Oman Power & Water Procurement Co.

Solar Energy

Solar Data Collection

2/25/2012

Contents

1 Introduction

In year 2008, a study commissioned by the Authority for Electricity Regulation (AER) to assess renewable sources of energy and their potential use for electricity has found Oman to be amongst the countries with the highestlevel of solar energy in the world. On this basis, PAEW conducted a feasibility study on the preparation for the country's first large scale renewable energy project with net power output ranging from 100MW to 200 MW. The Meteorological Office Oman was contracted by the Public Authority of Electricity and Water to supervise, monitor and maintain 2 meteorological stations as part of a feasibility study and implementation of the solar power generating facility. The sensors for the meteorological stations were supplied and installed by Microstep.The feasibility studyand recommendations have been submitted to the government to be reviewed, while in the meantime OPWP is progressing work required to support the implementation and is actively processing data collected from installed and monitoring stations located within potential project site locations.

Along with this publication, we will be including all the raw data that has been obtained from the solar monitoring stations as well as all the details regarding the equipment used to obtain the data shown. The objective of this publication is to offer the opportunity for all parties that are interested in the Solar Project in the Sultanate of Oman, whether for development, investment, or other purposes to receive an update of data collection progress and to allow for further analysis and interpretation of the raw data provided. OPWP has also provided its own interpretation of the data for review, and is open to feedback from interested parties.

2 Site Study and Results

WorleyParsons, Macquarie,and Chadbourne&Parke Consortium was awarded a consultancy contractin 2010 by the Public Authority for Electricity and Water (PAEW) to advise on how to implement alarge-scale solar power project in Oman.

A country wide site selection study was conducted with an assessment of a number of potential sites based on a set of selection criteria suited to potential solar sites. The process of assessment involved the following steps:

1) Development of a set of selection criteria
2) Elimination of unsuitable regional areas
3) Selection from remaining regional area candidate sites
4) Recommendation of 4 sites with the highest achievable ranking

In the assessment, three potential regions were found to have characteristics that most closely matchedthe site selection criteria as follows:

