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Solmap: Project In India's Solar Resource Assessment

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ABSTRACT: India launched Jawaharlal Nehru National Solar Mission in 2009, which aims to set up 20 000 MW of grid connected solar power, besides 2 000 MW equivalent of off-grid applications and cumulative growth of solar thermal collector area to 20 million m² by 2022. Availability of reliable and accurate solar radiation data is crucial to achieve the targets. As a result of this initiative, Ministry of New and Renewable Energy (MNRE) of Government of India (GoI) has awarded a project to Centre for Wind Energy Technology (C-WET), Chennai in the year 2011 to set up 51 Solar Radiation Resource Assessment (SRRA) stations using the state-of-the-art equipment in various parts of the country, especially the sites with high potential for solar power. The GoI project has synergy with SolMap project, which is implemented by the Deutsche GesellschaftfürInternationaleZusammenarbeit (GIZ) in cooperation with the MNRE. SolMap project is contributing to SRRA project in establishing quality checks on the data obtained as per International protocols and helping data processing to generate investment grade data. The paper highlights the details of SRRA stations and an attempt has been made to present some of the important results of quality control and data analysis with respect to GHI and DNI. While our analysis of the data over one year finds that intensity and profile of the insolation are not uniform across the geographic regions, the variability in DNI is particularly high. Strong influence of monsoon is also identified. SRRA infrastructure aims to develop investment grade solar radiation resource information to assist project activities under the National Solar Mission of India.

Keywords: solar radiation, DNI, GHI, resource assessment, India, pyrheliometer.

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1. Introduction

In 2009, the Indian Ministry for New and Renewable Energy (MNRE) launched its ambitious Jawaharlal Nehru National Solar Mission (JNNSM) under which it has set a target of installing 20 GW of grid connected solar power by the year 2022. In addition there are targets of 2000 MW off grid solar and 20 million square meters of solar thermal collector areas by 2022 as well.

While conventional PV plants utilize global component of solar radiation, all CSP technologies need to concentrate sunlight. As optical concentration cannot be achieved based on diffuse light coming from various directions, only the direct beam irradiance component is relevant for CSP.Therefore accurate information on globalsolar irradianceon horizontal plane (GHI) anddirect normal irradiance (DNI) for India is very essential prerequisite to set up solar power stations under JNNSM.

Until around 2008 availability of solar radiation maps of India was quite limited. Besides worldwide data sets in coarse resolution like NASA-SSE (NASA-SSE 2012) there was the Global Horizontal(GHI) map provided by the India Meteorological Department (IMD) based on interpolation of ground-based measurements(SEC &

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IMD 2008). IMD has 18 stations where global and diffuse components of solar radiation are being measured. But many of those IMD stations are located in cities or in the airports etc. which do not represent large solar project sites.Additionally time-series and maps based on ground-based measurements and model-derived solar radiation values of DNI and GHI also can be obtained from the Meteonorm software(Meteotest 2008). Several efforts were made to estimate solar resources of India using satellite derived information (Bhattacharya et al. 2013).In 2009 NREL released its first version of a satellite-based solar radiation map providing GHI and DNI covering the North West of the country. In 2010 an updated version was released by NREL, which then covered entire India. Meanwhile several commercial satellite-derived data sets became available like 3TIER (2011), the Solemi data set of DLR (DeutschesZentrumfürLuft- und Raumfahrt – German Aerospace Center), the iMaps data of GeoModel Solar(GeoModel 2011), and the data from IrSOLaV(Cony et al. 2012)(Polo, J. et al). But the uncertainty of solar radiation data in India is still very high(Gueymard and George 2011). Ground truth of the satellite-derived data sets is still widely missing.This is mainly due to a lack of radiation measurement campaigns appropriately designed for solar project development in India. All of these have resulted in demand of high quality solar resource data for India.

The high uncertainty of solar radiation data is acting as a hurdle to the development of solar power plants in India. As a result, to provide a solid database for solar energy deployment in India MNRE is funding the project Solar Radiation Resource Assessment (SRRA) at Centre for Wind Energy Technology (C-WET). The SRRA-project is mainly covering the set up and operation of a countrywide collection system of solar radiation data. In 2011 a network of 51 solar radiation measurement stations distributed all over most states of India was erected. These stations are measuring direct, diffuse and global irradiance with high quality.

SolMap is a project under the Indo-German Bilateral Cooperation and supported by the German Ministry for Environment, Nature Conservation and Nuclear Safety (BundesministeriumfürUmwelt, Naturschutz und Reaktorsicherheit - BMU). In SolMap the Deutsche (GIZ) together with its contractors PSE AG and Suntrace GmbH are cooperating with C-WET. The project Solar Mapping and Monitoring (SolMap) has the main goal to accelerate the planning and implementation of solar power plants in India and increase their power output. SolMap is supporting a countrywide system for the collection and analysis of solar and other relevant meteorological data. Further, the project is supporting for establishing a system for performance benchmarking of photovoltaic plants.

