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# Identification of potential areas to achieve stable energy production using the SWERA database: A case study of northern Chile

Germán Salazar [a, *], Miguel S. Checura Diaz [a], María J. Denegri [b], Chigueru Tiba [c]

[a] Department of Physics, School of Exact Sciences, National University of Salta, Bolivia Avenue #5150, 4400 Salta Capital, Salta, Argentina
[b] GERSolar, Institute of Ecology and Sustainable Development, Basic Sciences Department, National University of Lujan, Route 5 and Constitución Avenue, 6700 Luján, Buenos Aires, Argentina
[c] Grupo de Pesquisas em Fontes Alternativas de Energía, Universidade Federal de Pernambuco, Av. Prof. Luiz Freire 1000, 50740-540 Recife, PE, Brazil

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ABSTRACT

The South American High Plateau (Altiplano) is one of the few regions on the planet believed to receive, at certain sites, an annual mean daily direct solar irradiation greater than 9 $kWh/m^2$ (32.4 $MJ/m^2$). The veracity of this estimation is important because it implies that establishing large solar power stations in the region would be highly profitable. However, the measured data are highly localised, and the knowledge of the spatial distribution of the resource could be insufficient. To address this problem, the global and direct normal solar radiation data measured at eight stations distributed in northern Chile were compared with the SWERA database for South America. The differences found between the estimated and measured values were as high as 11%, on an annual basis. Thus, the SWERA database could be used to construct maps of the isolines of direct solar radiation to help visualise the spatial distribution of the resource. An analysis was performed to determine the per cent variation of a solar field collection area designed to achieve stable energy production throughout the year. Based on the analysis results, the northern region of Chile presents an economic potential much greater than that of the Mojave Desert from the point of view of the economic risk for a solar venture. This information can serve as a useful and reliable tool because it represents the initial assessments of optimal sites for installing solar power stations.



## 1. Introduction

The use of renewable energies could be a way to reduce the current greenhouse gas (GHG) emissions into the atmosphere, which are produced by the burning of oil, gas and coal. The current GHG concentration, particularly of carbon dioxide, produces what is known as global warming by increasing the natural greenhouse effect of the atmosphere. Global warming alters the climate of the planet, directly affecting human society as well as many ecosystems [1].

The Sun is a renewable energy source that currently can provide industrial quantities of electric power [2,3]. However, the availability of the resource is not distributed homogeneously at the surface of the planet and is seasonal. As a result, measurements of solar radiation must be performed to determine the temporal and spatial variability. Ground-based measurements of solar irradiance are provided at many stations around the world, such as the World Radiation Data Centre (WRDC) [4] or the Baseline Surface Radiation Network (BSRN) [5]; even so, measurements that provide sufficient coverage cannot be ensured everywhere.

Reliably determining the solar resource availability at a site requires the mounting of sensor equipment and the personnel to operate and maintain the equipment. The figures from the National Renewable Energy Laboratory (NREL) document for the Solar Resource and Meteorological Assessment Project (SOLRMAP) [6] indicate that $15,000 USD and $73,000 USD might be necessary to establish a station capable of providing representative data. These figures may be excessive for the cases of the South American countries. However, even having quality data sites does not help to determine the variability of the resource over an entire region or country.

The analysis of the spatial and temporal distribution of the solar resources is a useful tool for determining the locations of potential

* Corresponding author. Tel./fax: +54 387 4255489.
*E-mail addresses:* germansalazar.ar@gmail.com, german.salazar@uv.es, salazarg@unsa.edu.ar (G. Salazar).

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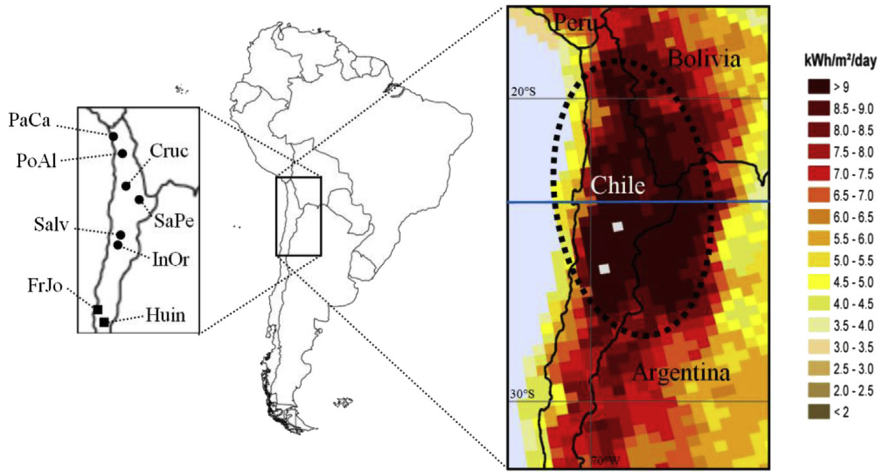