- Adam/Manah Areas
- Ibri Area
- Sohar/Al Khaburah/Barka Areas

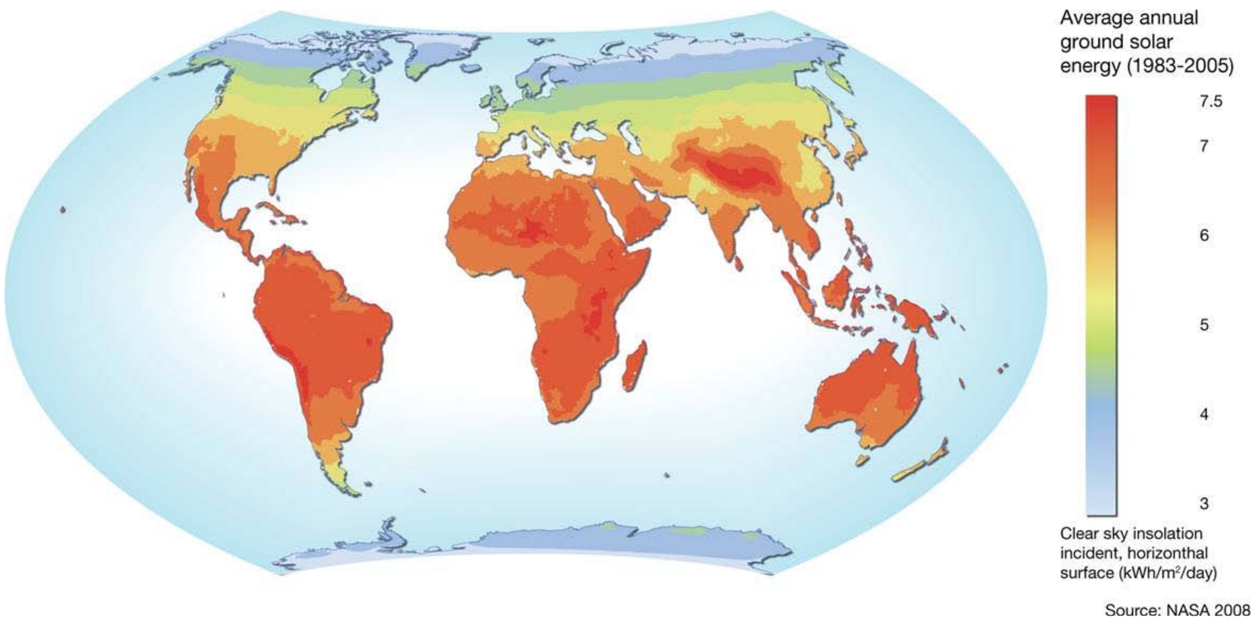

Figure 2-1 World Average Annual Ground Solar Energy (extracted from UNEP/GRID, 2008)

Sites within the Central Region of Oman were found unsuitable due to lack of infrastructure, proximity to load centres as the region is far away, as well as concerns with it consisting many sensitive habitat areas. The eastern coastal areas exhibited unfavourable conditions with the presence of haze and/or fog and loose shifting sand with sand dunes. Wahiba Sands areas were also found unsuitable due to the existence of extensively rolling sand dunes, as well as its proximity to load centres. Sites within the South of Oman experience effects of the monsoon season, leaving suitable areas remote from the main load centre, in addition to the fact of the grid in the Dhofar Power Region being of insufficient to support a large-scale solar project. Areas in the Mountains including Sayq Plateau are found uneconomical and unsafe.

Within the selected regions,total of twenty three (23) sites were identified as having the potential tobe suitable for a large-scale solar plant within the three regions. A comparative analysis followed using acombination of aerial topography, geological, meteorological and infrastructure data.Upon analysis, the two sites in Adam/Manah area (as seen in (***Figure 2-2***)) and the one in Ibri were found to have ideal characteristics for a large-scale solar power project. A site of lower ranking in the Al Khaburah area was also found suitable for if an integration wasto be established between a solar plant and a Combined Cycle Gas Turbine Plant (CCGT).

ManahSite 1 is ranked the highestand is considered an excellent site location for a stand-alone large-scale solar power plant. The solar insolation for Manah Site 1 is rated between 6.47-6.85 kWh/m2/day. Adam Site 2 has ranked second with a solar insolation rating of 6.61 kWh/m2/day. Ibri Site 1 is ranked third highest overall with a solar insolation rating of 6.26kW/m2/day. Both Adam Site 2 and Ibri Site 1 are also considered excellent for a stand-alone large scale solar power plant. Al Kahaburah Site 1 with the lowest overall ranking has an insolation rating of 6.18 kWh/m2/day. The topsoil conditions for all sites appear stable and sufficient for solar facilities construction.

