THE SOUTH AFRICAN REFIT: SOLAR RESOURCE ASSESSMENT OPTIONS FOR CSP DEVELOPERS

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Abstract

Southern Africa, and especially South Africa, Namibia and Botswana, have some of the best DNI resource. The development of CSP plants in South Africa was stimulated when the South African government announced the REFIT programme.

The REFIT was later changed into a bidding based procurement programme; the Renewable Energy Independent Power Producer Procurement Programme - RE-IPP. In the RE-IPP 200 MW was allocated to CSP out of a total allocation of 3750 MW for all renewable technologies. The 200 MW has been allocated to a 50 MW central receiver, 100 MW parabolic trough and a 50 MW parabolic trough with 9 hours of storage. Although the CSP allocation is exhausted, a number of CSP plants are being developed with the hope that additional future allocation will be awarded to CSP.

South Africa has a general lack of high quality ground measured solar data, especially DNI. The South African Weather Services is in the process of re-establishing its solar network that seized operations about 20 years ago. Apart from three Universities, one BSRN station and four stations owned by the utility Eskom, all the DNI measurements in South Africa are being done by private solar developers and were installed in the past five years.

The author is aware of 23 DNI solar stations in South Africa and 7 in the neighbouring countries. Of these 30 stations 28 employ a pyrheliometer mounted on a two-axis solar tracker. The remaining two stations use a RSR.

Modern day solar trackers are reliable and have a relatively small power consumption. A pyrheliometer has high accuracy and requires no additional calibration before deployment. Apart from quality checks; measurements that are recorded by these instruments do not require any post processing. If GHI and diffuse measurements are included in these stations, independent validation of the DNI measurements can be performed in a simple manner.

A RSR require less regular cleaning than a pyrheliometer, but requires pre-installation calibration against a pyrheliometer. These stations do not offer independent GHI and Diffuse measurements for validation. A RSR are lower in capital and operation cost than a pyrheliometer and tracker based stations and is ideally suited for very remote locations.

Keywords: South Africa, RE-IPP, solar resource, solar measurements, pyrheliometer, RSR

1. Introduction

When the National Energy Regulator of South Africa (NERSA) announced the implementation of the renewable energy feed-in tariffs (REFIT) programme in March 2009 [1] and in October 2009 [2], it stimulated an interest of various renewable energy developers. Renewable energy developers consequently became eager to construct renewable energy power plants in South Africa. The REFIT was later changed into a bidding based procurement programme called the Renewable Energy Independent Power Producer Procurement Programme, RE-IPP. In the RE-IPP 200 MW was allocated to CSP out of a total allocation of 3750 MW for all renewable technologies [3].

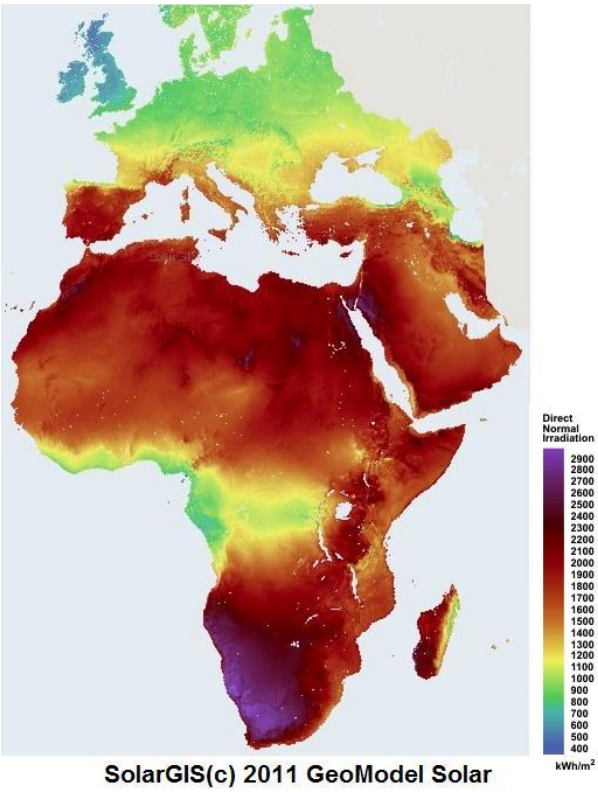

Fig.1 DNI map of Africa and Europe [5]

During the first of five bidding rounds of the RE-IPP, 150 MW capacity of CSP was awarded of which a 100 MW parabolic trough and 50 MW central receiver plant. Both plants were awarded to South African subsidiary of the Spanish firm Abengoa [3].

