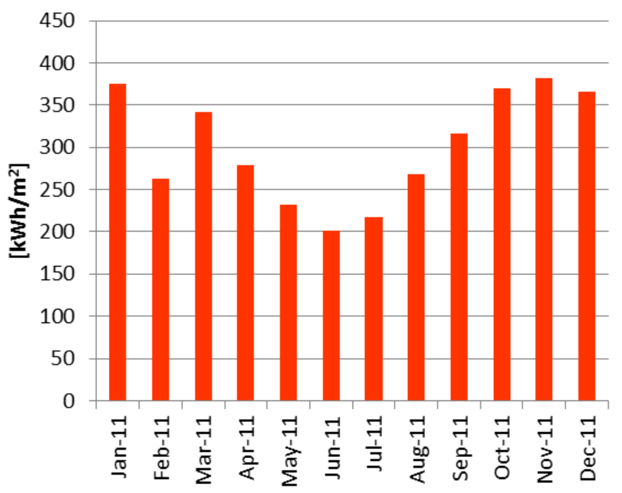


Figure 3: Monthly global irradiation including tracking for Calama/Antofagasta Region in 2011

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. This dataset offers wind and solar ground measurement data at a 10-minute time resolution [9] [10]. 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 3 shows this monthly global irradiance measured by a pyranometer with 2-axis tracking along the reference year of 2011. According to this dataset, the useable annual global irradiance (including 2-axis tracking) was calculated to be at 3614 kWh/(m^2*a).

Plant configuration. The design of the photovoltaic system modelled is orientated along the PV project "Calama Solar 3" which started operation in 2014 [5]. The calculation of the energy yield was performed by using the methodology described by Duffie Beckman (2013). As the Calama Solar 3 plant uses single axis tracking, measurement values were converted from 2-axis tracking to single axis tracking of a collector which is continuously tracking on a polar axis [11]. The installed peak capacity accounts for 1.1 MW_p and is made up of 4080 multi-crystalline silicon modules and two 500 kVA inverter stations. The used surface area is at about 6 ha [12]. We assumed a module efficiency of 16.3% and a peak capacity of a single module at about 270 W based on the technical datasheet of Suntech (2016) [13]. Moreover, the performance ratio of the entire power plant, the inverter efficiency and the yearly degradation rate is assumed at 80%, 97% and 0.5%, respectively. Based on this assumptions and input data an average energy yield of 2.4 GWh_{el}/a is calculated for this plant layout.

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 [14] [15]. 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 an open space photovoltaic power plant with single axis tracking 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 photovoltaic 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 25 years. The data quality requirements were met by using actual solar measurement data at 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 power plant based on ecoinvent datasets, which are adjusted to Chilean conditions.

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 of the ecoinvent dataset and adjusted it to Chilean conditions, taking into account changes of the sizing of the different power plant components. Moreover, all energy-related processes during the construction of the PV plant were modelled using the Chilean electricity mix. LCI data of the subcomponents (e.g. PV panels, inverters) are modelled based on global average inventories. For this purpose data of the LCA database ECOINVENT V3.1 was used to consider emissions of pre-processes and raw material extraction [16].

Life Cycle Impact Assessment (LCIA). The material and energy requirements outlined in the LCI are used to calculate the environmental impacts in 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 the 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 over the life cycle of the investigated photovoltaic plant is at 43 gCO_{2eq}/kWh_{el}. This means a significant reduction potential of GHG emissions in comparison to the emissions caused by electricity provision 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 [17] (see Figure 4).