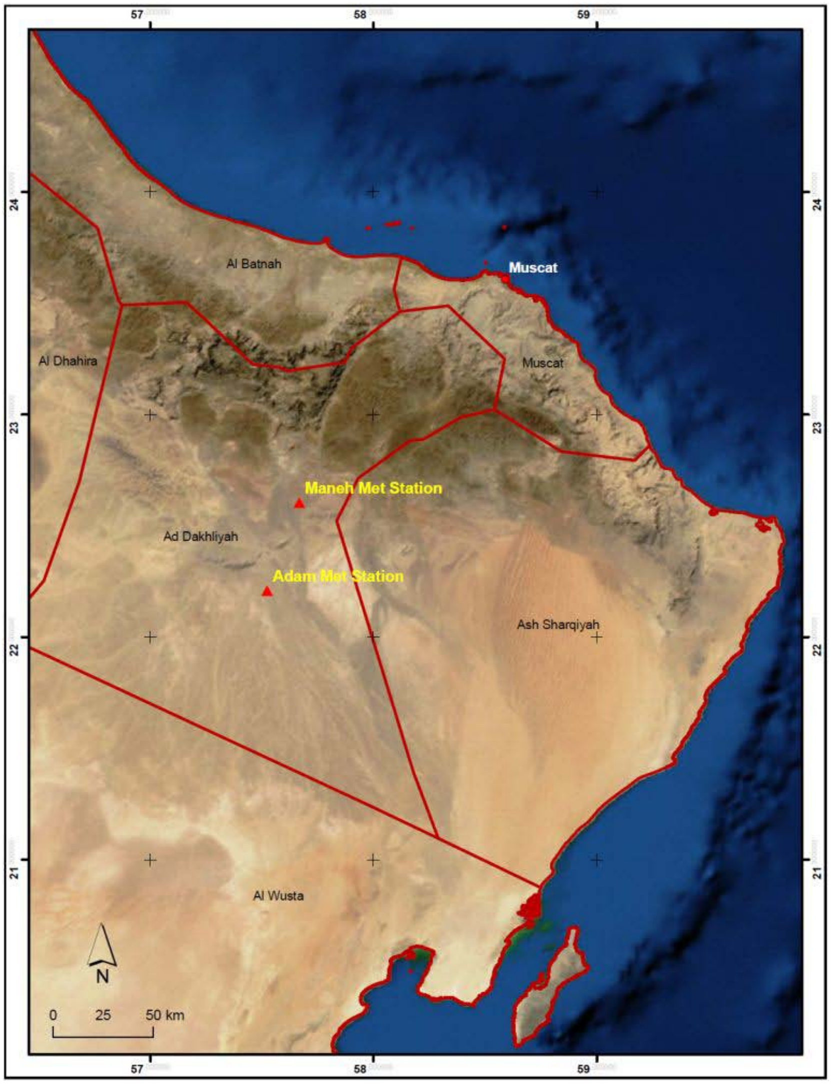

Figure 2-2 Location of Manah and Adam Meteorological Stations

Site	Easting	Northing
Manah Met station	057 40.033	22 36.186
Adam Met station	057 31.378	22 12.434

Table 2-1 Manah and Adam Location Coordinates

3 Solar Stations & Monitoring Equipments

3.1 Definitions:

The Direct Normal Irradiance, Global Horizontal Irradiance and Diffuse Horizontal Irradiance are the parameters used for measuring the solar radiation in both sites, following is a definition on the parameters:

- **Direct Normal Irradiance (DNI)**
  Direct Normal Irradiance is also known as Direct Solar Radiation, is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. This represents the maximum possible beam radiation that is measurable. The monitoring equipment for DNI is the Pyrheliometer.

- **Diffuse Horizontal Irradiance (DHI)**
  Diffuse Horizontal Irradiance which is also known as Diffuse Solar Radiation is not the radiation that is absorbed directly from the sun, however, it is defined as the radiation scattered by aerosols, dusts and particles. This is radiation is represented by the horizontal line as shown in (***Figure 3-1***) but generally does not have a unique direction. DHI is measured by a shading Pyranometer.

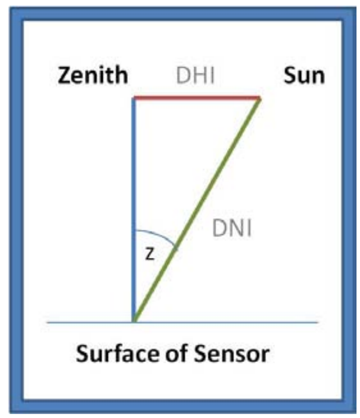

Figure 3-1 **GHI = DNI. Cos (Z) + DHI**

- **Global Horizontal Irradiance (GHI)**

  Also known as Global Solar Radiation, it is the total amount of the direct and diffuse solar radiation as calculated using the following formula:

  GHI = DNI. Cos (Z) + DHI

  <u>Where:</u>

  GHI = Global Horizontal Irradiance

  DNI = Direct Normal Irradiance

  DHI = Diffuse Horizontal Irradiance

  (Z) = Zenith Angle

  The GHI is measured by the total of direct and scattered radiation being received on a commonly horizontal surface as seen in (***Figure 3-2***).