One of the main goals of SolMap project is to implement a quality control and data processing system for data being measured by 51 SRRA stations. In this article we describe quality control algorithms implemented as part of SolMap project. Initial data of a short duration has been analyzed and preliminary results are presented here for various representative sites.

2. Solar Radiation Resource Assessment (SRRA)

The Solar Radiation Resource Assessment (SRRA) cell of MNRE is located at C-WET, Chennai. The SRRA team was initially responsible for selecting locations where these 51 SRRA stations would be installed. Different regions of the country have been selected so as to gain knowledge of as many regions as possible; especially regions of India with highest potential for development of solar power plants are covered densely with SRRA stations. As can be seen in Figure 1, majority of stations are located in North-West of India, covering the states of Rajasthan and Gujarat.

Figure 1: left: Map showing the location of 51 SRRA stations in India;center: a typical complete SRRA station; right: solar tracker with pyrheliometer, two pyranometers and tracking mechanism.

The SRRA team was also responsible for determining the type of instruments required, minimum requirements that should be met by instruments, the design of SRRA station etc. A global tender was floated for supply, installation and maintenance of 51 stations. After reviewing the bids received, the tender was awarded to SGS Weather and Environmental Systems India Pvt. Ltd. The installation of SRRA stations began in end of May 2011 and ended in November 2011.

2.1. Standard SRRA Station Design

All 51 SRRA stations are identical in design and have the same quantity and model of instruments. Table 1 below gives a list of the instruments that form a complete SRRA station. It should be noted here that only first class pyrheliometers and secondary standard pyranometers as classified by ISO 9060 (ISO 9060 1990 2008) are used in this network. In addition to this, SRRA has also acquired two absolute cavity radiometers (ACR), which will be required for recalibration of solar radiation sensors.

All other meteorological parameters like ambient temperature, relative humidity, atmospheric pressure, wind speed and direction and precipitation are also measured by SRRA stations, following WMO guidelines(WMO 2008). SRRA stations are provided with autonomous power using solar photovoltaic panel and battery storage system in order to provide uninterrupted power supply.

Table 1:
Typical configuration of instruments used in all SRRA stations.

	Instruments used	Parameter measured
Solar Radiation Sensors	Pyranometer 1	Global Horizontal Irradiance
	Pyranometer 2	Diffuse Horizontal Irradiance
	Pyrheliometer	Direct Normal Irradiance
Meteorological Parameter Sensors	Air temperature sensor	Ambient air tempera-ture
	Relative Humidity Sensor	Ambient Air Relative Humidity
	Ultrasonic wind Sensor	Wind speed and wind direction
	Barometer	Atmospheric Pressure
	Pluviometer/rain Gauge	Rain precipitation

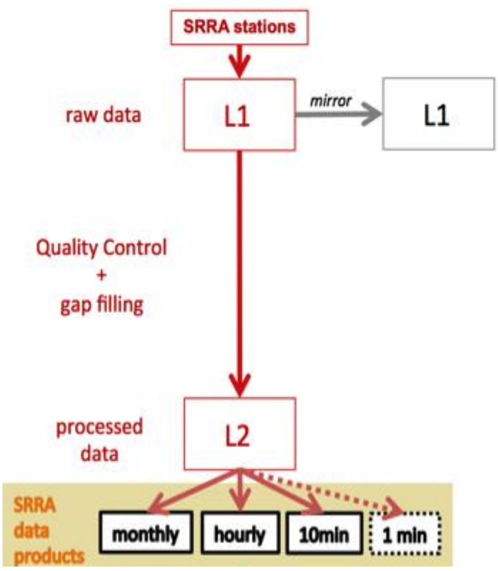

Figure 2: Data flow from SRRA-stations to L2 products.

Initially all meteorological parameters were sampled every 10 s and mean of 10 minutes were being stored in the data logger. All SRRA stations are equipped with GPRS based telecommunication system and transmit data stored in data logger to Central Receiving Station (CRS) located at C-WET head office in Chennai every 10 minutes. At present all SRRA stations have been upgraded and all parameters are sampled every 1 s and mean of 60 such samples is taken and stored in the data logger. So the current temporal resolution of this network of 51 radiation monitoring stations is 1 minute. This is world's largest network pyrheliometric network at the moment.

2.2. System Architecture and general characteristics of the system

At present the data measured by the stations are received and stored in a Central Receiving Station located at C-WET head quarter in Chennai. The receiving server system is named as Level 1 (L1) and stores all data received from all 51 stations. In the L1 server system only basic quality tests are implemented. To avoid data losses and reach high availability, a RAID 5 back-up system with two hot-swappable servers is used.