After this allocation there has been a number of lobbying events, co-ordinated by the Southern African Solar Thermal Electricity Association (SASTELA), to increase the CSP allocation. It is still uncertain if the CSP allocation will be increased. During the second round of the RE-IPP, the remaining 50 MW of CSP allocation was awarded to a 50 MW parabolic trough plant with 9 hours of salt storage. The local developer of this plant is Solafrica Thermal Energy with ACWA Power International from Saudi Arabia as the lead developer [4].

South Africa has some of the best DNI resource in Africa, Fig. 1. Other countries with a high DNI resource are Namibia and Botswana. The best CSP sites in Spain have a DNI value of 2100 $kWh/m^2/a$ [5]. In South Africa the best sites have a DNI value just below 3000 $kWh/m^2/a$ [5].

The CSP-projects under development in South Africa include (only projects where the Environmental Impact Assessment (EIA) study and/or ground solar measurements have been commissioned form part of the list) [6]:

- 100 MW parabolic trough plant located near the town of Kathu in the Northern Cape by Renewable Energy Investments South Africa (REISA)
- 100 MW parabolic trough plant near the town of Upington in the Northern Cape by Ilangalethu Solar Power;
- 100 MW linear Fresnel plant near the town of Kimberley in the Northern Cape by Afri-Devo/Ample Solar;
- 50 MW linear Fresnel plant near the town of Daniëlskuil in the Northern Cape by Afri-Devo/Ample Solar; and
- 100 MW parabolic trough (to be confirmed), near De Aar in the Northern Cape byAfrican Clean Energy Developments, (ACED).

The RE-IPP has placed a 100 MW size limit on CSP plants.

2 Ground Solar Measurements in South Africa

In most developing countries high quality solar resource data is obtainable from weather stations operated by government or related agencies. These measurements, typically spanning multiple years, are used in the planning phase of solar developments. High quality, high resolution satellite derived data sets is also available from various suppliers, especially from those that are in Europe. When ground measured data is combined with satellite derived data, a bankable solar data set comprising of multiple years of data can be obtained. South Africa suffers from a lack of high quality ground-based solar monitoring stations, especially DNI measurements. This is similar in other developing countries and is mainly due to the cost of acquiring and maintaining instrumentation.

In the past, the South African Weather Service (SAWS) has been the main source of ground irradiation data. The measurement of solar radiation in Southern Africa dates back to 1914 [7]. During the 1950's the Weather Service established a network of global and diffuse (mechanical shadow band) solar radiation measurements at its main "manned" weather offices around the country, including stations in Namibia (formerly South West Africa and part of the Republic of South Africa). The network was deployed with Kipp&Zonen CM2 and CM5 instruments. This also was established at the South Africa National Antarctic Expedition Base - SANAE, and at both Marion- and Gough Islands as the Island Meteorological measurement programmes were established. These instruments and points of measurement were complimented by non-SAWS owned station such as Roodeplaatdam and Grootfontein operated by the agricultural community. [7]

In the period from 1950 up until the 1980's this network functioned well as it was assigned with dedicated staff to the operational maintenance, data processing and archiving of data of the network. Since the 1980's, it was decided that the conventional solar radiation network must gradually be superseded by a network of Automated Weather Stations which is to be equipped with radiation sensors. The current CM2 and CM5 had become old and spare consumables were hard to obtain. Requests for new conventional instruments were invariably vetoed on many occasions and only expenditure on consumables and maintenance items have been approved in recent years [7].

In 1994 the SAWS embarked on the roll-out of an Automated Weather Station (AWS) Network. These stations were equipped with photoelectric pyranometers (Licor LI-200) measuring only global radiation [7],[8]. The AWS solar network showed a decline in monitoring capabilities during the period starting from 2000 to 2010.