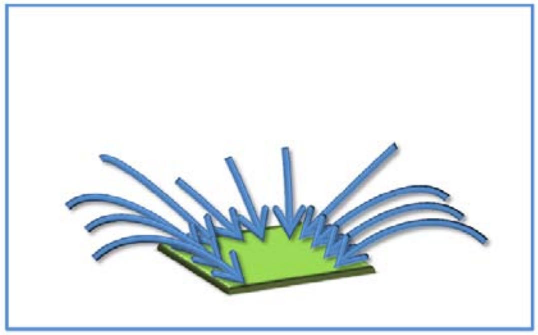

Figure 3-2 Global Horizontal Irradiance

3.2 Description

Thetwometeorological stations are located in Adam and Manah as seen in (***Figure 2-2***) and coordinates are provided in (***Table 2-1***).The Manahmet station, located 17 km north-northwest of Nizwa, is installed in an enclosed area as shown in (***Figure 3-3***), while the Adam met station, located approximately 295 km from Muscat on the Salalah road on the southern-most end of Dakhiliya, is installed in an enclosed area as shown in (***Figure 3-4***). Stations at both sites started collecting data on the 8th December 2010.

The sensors installed at the sites are designed to measure or derive the following parameters all of which are required for the Oman solar power stations:

- Direct Normal Irradiance (**DNI**)
- Global Horizontal Irradiance (**GHI**)
- Diffuse Horizontal Irradiance (**DHI**)
- Atmospheric Pressure
- Dust
- Dry Bulb Temperature
- Precipitation
- Relative Humidity
- Wind Speed
- Wind Direction
- Visibility
- Ground temperature
- Soil Temperature

Figure 3-3 Manah Met Station

Figure 3-4 Adam Met Station

One Dust Sampler is installed within the Adam Police Head Quarters as part of the existing meteorological garden enclosure at Adam (***Figure 3-5***). The Dust sampler is located half way between the Manah and Adam Met stations. The sampler installed at the Adam Dust sampler station is manufactured by Zambelli Instruments and consists of the following:

- Aluminium Cabinet

- Control Unit which consists of a Pump and Filter Cassettes
- Sample Heads (PM2.5 and PM10)
- Air conditioning unit
- AC power supply

Figure 3-5 Dust Sampler installed at Adam

The dust sampler has been unfortunately facing technical issues and the data received is not reliable.

Stations in both sites consist of 9 meteorological sensors. The manufacturers of the meteorological station sensors are Vaisala and Kipp and Zonnen. All sensors were supplied by Microstep – MIS.

In each of the installed stations, two independent solar panels with four 24VDC rechargeable batteries each provide the met station with sufficient power. The humidity and temperature sensor is installed on a horizontal structure on top of the DataLogger housing approximately 2 metres from the ground. Also installed on the horizontal structure is the modem for GSM transmission and Pyranometer. The Pyranometer is installed on a levelled solid surface and measures global horizontal radiation in Watt per square meter (W/sq.m).

The wind speed and direction sensors are installed on a 10 m meteorological mast positioned in the middle of the enclosed area of both sites. A Sun Tracker is installed at each site and situated near ground level on a concrete base to automatically point the Pyrheliometer at the sun. The Pyrheliometer, fitted with rain shield, is connected to the side of the sun tracking device and measures direct normal irradiance. Stations are supplied with a rain gauge which uses a tipping bucket mechanism when it receives a small quantity of rainfall.

Ground and Soil temperature at the site is measured by using a thermometer. The thermometers are placed at 5, 10, 20 and 40cm in the ground to measure soil temperature at each site. A visibility sensor is also installed and measures the visibility and fog density at the site.

An Automatic Weather Station (AWS) interfaces all sensors and telecommunication devices of the meteorological stations.

A summary of the meteorological sensors installed in each of the sites within Manah and Adam are presented in (***Table 3-1***). For more information, please see References for links to datasheets for each of the installed equipment in the monitoring stations.