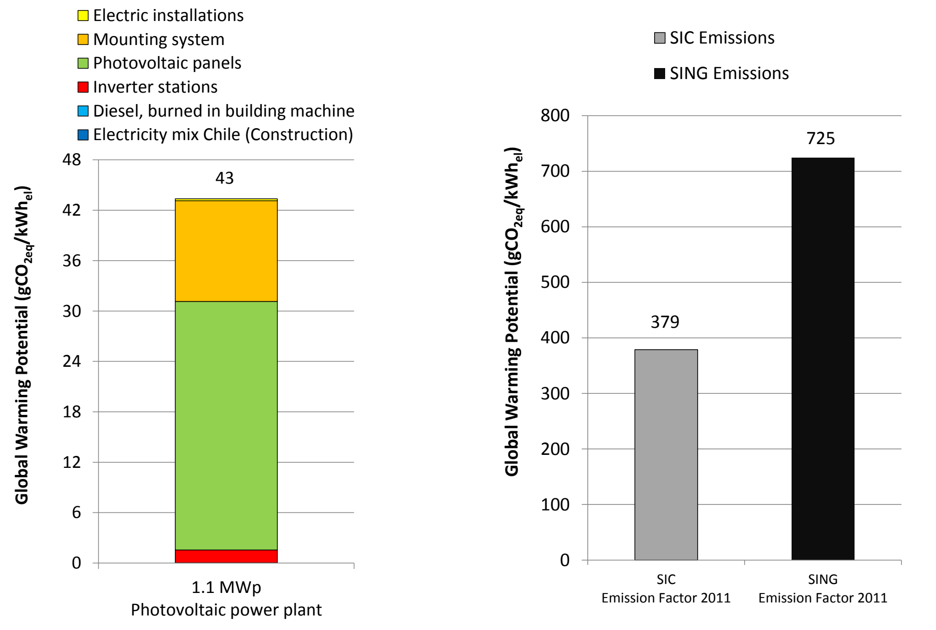


Figure 4: Global Warming Potential of an open space photovoltaic plant (left-hand side) and GWP emission factors from the SIC and SING electricity mix (right-hand side).

The assessment of the copper demand for the different sections and services of the photovoltaic plant identifies the photovoltaic panels (44%), the inverter stations (32%), the electric installations (20%) and the mounting system (4%) as main copper containing components. The copper demand of energy-related pre-processes in the life cycle of the power plant are negligible. Based on this assessment a specific copper demand for solar energy generation with a photovoltaic plant of 136 kg/GWh_{el} was calculated.

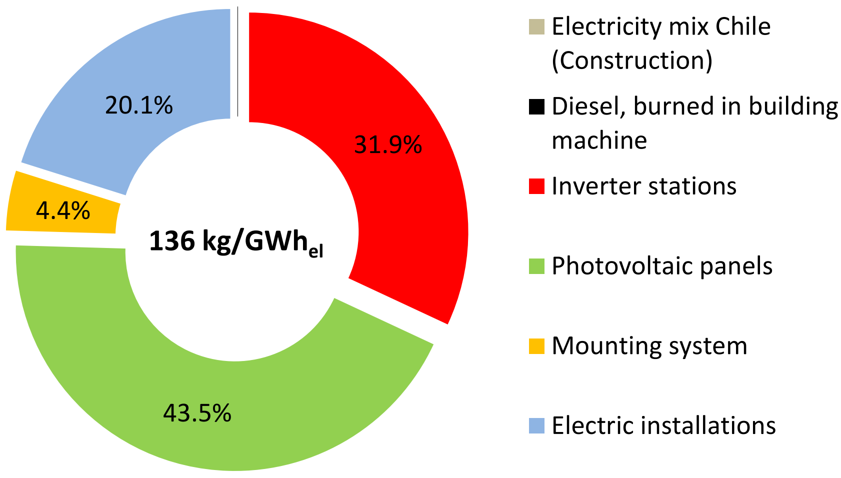


Figure 5: Copper demand of different components of a photovoltaic plant

IV. The economic performance

The economic assessment is performed by calculating the levelised costs of electricity (LCOE) of the photovoltaic power plant according to the methodology described in IEA/NEA (2010) [18]. A stable interest rate of 10% and a plant lifetime of 25 years were 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 6 ha was assumed for the plant layout.

The investment costs were estimated from average multi-crystalline silicon module prices on the world market and shares of investment costs for open space PV systems of subcomponents [19][20]. Investment costs for the main power plant components were subdivided into investment costs of the modules, inverters, installation materials, labour costs, installer costs and supply chain costs.

Operating costs include fixed operating costs (FOM) considering the overall manpower and insurance costs during operation of the power plant.

Technology		Open space photovoltaic power plant
Technical data		
Location		Calama/Antofagasta
Aperture Area Solar Field	[m^2]	5960
Land Area (Estimate)	[ha]	6
Capacity	[MW_{peak}]	1.1
Full load hours	[h/a]	2180
Economic data (Estimate)		
Specific investment costs	[US_{2010}/kW_{peak}]	1809
FOM	[$US_{2010}/kW_{peak}/a$]	21.7
Interest rate	[%]	10%
Lifetime	[a]	25
LCOE	**[US_{2010}/MWh_{el}]**	**92.9**

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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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