Once the data is stored in L1 server, it is checked for its quality i.e. missing data, plausibility of data measured etc. This is done in another server system, which is called Level 2 (L2) system. L2 system consists of data processing and processed-data storage. Once data are quality controlled, various reports and data products are created in different temporal resolutions like hourly, daily, monthly, yearly reports etc.

3. Quality Control of data

Quality control algorithms are directly applied to the raw data. This chapter describes various tests performed on raw measured data as part of the quality control processing implemented in L2 system. The quality control algorithms test solar radiation parameters (DNI, GHI and GHI) and auxiliary meteorological parameters like ambient temperature, relative humidity, wind speed and direction etc. separately. Data is checked for various errors and is flagged accordingly.

3.1 Irradiance

The tests applied for global horizontal irradiance (GHI), direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI) are based on Baseline

Surface Radiation Network (BSRN) rules set by the World Meteorological Organization (WMO). These tests are elaborated by the project Management and Exploitation of Solar Resource Knowledge (MESOR), see(Hoyer-Klick et al. 2009), and those developed and published by (Long and Dutton 2002) and(Long and Shi 2008). These tests are enhanced by further experiences by CIEMAT, DLR, NREL, ENTPE and others in the evaluation of ground-measured solar radiation data with the goal of reaching low false alarm rates and good detection efficiency.

The data is tested on physical limits, if the data are below or above physical possible values. Another test considers a clear sky model. The measured values should be lower than the model output of a clean and dry atmosphere. As the three components of irradiance (global, diffuse and direct) are measured by independent instruments, these measurements can be checked for redundancy and for tracking errors.

3.1.1 Physical limits

Following (Hoyer-Klick et al. 2009)and (Long and Dutton 2002)physical possible maximum, (individual for GHI, DNI and DHI) and minimum limits are applied. According to BSRN the physical minimum for irradiance values is with -4 W/m^2 below zero as negative values can be produced by thermal sensors due to radiative cooling at night and can be used for zero offset calibration. Since the incoming irradiance never can be negative the limit for the L2 post processing of the raw data is set to 0 W/m^2. This is avoiding a slight negative bias by negative nighttime values for daily and monthly averages.

3.1.2 Limits of a clear sky condition

In this test the GHI, DHI and DNI are compared to the values obtained under clear sky conditions.

The DHI is tested against the clear sky GHI as a maximum limit since the DHI can be very low under clear sky conditions in a clear and dry atmosphere. In (Long and Shi 2008) a minimum limit, the Rayleigh Limit as DHI under really clear and dry sky conditions is given for the DHI. Most of the time, these conditions lead to the maximum values of the GHI and the DNI. However, there are some conditions mainly at broken cloud conditions when scattering on cumulus clouds can lead to situations when GHI is exceeding even the 'solar constant'. This cloud enhancement effect can cause irradiances higher than the clear sky limit, only concerns GHI. GHI data, which exceed the clear-sky limit, thus should be considered only as "potentially" erroneous.

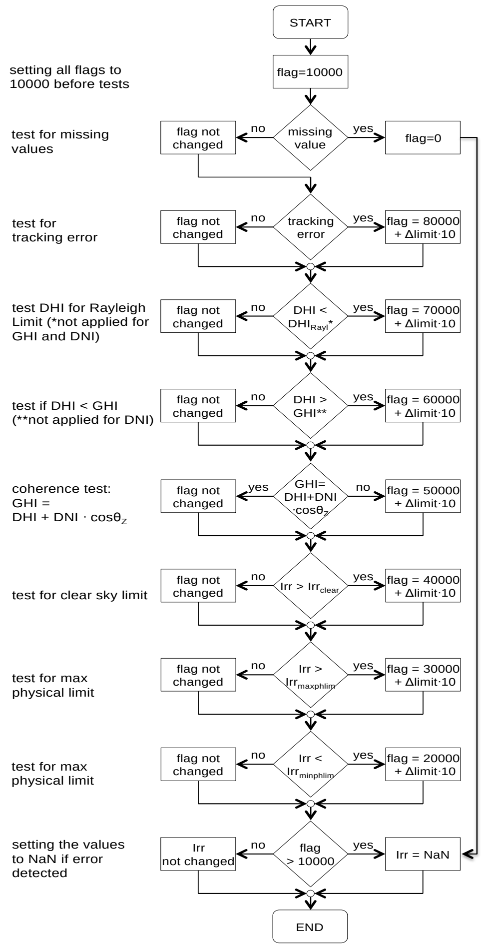

Figure 3: Flow chart showing the various tests performed on three major solar radiation parameters GHI, DNI and DHI.