Sensor	Supplier	Model	Calibration Date
Anemometer	Vaisala	WAA151	24th October 2009
Automatic Weather Station	MicroStep - MIS	IMS AMS 111	not applicable/required
BAROCAP Digital Barometer	Vaisala	PTB330	Not Provided
DustTrak Dust Monitor	TSI Inc.	8533	Not Provided
HUMICAP Humidity and Temperature Probe	Vaisala	HMP155	22nd May 2010
Normal Incidence Pyrheliometer	KIPP & ZONEN	CHP1	23rd June 2010
Pyranometer	KIPP & ZONEN	CMP 21	07th July 2010
Rain Gauge	Vaisala	RG13	02nd June 2010
Sun Tracker	KIPP & ZONEN	Solys 2	not applicable/required
Thermometer	MicroStep - MIS	PT-100	05th May 2003
Visibility Sensor	Vaisala	PWD 10/20	12th May 2010
Wind Vane	Vaisala	WAV151	21st October 2010
FALCOM GSM Receiver	FALCOM	TANGO864	not applicable/required

Table 3-1 Sensors and Calibration information for Manah and Adam meteorological stations

The solar sensors installed measure the solar radiation in Watt per square m (W/m^2). The pyranometer as seen in (***Figure 3-6***) measures the Global Horizontal Radiation (**GHI**), while the pyrheliometer measures the Direct Normal Radiation (**DNI**) as seen in (***Figure 3-7***).

Figure3-6: Kipp&ZonnenPyranometer installed at Adam

Figure 3-7: Sun Tracker with Pyrheliometer installed at Manah

3.3 CMP21 Pyranometer

The CMP series pyranometer (CMP 21 installed at the MET Stations) is a high quality radiometer designed for measuring short-wave irradiance on a plane surface (radiant flux, W/m_2) which results from the sum of direct solar radiation and the diffuse radiation incident from the hemisphere above the instrument.

The irradiance value (E) can be computed by dividing the output signal (U_{emf}) of the pyranometer by its sensitivity (S)

$$E_{DirectSolar} = U_{emf} / S$$

Where:

$E_{DirectSolar}$ = Solar radiation [W/m^2]
U_{emf} = Output of radiometer [µV]
S = Sensitivity of radiometer [$\mu V/W/m^2$]

Typical Values for Pyranometer:

- Fully Clouded: 50 – 120 W/m^2
- Sunny, partly clouded: 120 – 500 W/m^2
- Clear and Sunny: 500-1000 W/m^2

Specification of Pyranometer	*CMP 21*
ISO Classification	*Secondary Standard*
Response time (95%)	*5 s*
Zero offsets	
a) Thermal radiation (200 W/m²)	*< 7 W/m²*
b) Temperature Change (5 K/hr)	*< 2 W/m²*
Non-stability (change/year)	*<0.5 %*
Non-linearity (0 to 1000 W/m²)	*< 0.2 %*
Directional error (up to 80° with 1000 W/m² beam)	*< 10 W/m²*
Temperature dependence of sensitivity	*< 1% (-20 °C to +50 °C)*
Tilt error (at 1000 W/m²)	*< 0.2 %*
Other Specifications	
Sensitivity	*7 to 14 µV/ W/m²*
Impedance	*10 to 100 Ω*
Level accuracy	*0.1 °*
Operating temperature	*-40 °C to +80 °C*
Spectral Range (50 % points)	*310 to 2800 nm*
Typical signal output for atmospheric applications	*0 to 15 mV*
Maximum irradiance	*4000 W/m²*
Expected daily uncertainty	*< 2 %*

3.4 CHP1 Pyrheliometer

The pyrheliometer CHP 1 is designed to measure the irradiance which results from the radiant flux from a solid angle of 5 °.
The irradiance value (E↓Solar) can be simply calculated by dividing the output signal (Uemf) of the pyrheliometer by its sensitivity (Sensitivity). In order to calculate the direct solar irradiance the following formula must be applied:

$$E_{DirectSolar} = U_{emf} / S$$

Where:

$E_{DirectSolar}$ = *Solar radiation [W/m²]*
U_{emf} = *Output of radiometer [µV]*
S = Sensitivity of radiometer [µV/W/m²]

When a pyrheliometer is in operation, its performance is linked to a number of parameters, such as temperature, level of irradiance etc. Normally, the supplied sensitivity figure is used to calculate the irradiances. If the conditions differ significantly from calibration conditions, uncertainty in the calculated irradiances must be expected.
For a first class pyrheliometer the WMO expects maximum errors in the hourly radiation totals of 3 %. In the daily total an error of 2 % is expected, because some response variations cancel each other out if the

integration period is long. Kipp&Zonen expects maximum uncertainty of 2 % for hourly totals and 1% for daily totals for the CHP 1 pyrheliometer.

