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# Solar resource assessment study for Pakistan

Steffen Stökler [a,*], Christoph Schillings [a], Birk Kraas [b]

[a] German Aerospace Center (DLR), System Analysis and Technology Assessment, Wankelstr. 5, 70567 Stuttgart, Germany
[b] CSP Services GmbH, Paseo de Almería 73, 2°, 04001 Almeria, Spain

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ABSTRACT

Solar resource assessment becomes a very important factor for planners of Photovoltaic (PV) and Concentrated Solar Power (CSP) systems. Choice between nearby locations can make a difference if a plant is profitable or not, especially in a climatic region with complex topography as can be found in Pakistan. Nevertheless, Pakistan's geographic location and climate offers a very high potential for solar energy applications. The solar resource assessment study presented in this article describes the approach and set-up required by the World Bank's Energy Sector Management Assistance Program (ESMAP).[1] The project aims to create a validated solar atlas for Pakistan based on a combination of satellite data and ground measurements to support country-driven efforts to improve renewable energy resource awareness and exploitation. There are several country-specific, ESMAP-funded projects conducted by the World Bank Group (WBG) that cover comprehensive mapping and geospatial planning, including ground-based data collection. The solar resource estimation of Pakistan was one of the first projects to be approved within the program.
The final and validated dataset ultimately will be published in the International Renewable Energy Agencies' (IRENA) global atlas for renewable energy.[2]



**Contents**



## 1. Introduction

Mapping national renewable energy (RE) resources is a crucial step in expanding investment into clean energy, by providing governments with the information necessary to strategically guide commercial development, establish pricing incentives, and take account of environmental and social constraints[3]. The Energy Sector Management Assistance Program (ESMAP) of the World

* Corresponding author. Tel.: +49 711 6862 483.
*E-mail address:* steffen.stoekler@dlr.de (S. Stökler).

[1] Further details are available at https://www.esmap.org/ and http://www.esmap.org/RE_Mapping (02/2015).
[2] Further details are available at https://www.irena.org/ and http://www.irena.org/globalatlas/ (02/2015).
[3] Information provided by http://www.esmap.org/RE_Mapping (02/2015).

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Bank supports RE mapping on countrywide scale within its Clean Energy Program framework. For several countries RE mapping projects are established to provide the information on available resources. This paper gives an overview on the solar project activities in Pakistan.

Pakistan is blessed with abundant renewable energy resources including wind, solar, biomass, geothermal and hydro. Some previous ground-based data has been collected for wind and also for solar insolation (Adnan et al., 2012) [1]. Although the results of previous studies delivered very promising outcomes (Perez et al., 2007 [2], Adnan et al. [1], 2012 and commercial products), an up-to-date and public available long-term satellite estimation with such a high nominal spatial resolution of below 10 km, does not exist. This lack of high-resolution and validated country-wide data is addressed with the ESMAP solar resource mapping project for Pakistan. Furthermore, in comparison with previous studies in the region, this study covers of a longer time-period of satellite data, including the periods from 2000 to 2017. In particular the years after 2008 show significant change of the aerosol concentration and rise of dense foggy days in some major regions of Pakistan (Aslam, 2012 [3], Yasmeen et al. 2012) [4].

The objective of this activity is to support the sustainable expansion of electricity generation from solar power by providing the Government of Pakistan and commercial developers with an improved understanding of the spatial distribution and potential of solar resources at country level.

This information will be contained in the main output of the project, a solar atlas containing monthly and annual values of Global Horizontal (GHI) and Direct Normal Irradiance (DNI). High resolution data from visible and infrared channels of geostationary satellites will be used to create the solar atlas. This data will be validated by using nine ground measurement stations installed during this project at various sites all over Pakistan. The measurement sites are set up in certain locations to cover a variety of typical solar regimes.

Within the three-year project, three phases of solar resource assessment are covered.

- Phase 1: Preliminary modeling using satellite data only: Preparation of an initial solar resource estimate for Pakistan based on solar radiation modeling using satellite and reanalysis data.
- Phase 2: 24-months ground measurement period at nine selected sites: Implementation of a ground-based measurement campaign using high quality solar measurement devices, with real-time data transmission and reporting, for the purpose of validating and improving the initial solar resource maps and for generating reliable benchmarking data.