3.1.3 Coherence between measurements

The DHI should not be higher than the GHI within the limits of accuracy of the instruments. In addition, the GHI should be close to the sum of the diffuse and the direct components. The used limits are suggested by(Long and Dutton 2002) and (Long and Shi 2008). Caution should be taken when dealing with values averaged over one hour or more. In those cases, the distribution of cloudy and non-cloudy conditions within the averaging period has an increasing influence, limits therefore should be higher. Since the quality control is applied on data in 1 minute and 10 minute time resolution these limits are adequate.

3.1.4 Tracking error

Following(Long and Shi 2008), if measured DHI is greater than 50 W/m^2 and the ratio of measured GHI to clear sky GHI is greater than 0.85 and if the ratio of measured DHI to measured GHI is greater than 0.85, the corresponding DHI values are flagged as tracking error. Additionally, if the measured

DNI value is less than 150 W/m² and the above-mentioned conditions are fulfilled, the corresponding DNI values are flagged also as tracking error. In addition tracking error is also assigned, when it is identified by visual analysis of the data or reported by the station keeper.

3.1.5 Testing sequence

A logical order of the various tests is applied from simple to more complex tests. Instead of a separate flag for each test a long integer value is used to avoid using too much memory. If the result of one test is identifying an error, the flag of the former test is overwritten(Schwandt. M, et al 2013).

4. Data analysis

Generally solar radiation values should be given for one complete year of measurements, which cover all sun-positions in the sky. Actual installation of 51 SRRA stations started in June 2011, with the first stations being installed and commissioned in Indian states Tamil Nadu and Rajasthan. The installation of other stations was carried out in different phases, with the last station being installed in Andhra Pradesh in November 2011. The results of data analysis are presented here only for selected stations for which one complete year of measurements is available. For this paper the results of SRRA stations located in Indian states of Rajasthan and Tamil Nadu based on quality-checked data.

However since values presented here are based on only one year of ground-measurements, they should not be mistaken to represent 'long-term average' value as they don't represent inter-annual variability of solar radiation. As a result these values should not be compared with long-term solar radiation averages derived from satellite data. Moreover, due to spatial variation of solar radiation, values presented here are representative of the single point measurements and should not be considered to represent the solar resources of the entire region or country as a whole. But at the same time these values can be used as a rough estimate of the values that can be expected in similar regions that have similar climatic conditions in the country.

4.1 DNI Solar resource in India

The DNI solar resource in Rajasthan and Tamil Nadu measured by SRRA stations are presented here as monthly averages as can be seen in Figure &Figure. At first look it can be seen that there is a variation in the annual cycle (seasonal variation) of DNI in both these states. This is mainly due to the fact there are two monsoon seasons in Southern India (Tamil Nadu) as compared to one monsoon season in Northern India (Rajasthan). During the months of October, November, December when N. India receives good DNI, it is relatively low in S. India due to the second monsoon season. This is called Northeast monsoon or retreating monsoon.

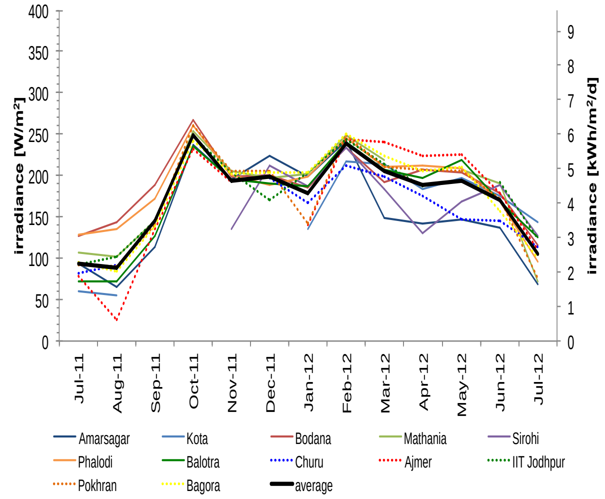

Figure 4: Graph showing monthly average values of DNI from July 2011 to July 2012 at SRRA stations in Rajasthan.

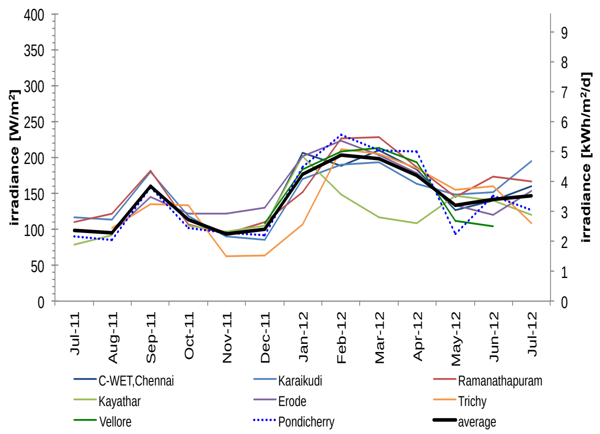

Figure 5: Graph showing monthly average values of DNI from July 2011 to July 2012 at SRRA stations in Tamil Nadu.