In 1999 the SAWS became a member of the Baseline Surface Radiation Network (BSRN) with a fully equipped ground station installed at De Aar. The station ceased operation due to technical difficulties and lack of capacity/maintenance [8]. The data period available from this station is from January 2000 – January 2005 with a few months of data missing in 2000 and 2001 [9].

SAWS have placed a moratorium on disseminating their solar data due to the high measurement uncertainties in the database, resulting from lack of proper quality control and declining instrument maintenance. Some primary stations have fallen into disuse since the introduction of the AWS equipment and in certain cases the instrumentation has not been calibrated in over a decade. Currently, there is only one operational radiometric ground station recording GHI and diffuse irradiance at hourly resolutions, situated in Cape Town. Fortunately, the issue of data quality is currently receiving attention from SAWS and personnel are working on restoring their radiometric network so that good quality ground-based irradiation data can be made available. This project has only just started and would be completed over the next two to three years. Historical database recovery and the assessment of the quality are also to be undertaken [7],[8].

There are three other sources of ground measured solar data, namely the South African Agricultural

Research Council (ARC), the South African Sugarcane Research Institute (SASRI) and the utility ESKOM. Both ARC and SASRI make use of photoelectric (silicon) pyranometers measuring GHI only [8] while Eskom makes use of pyrheliometers mounted on trackers, with only some of their stations equipped with photoelectric pyranometers. Eskom data was reported to be of low quality due to a lack of regular cleaning [10]. This is due to the remote locations of their stations in the Northern Cape.

Although ground stations are limited, several Universities have carried out research, or continue to do so, and contribute high quality data free of charge. These include [8]:

- The University of Durban-Westville (UDW) with an operational station from 1996 - 2002. GHI and DNI was recorded.
- The Mangosuthu University of Technology (MUT) in Durban. Measurement started in 2003 and is ongoing. Data includes GHI, diffuse and DNI.
- The University of KwaZulu Natal (UKZN) Howard College campus. Measurements started in 2009 and are ongoing. Data include GHI, diffuse and DNI.
- Stellenbosch University started solar measurements in 2010 and is ongoing. Data include GHI, diffuse and DNI, among other weather and solar data being monitored.
- Nelson Mandela Metropolitan University (NMMU) in Port Elizabeth has solar measurement at their outdoor research facility. In August 2012 they installed a full solar measurement station recording DNI, GHI and Diffuse.

Most of the DNI measurement stations are located inland, particularly in the Northern Cape Province. All the stations that are run by the Universities are located near the coast, Fig. 2. It is the vision of the Centre for Renewable and Sustainable at Stellenbosch University to facilitate the installation of additional DNI measurement stations at other Universities throughout the country. The aim of these installations is to stimulate research in the field of solar resource and to ensure that high quality solar data is made available in the public domain.