**Fig. 1.** The region being studied is highlighted on a political map of South America (centre). To the right the estimated distribution of the annual average daily values is shown. On the left, the positions of the stations are shown.

future solar thermal and/photovoltaic power stations, with a view towards optimising the resource availability, the power to be generated, and the available or necessary infrastructure (roads, water supply, power supply, telephone system, internet, etc.). Concentrating photovoltaic (CPV) systems and especially high concentration photovoltaic (HCPV) systems, present a number of advantages when deployed at sites with a high level of direct normal solar irradiation. Concentrated Solar Power (CSP) also requires a high availability of direct normal solar irradiation to ensure optimal performance and production. A map can show the spatial and temporal distribution of the values of the solar radiation in an easy-to-interpret and useful manner. Based on satellite images and data measured at the surface, such maps can be produced, including the seasonal variations [7–10].

Direct and global solar radiation data measured during at least one year in eight stations in north Chile were analysed and compared to the Solar and Wind Energy Resource Assessment program (SWERA) database values [11]. The SWERA database values correspond to 40-km square cells covering the entire South American subcontinent. The correlation results between the SWERA and measured data are equal or lower than 15% (in a monthly mean annual basis); therefore, it is reasonable to utilise the SWERA data to build direct normal irradiation maps to assess the time and spatial availability of the resource.

The information provided by these solar radiation maps could be used not only for technical design aspects but also on the economic issues related to the bankability of those ventures. The value of solar irradiation has a significant impact on the risks associated with a solar venture. In fact, the Fitch Rating and Moody's Investor Services use P90 (Percentile 90) forecast scenarios in calculating the base case financial ratios. To achieve this level of confidence, a minimum amount of on-site data is required for a reliable solar resource supply assessment. In this work, all stations have data of at least one year of measurements, i.e., these measurements qualify as quality data for an economic risk analysis [12]. Therefore, the SWERA data could be used to estimate the size of a solar field to obtain a constant power throughout a year. This parameter is important during the design of a solar power facility because it involves the cost-benefit ratio that matters to investors [13,14].

Thus, in this paper, the SWERA database values are compared with the measured data of the global and direct solar radiation at eight stations in the North of Chile. Because good correlation is observed between the SWERA data and the measured data, the use of the entire satellite database is proposed to assess the spatial distribution of the solar resource to detect areas with potential to achieve stable energy production by building maps obtained and applying the Kriging technique to the satellite cells data.

## 2. Data and methodology of analysis

The region being studied is highlighted on a political map of South America (Fig. 1). It covers latitudes $-17°$ to $-33°$ and longitudes $-66.5°$ to $-73°$ (the negative sign denotes south latitude and west longitude, respectively). To the right the distribution of the annual average daily values is shown, where each coloured square is a SWERA satellite cell 40 km to a side. The dotted ellipse encloses the Solar Radiation Goldilocks Zone (SRGZ). The blue(in web version) line represents the Tropic of Capricorn. The measured data analysed in this paper were obtained from eight stations in northern Chile, a country that currently has a vast network of stations across its territory. On the left (Fig. 1), the positions of the stations are shown. Black circles indicate the stations with thermal pyranometers (K&Z CMP11) and black squares indicate the stations with PAR pyranometers (Li-200SA). Chile is divided into 15 regions, which are the country's first-level political divisions. The analysed data comes from stations supported by CENMA[1], CEAZA[2] and INIA[3] (Table 1). CENMA meteorological stations use NES MODAS1632S dataloggers and Kipp & Zonen CMP11 pyranometers; these stations measured the diffuse and global irradiance, calculating the direct component by subtraction. The remainder of the stations use Campbell Scientifics CR1000 dataloggers with LICOR LI-200SA pyranometers.

The number of data does not consider the values measured at night. The characteristics and accuracy of measuring instruments is available in Ref. [15].

Global and direct solar irradiation data measured at these stations were compared to those estimated with SWERA database [16]. The SWERA database estimates its values through the application of the CSR (Climatological Solar Radiation) model [17,18] from satellite images, which are 40-km square cells. This size

[1] *Centro Nacional del Medioambiente* (*National Environmental Center*).
[2] *Centro de Estudios Avanzados en Zonas Áridas* (*Center for Advanced Studies in Arid Zones*).
[3] Instituto de Investigaciones Agropecuarias (Agricultural Research Institute).