The average standard deviation of DNI monthly average values within Rajasthan for the whole period is 22 W/m², whereas the minimum and maximum standard deviation is 12 W/m² and 34 W/m² respectively. For the same period the average standard deviation of DNI monthly averages for the whole period is 24 W/m², whereas the minimum and maximum standard deviation is 12 W/m² and 34 W/m² respectively. Despite of applying quality checks, there are outliers in the data that were questionable. In the absence of proper documentation of soiling/cleaning of stations, it becomes difficult to identify the exact source of error. This is also one reason for the lower than expected values measured by these stations.

The maximum annual average DNI measured in

Rajasthan is at Phalodi, equal to 1702 kWh/m²/a or 4.66 kWh/m²/d or 194 W/m². The maximum annual average of DNI measured in Tamil Nadu is at Ramanathapuram, equal to 1397 kWh/m²/a or 3.83 kWh/m²/d or 159 W/m². During one year of ground-based measurements from August 2011 to July 2012, the average DNI values from all stations in Rajasthan is found to be 182 W/m² or 1600 kWh/m²/a or 4.38 kWh/m²/d. Similarly, for the same period, the average values from all stations in Tamil Nadu is found to be 149 W/m² or 1300 kWh/m²/a or 3.58 kWh/m²/d.

These values are quite low compared to the values from satellite-derived data for these locations. However, as mentioned before, the values presented here are based on only one year of measured data, without considering the factor of inter-annual variability. It should also be noted that these low values are suspected due to soiling of instruments, pyrheliometers in particular. It is suspected that these low values are caused due to high turbidity (high humidity and aerosol load) in India, which varies a lot in India from one region to another.

Comparison of DNI values with some other CSP countries

Compared to some other sunny countries where a lot of solar power activities are carried out or are currently going on, DNI values in India are comparatively low as can be seen in Table 2. The DNI values for Spain and South Africa considered for this study are long-term average values, whereas DNI values for the Indian sites are just based on one year of measurements. From Figure 2, the first difference one notices is in the annual cycle of DNI. Both Spain and South Africa receive most of the DNI during their summer seasons and less DNI in winter season. In contradiction, India receives more DNI in winter and less in summer due to the monsoon effect. As a resultDNIsolar resource in India is distributed more uniformly throughout the year, instead of having very high solar radiation in summer and low in winter (see Figure). This means that CSP and CPV plants can run at optimum loads also during winter seasons. This is beneficial to CSP & CPV power plants as they can be designed to operate over a significantly greater time of the year.

On the other hand side, winters in India are generally sunny with low cloud cover. It is expected that there would be less transient cloud conditions during winter in India as compared to other countries like Spain. This is also beneficial for operation of CSP plants leading to higher plant capacity load utilization factor, leading to greater yield.

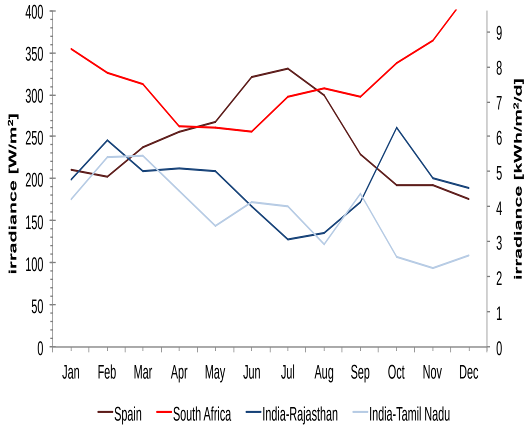

Figure 6: Graph comparing the annual cycle (seasonal variation) of DNI in Phalodi, Rajasthan and Ramanathapuram, Tamil Nadu with that in Plataforma Solar de Almería, Spain and De Aar, South Africa.

Table 2:
Comparison of DNI & GHI annual averages of SRRA stations in Phalodi, Rajasthan and Ramanathapuram, Tamil Nadu with that in De Aar, South Africa and Plataforma Solar de Almería, Spain (Chhatbar and Meyer 2011). * Values based on only one year of measurements

Country		India	India	S. Africa	Spain
State		Rajas-than	Tamil Nadu	N. Cape	Anda-lusia
Site	Quantity	Phalo-di	Ramana-thapuram	De Aar	PSA
kWh/m²/ a	DNI	1702	1397	2770	2130
	GNI	1916	1853	2100	1900
kWh/m²/ d	DNI	4.66	3.83	7.6	5.8
	GNI	5.25	5.08	5.8	5.2
W/m2	DNI	194	159	317	243
	GNI	219	212	240	217