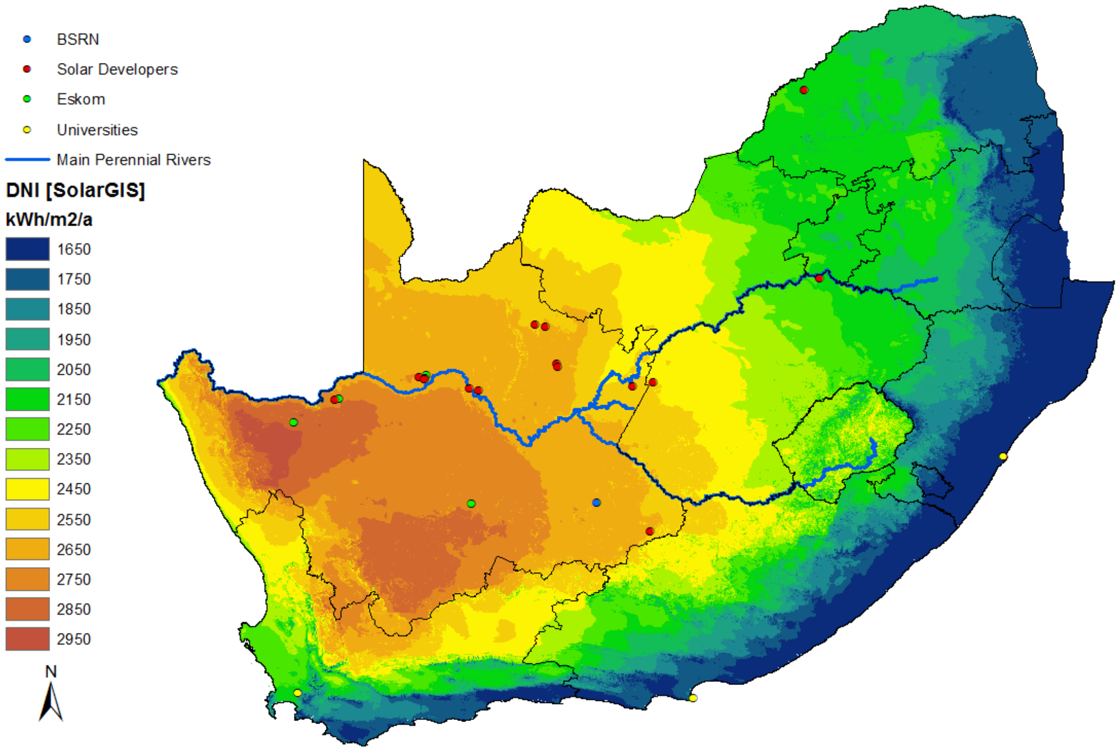

Fig. 2: DNI solar measurement stations in South Africa [5],[11]

In addition to the DNI stations in South Africa, the author is aware of three DNI stations that were installed in Lesotho in 2012 for the Lesotho Meteorological Services, three that were installed in Botswana in 2011 to 2012 by CSP developers and one that was installed in Namibia in 2012 for research purposes.

3 Solar Developers

The RE-IPP requires CSP developers to have on-site solar measurements for at least one year [12]. The author is aware of 18 on-site solar measurement stations installed by CSP developers (excluding those operated by Eskom) at various locations in South Africa and Botswana. These stations were installed in the past 5 years and most of them are located in remote sites. The author has installed eight of these stations. Out of the 18 stations, 16 uses a pyrheliometer mounted on a solar tracker. Some developers also make use of additional thermopile pyranometers to measure GHI and diffuse irradiance. Two developers use a rotating shadow band radiometer (RSR). Eskom initially installed three RSR devices which were later replaced by pyrheliometers and trackers. The following section describes the cost, advantages, disadvantages and maintenance requirements of the pyrheliometer and RSR solar station.

3.1 DNI Measurement Option 1: Pyrheliometer

The core of this system consists of a pyrheliometer mounted on a solar tracker. The solar trackers that are available today have significantly lower power consumption when compared to the first generation solar trackers and can therefore be powered of a relatively small size PV/battery system for remote sites.

The author recommends the following instruments: one ISO *first class* pyrheliometer (e.g. Kipp&Zonen CHP1 or SHP1, EKO MS-56 or Eppley NIP) mounted on a solar tracker. In addition to this two ISO *secondary standard* (thermopile) pyranometers (e.g. Kipp&Zonen CMP11 or SHP11, EKO MS-802 or Eppley PSP) mounted horizontally to measure GHI and diffuse irradiance (with the aid of a shadow ball) are recommended. The ISO *secondary standard* instruments have an expected daily uncertainty of ±2%. Care should be taken not to select an ISO *second class* instrument (e.g. the Kipp&Zonen CMP 3, EKO MS-602) with an expected daily uncertainty of ±10%. The GHI and diffuse measurements serves as redundancy – DNI can be calculated from these measurements. Many of the high DNI areas in South Africa are also areas that are known for frost in winter. In such areas ventilators should be installed on the solar measurement equipment.

In addition to the solar instruments, ambient temperature, wind speed and wind direction at 2 m or 10 m (10 m is recommended) should be recorded. Such a system is easy to install and the cost of a complete system is about R 296 000 [13], Fig. 3, excluding installation and security fencing. Data from the system is downloaded via a cellular phone network.

Fig. 3: DNI measuring station [11]

Regular maintenance on such a system involves cleaning the pyrheliometer glass and pyranometer dome, changing the desiccant and ensuring the rain gauge is free of leaves or other objects. Some sources recommended to clean the pyrheliometer daily or every second day [14] while others state that every two weeks is sufficient [15]. The author recommends cleaning it twice a week. The desiccant of the pyrheliometer requires change every 3 – 6 months, depending on the humidity of the climate [16]. The author’s own experiences show that the desiccant needs replacement about every 4 months, for sites located in the Northen Cape. More regular changing might be required for more humid regions.