- Phase 3: Establishment of the validated solar atlas: Validated solar resource maps and a solar atlas report which describes the final outputs, methodology and process, and includes provision of the final data to be used in a Geographical Information System (GIS).

## 2. Project outline

### 2.1. General approach

Pakistan covers an area of more than 800,000 km² and is divided into several, heterogeneous geographic regions. Remote sensing data on its own may not cover all of these diverse landscapes in the same quality. Using solely precision data from measurement stations would not lead to a satisfactory solar resource assessment in a country wide study, even if the stations are maintained and cleaned regularly. Perez et al. (1997) [5] have demonstrated that interpolation/extrapolation between measurement stations leads to less accurate results than satellite models do, once the distance between the stations exceeds 34 km. As the performance of the satellites instruments, satellite models and atmospheric input parameters have improved since this study, this distance may even have decreased. Perez also emphasized that it would need at least 800 ground stations (on 100 km grid) for the U.S.A. to outmatch the performance of satellites (Perez et al., 1997 [5]). If transferred to the area of Pakistan, at least 65–70 well maintained measurement stations would have been needed in operation since the year 2000 to surpass the satellite model's performance.

For this reason, surface measurement stations are used to validate the satellite data in different locations, combining the advantages of high-precision pinpoint measurements with the availability of multi-year spatial data from satellite. For this study, nine sites are set up throughout the country (Fig. 1). The locations of these measurement sites have been selected in a multi-criteria selection process, involving local partners and project stakeholders. In a first step, *solar regimes* were identified that exhibit the highest possible differences in annual sums of solar irradiance as well as high differences in intra-annual irradiance values, based on monthly sums. This is to evaluate the performance of the used satellite-based method in a wide range of different climatological locations. Each of the identified solar regimes should be provided with at least one ground measurement site. In a second step, input from local partners and stakeholders was collected and evaluated. This included availability of maintenance staff and host organizations for the measurement stations, socio-economic considerations and the probability of long-term sustainable use of the measurement stations after the project duration. To achieve this sustainability, training of local staff in operation and maintenance of the measurement equipment, as well as in understanding and evaluating the data, has a strong focus in the ESMAP project. Point-wise validation by using data of the measurement sites will lead to an improvement of the spatial data in Phase 3 of the study. This methodology will lead to a better understanding of meteorological processes and possible systematic satellite model deviations for each of the solar regimes, as it is widely transferable to the entirety of the respective solar regimes' area.

### 2.2. Data used

As stated above, primary data sources are satellite-based and ground-based. During Phase 1 and Phase 3 of the project satellite-based data is processed. Preliminary results of Phase 1 resource

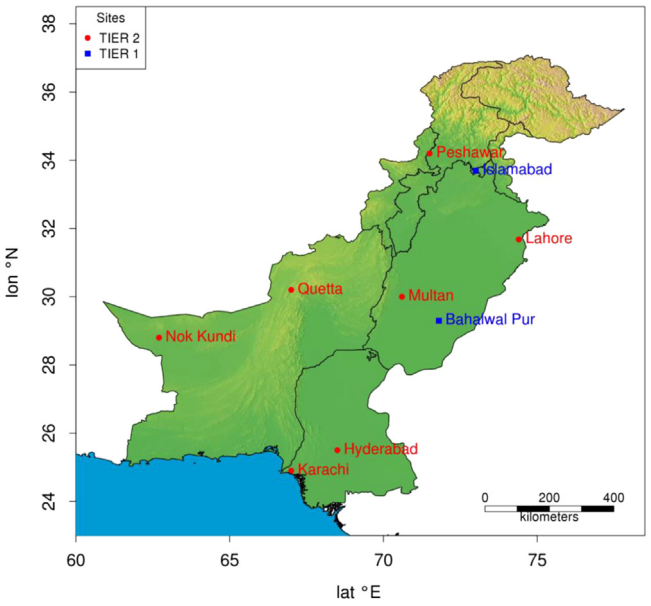


**Fig. 1.** Location of measurement sites for validation purposes in Phase 3 of the project.