4.2. DNI frequency distribution

The most important parameter that affects performance of CSP plants is DNI. CSP plants are designed to operate within specific range of DNI values. If instantaneous DNI values are outside this range, the plant could not utilize such DNI values and hence energy incident is lost. The design range of DNI values within which a plant could operate are generally determined from long-term frequency distribution of DNI. Frequency distribution of DNI describes the expected number of occurrences of DNI values at a particular site. DNI frequency distribution generally follows properties of normal distribution. It is shown that for years having same DNI annual averages, differences in DNI frequency distribution may result in significant differences in annual energy yield, which can be as high as -8 % to +9 % (Chhatbar and Meyer 2011). The frequency distribution of DNI measured by SRRA stations in Rajasthan and Tamil Nadu is shown in Figure7&Figure respectively. These values are based on 10-minute averages, which is the highest time resolution data available from SRRA stations for the period considered for this analysis.

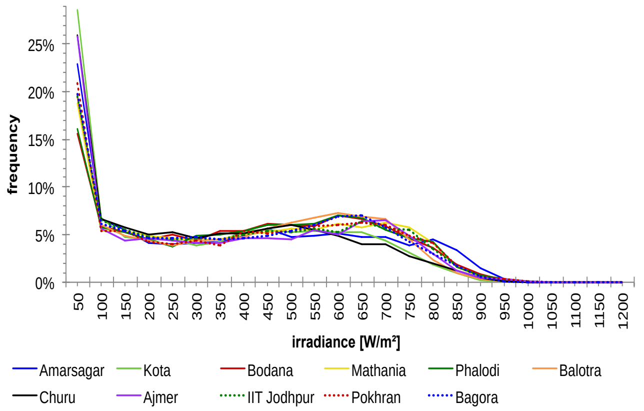

Figure7: Frequency distribution of DNI at SRRA stations in Rajasthan

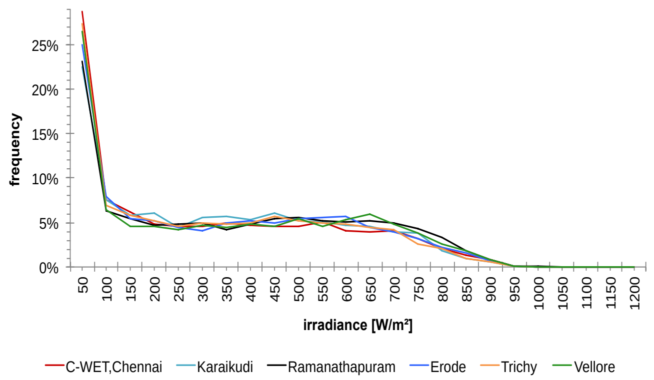

Figure 8: Frequency distribution of DNI at SRRA stations in Tamil Nadu

It can be seen that for stations in Rajasthan, DNI values are more concentrated in the moderate range from 500 W/m² to 900 W/m². While for the stations in Tamil Nadu, DNI values are uniformly distributed over DNI range from 400 W/m² to 700 W/m². These values and the figures suggest that very high DNI values are not frequently observed in the stations in Rajasthan and Tamil Nadu. It might happen that there are many instances with instantaneous DNI > 1050 W/m², but DNI > 1050 W/m² are not observed in the 10-minute averages. The frequency distributions are shifted more towards the left side (low DNI values) than on the right side (high DNI values).

Comparison of DNI frequency distribution with some other CSP countries

Just like DNI monthly/yearly averages, frequency distributions are determined for two sites in Spain and South Africa from long-term data and shown in Figure . From one can see that the sites in Spain and South Africa receive very high values of DNI (> 900 W/m2) very frequently, while such high DNI values are seldom observed in the Indian sites.

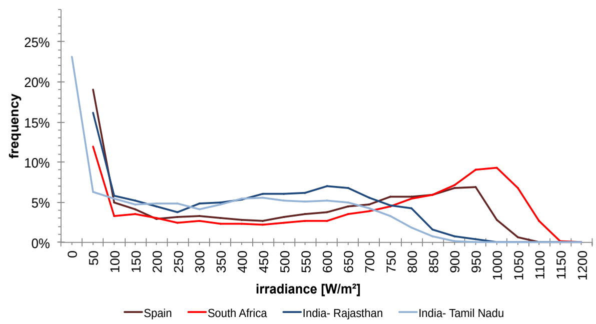

Figure 9: Comparison of DNI frequency distribution observed in Phalodi, Rajasthan and Ramanathapuram, India with those in Plataforma Solar de Almería, Spain and De Aar, South Africa.