Wind measurements are important for CSP developers in order to assess the wind loads on the mirrors and receivers. Wind, temperature and humidity data is an important factor to design the condenser of a CSP plant, especially an air (dry) cooled condenser [17].

3.2 DNI Measurement Option 2: RSR

A RSR (Rotating shadow band radiometer) can be used to calculate DNI as an alternative to using a pyrheliometer to measure DNI. The RSR measures GHI and diffuse irradiance and calculates DNI. Both GHI and diffuse are measured with the same silicon pyranometer. A rotating shadow band is used to shade the pyranometer every 2 minutes (typically). The fast response of the silicon pyranometer (about 10 µs) allows for diffuse measurements with a rotating shadow band while thermopile pyranometers requires a stationary shadow band.

RSR systems are aimed to provide a lower cost alternative for autonomous operation in remote locations. Development of this instrument took place during the times when solar trackers were less reliable (e.g. the onboard clocks experience time drifts) and had relatively high power consumption needs. Modern day solar trackers, e.g. the Kipp&Zonen Solys2, have low power consumption and the clock is updated from an on-board GPS. The tracker can also be remotely controlled (e.g. to download status/log files and perform a system reset) via the same cellular link through which data is download.

A RSR requires calibration against a pyrheliometer (typically for a few months and ideally in an area with similar weather conditions of the deployment location) in order to, among other factors, to better understand the spectral response of the silicon pyranometer. Post processing of data is normally required and quality checks are limited due to the absence of additional sensors. This results in higher uncertainties in the DNI time series when compared to that of a pyrheliometer based station [18].

Even with the mentioned limitations, RSR devices are widely used for solar prospecting by CSP developers. The cost of a RSR, including a full weather station with wind measurements on 10 m, ranges from R 210 000 (Irradiance) [13], Fig. 4, to R 320 000 (YesInc.) [19].

Fig. 4: An Irradiance RSR being tested at Stellenbosch University [11]

4. Satellite derived solar data

The RE-IPP is prescriptive on the satellite derived data basis that can be used by PV and CPV projects [12] but not on CSP projects. For PV and CPV projects satellite derived data with a period of at least ten years should be obtained from one of the following sources: Meteonorm v6.1, PVGIS, NASA SSE, 3TIER, ENEA, SolarGIS and HelioClim-1.

It is assumed that CSP developers will combine their on-site solar measurements with multi-year satellite derived data that has a temporal resolution of at least one hour. From the site-adapted multi-year satellite derived data TMY and other files can be derived. The satellite derived data sources available for South Africa that are known to the author and that adheres to these requirements are:

- SolarGIS data supplied by GeoModel Solar in Slovakia
- Solemi data supplied by the DLR in Germany
- Helioclim1&3 data supplied by Mines Paris Tech in France
- Data supplied by Sun2Market based in Spain
- Data supplied by 3Tier based in the United States

For CSP prospecting the following suppliers have products for South Africa:

- GeoModel Solar in Slovakia: solar poster maps, online interactive solar maps, GIS layers and Google Earth layers
- Data supplied by 3Tier based in the United States: solar poster maps and GIS layers

Other satellite derived data sources that are available for South Africa but do not adhere to the requirements above are:

- NREL – poor spatial resolution of 40 x 40 km, no hourly data available
- NASA – poor spatial resolution of 90 km x 110 km, no hourly data available

5. Conclusion and Recommendations

Due to the general lack of high quality solar measurements and requirements from the RE-IPP, site specific solar measurements are important to develop a successful solar project in South Africa.

An ISO first class pyrheliometer mounted on a solar tracker form the core of the recommended measurement station for CSP projects. Additional GHI and diffuse measurements are highly recommended. Solar instruments should be regularly cleaned while on site and should be calibrated at recommended intervals.

The lower cost alternative to on-site DNI measurements is a RSR. It has a less regular cleaning interval but requires pre-installation calibration and data post processing.

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