On the one hand, this is beneficial to CSP plants as they can be designed to operate at moderate DNI values, which are observed frequently throughout the year. This might lead to larger solar fields as compared to that in other countries for same installed capacity. On the other hand side, very high DNI as observed in Spain and South Africa that is outside the design range of CSP plant cannot be utilized and hence leads to ‘dumped energy’. Moreover, each CSP plant can be optimally designed based on the DNI frequency distribution expected at the site. In addition to this, CSP plant operation strategy also plays an important role in determining the energy yields. Hence, moderately low DNI values in India may not mean low energy yields of CSP plants.

4.3 GHI solar resource in India

The GHI solar resource in Rajasthan and Tamil Nadu measured by SRRA stations are presented here as monthly averages as can be seen in Figure 10&Figure. At first look it can be seen that there is a small variation in the annual cycle (seasonal variation) of GHI in both these states. During the months from April to June 2012, when N. India (Rajasthan) experiences an increase in GHI, S. India experiences a decrease in GHI. From Figure 10&Figure it can also be noticed that the spatial variability of GHI within the respective states is also quite less. The average standard deviation of GHI monthly average values within

Rajasthan for the whole period is 13 W/m², whereas the minimum and maximum standard deviation is 5 W/m² and 22 W/m² respectively. For the same period the average standard deviation of GHI monthly averages for the whole period is 12 W/m², whereas the minimum and maximum standard deviation is 6 W/m² and 20 W/m² respectively.

During one year of ground-based measurements from August 2011 to July 2012, the average GHI values from all stations in Rajasthan is found to be 210 W/m² or 1835 kWh/m²/a or 5.02 kWh/m²/d. Co-incidentally for the same period, the average values from all stations in Tamil Nadu is also found to be 210 W/m² or 1835 kWh/m²/a or 5.02 kWh/m²/d. These values are low compared to the values from satellite-derived data for these locations. However, as mentioned before, the values presented here are based on only one year of measured data, without considering the factor of inter-annual variability. It should also be noted that these low values are suspected due to soiling of instruments.

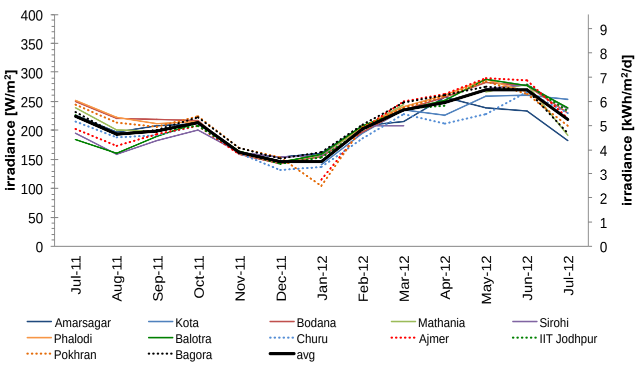

Figure 10: Graph showing monthly average values of GHI from July 2011 to July 2012 at SRRA stations in Rajasthan.

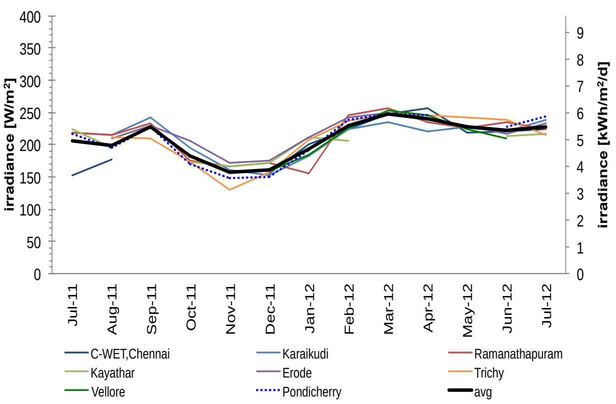

Figure 11: Graph showing monthly average values of GHI from July 2011 to July 2012 at SRRA stations in Tamil Nadu.

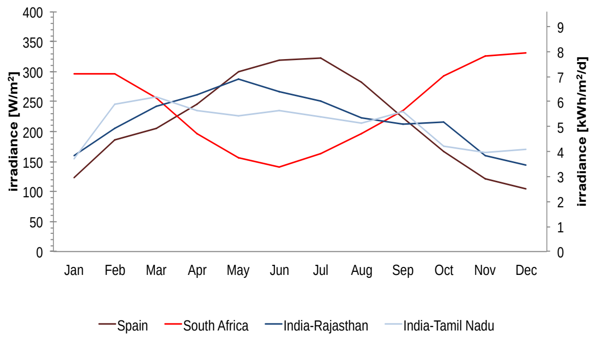

Figure 12: Graph comparing the annual cycle (seasonal variation) of GHI in Phalodi, Rajasthan and Ramanathapuram, Tamil Nadu with that in Plataforma Solar de Almería, Spain and De Aar, South Africa.

4.4 Recent Developments

Early data gathered by this network were biased, because regular cleaning of the instruments was not realized. Due to soiling the readings tend to underestimate. In order to rectify the situation several awareness events were organized where the station keepers were given information on importance of proper and regular cleaning of the sensors. Also automatic press buttons were introduced which are to be pushed just before and after the cleaning in each individual station. Automatic email alert system was introduced in case of malfunctioning of the measurements. In this manner a structured approach of keeping the stations' health good was started. Simultaneously work has been started to investigate the effect of soiling and accordingly post process the data sets for getting soiling corrected.

A focused study was conducted on the field experience from the operational aspects of the stations. . From the data analysis, it is observed that some stations are performing very well. Other stations show some operation issues. On average the network is running well.In the period from January 2012 to March 2013 on an average over all 51 stations, 92 % of the solar radiation data were classified as correct. The most frequent error observed in the data from this network is when GHI, DNI and DHI values do not pass the coherence test (ca. 4 %). Missing values due to unavailability of the solar radiation sensors was the second most frequently observed error (ca. 3%). This analysis helps in future to improve the operation of the network(Kumar. A et al. 2013).

Quality check procedures identify such malfunctioning and mark untrustworthy data by flags. Thus even well maintained stations with good equipment usually show some gaps. However many applications such as solar energy performance simulations need continuous time-series. Therefore it is required to fill the measurement gaps with reasonable data. Depending on duration and type of missing parameters various procedures can be used to fill gaps. A basic gap filling procedure has been developed and applied in SolMap for SRRA stations. The accuracy of the applied basic gap filling methodology is tested and the results show a mean bias of ca. 3 % over GHI, DNI and DHI over all types of gaps (Schwandt. M, 2013).

MNRE has sanctioned the phase II of SRRA initiative under which 64 new stations will get installed before May 2014. Additionally a few advanced measuring facilities, like aerosol optical depth, albedo, long wave etc, will get commissioned at four locations in India. Therefore this network will get extended covering the entire country soon.

SRRA/SolMap project already created huge interest among various stakeholders in the national and international level. Solar data have been made available to the public by introducing the "solar data sharing and accessibility policy 2012" of MNRE (CWET 2014).The commercial solar project developers are keen to access the data and to takeadvantage of the accurate solar resources data to plan anddesign projects more effectively. Similarly, several national and international banks involved in financing solar projects in India have shown interest in using the data. Several national and international organizations have already procured data from specific stations.IRENA (International Renewable Energy Agency) has launched the "Global Atlas for Renewable Energy" where India is a participating country (IRENA 2014). SolMap initiative has been included in their IRENA case study 2013: Solar Radiation Resource Assessment in India" document. Several satellite based solar radiation providing organizations have procured data from SRRA for their own model validation.

5. Conclusions

The SRRA measurement network is running since its commissioning in October 2011. With its 51 stations each equipped with a solar tracker, a pyrheliometer, a shaded and an unshaded thermopile pyranometer it is today the largest known national network of precision pyrheliometers. The data are of high resolution with 1 minute average values. Data are continuously checked for their quality. The ratio of DNI to GHI is relatively low at most stations due to high aerosol load. Thus, there are only few regions in India, which are well suited for concentrating solar power for large electricity generating plants.

Due to monsoon the irradiation levels in summer are relatively moderate compared to other countries. On the other hand there is relatively high irradiation during winter, because cloud frequency tends to be low then. Together with low temperatures in Northern India this are very favorable conditions for CSP and PV yields. Due to the observed low seasonal variation, CSP& PV output is expected to be high during winter and spring season, while during summer it will be low due to monsoon.

The absolute level of the measured solar radiation has still moderate uncertainty due to soiling issues and the short observation period for the early months of the operation. Measurements should be combined with satellite-derived solar radiation time-series to get reliable long-term averages. Continued measurements by SRRA help to achieve better results from year to year. Various corrective measures have been undertaken in order to reach more accuracy in the measurements.

Considering that the SRRA equipment has been working at remote sites, the experiences from sites has been very valuable. Effective measures and action were initiated in time by the C-WET and associated organizations like GIZ to ensure that the quality of SRRA data does not get adversely affected. The quality of sensors and associated equipment like solar tracker, data logger, power supply system etc. were found to be mostly trouble free. From the experience gained with this system it can be said that daily cleaning and maintenance is an integral part of such high precision measurement system and hence such sensors should be installed only when necessary daily cleaning can be assured at the sites.

The 51 stations are distributed mainly in the Northwest and South India where JNNSM Phase 1 was expecting highest number of solar energy projects. Also in other parts of the country good conditions for PV are expected. The MNRE decided to extend SRRA by another 64 stations of similar kind.

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