Typical Values for CHP 1:

- Sunny, partly clouded: 10 – 500 W/m2
- Clear and Sunny: 500-1000 W/m2

Specification of Pyrheliometer	
ISO CLASSIFICATION	***First Class***
Response Time (95%)	*5 s*
Zero offsets due to temperature change (5 K/hr)	*± 1W/m2*
Non-stability (change/year)	*± 0.5 %*
Non-linearity (0 to1000 W/m2)	*± 0.2 %*
Temperature dependence of sensitivity	*± 0.5 % (-20 to +50°C)*
Sensitivity	*7 to 14 µV/W/m2*
Impediance	*10 to 100 Ω*
Operating Temperature	*-40 to +80°C*
Spectral Range (50% points)	*200 to 4000 nm*
Typical Signal output for atmospheric applications	*0 to 15 mV*
Maximum Irradiance	*4000 W/m2*
Expected Daily uncertainty	*± 1 %*
Full opening view angle	*5 °± 0.2°*
Slope angle	*1 °± 0.2°*
Required tracking accuracy	*± 0.5° from ideal*
Weights (excluding cable)	*0.9 kg*

4 Data Acquisition and Preliminary Interpretation:

Data measured from the monitoring station and presented on the website includes measurement of DHI, GHI, DNIon an hourly basis, starting from January 2011, including related parameters such as temperature, pressure and wind speed.The raw data is presented as collected at the time the measurement was taken. Quality control and quality assurance occur before and during data collection and include procedures such as the proper selection and regular maintenance and calibration.

An agreement was put in place to maintain the cleanliness of the sensors, but unfortunately was not carried out in a routine manner, which led to inconsistencies in the data collected from the monitoring stations.For this reason, some data points have been ignored when conducting the preliminary data assessment, excluding days that registered 0 W/m^2 (GHI or DNI) from the calculations. As such, when calculating the average DNI readings for the year 2011, each day that did not register anything in terms of DNI (W/m^2) throughout the day, even when it’s obvious that it should have picked up some readings, would get excluded from the monthly average calculations. A similar approach has been used for the GHI data review.

For example, it was found that after the preliminary data assessment, the average monthly DNI ($kWh/m^2/day$) for the month of February (2011) was equal to 2 $kWh/m^2/day$; this is because 22 out of 28days were excluded from the calculations due to the fact that the DNI readings for 22 days in that month returned a '0' value. Following tables list the number of days ignored in each site for each month.

Table 4-1 DNI - Table displaying days ignored in each month for averaging DNI

Month	Adam remarks	Manah remarks
Jan-11	3 days ignored	3 days ignored
Feb-11	22 days ignored	1day ignored
Mar-11	8 days ignored	no day ignored
Apr-11	no day ignored	1day ignored
May-11	no day ignored	5 days ignored
Jun-11	no day ignored	10 days ignored
Jul-11	2days ignored	no day ignored
Aug-11	1day ignored	no day ignored
Sep-11	1day ignored	no day ignored
Oct-11	1day ignored	no day ignored
Nov-11	11 days ignored	2 days ignored
Dec-11	no day ignored	no day ignored

Table 4-2 GHI - Table displaying days ignored in each month for averaging GHI

Month	Adam remarks	Manah remarks
Jan-11	one day ignored	2 days ignored
Feb-11	no day ignored	no day ignored
Mar-11	no day ignored	no day ignored
Apr-11	no day ignored	no day ignored
May-11	no day ignored	no day ignored
Jun-11	no day ignored	no day ignored
Jul-11	no day ignored	no day ignored
Aug-11	no day ignored	no day ignored
Sep-11	no day ignored	no day ignored
Oct-11	no day ignored	no day ignored
Nov-11	no day ignored	no day ignored
Dec-11	no day ignored	no day ignored

The following is a graph showing the results of the preliminary data assessment of the data acquired(DNI readings for both Adam and Manah):

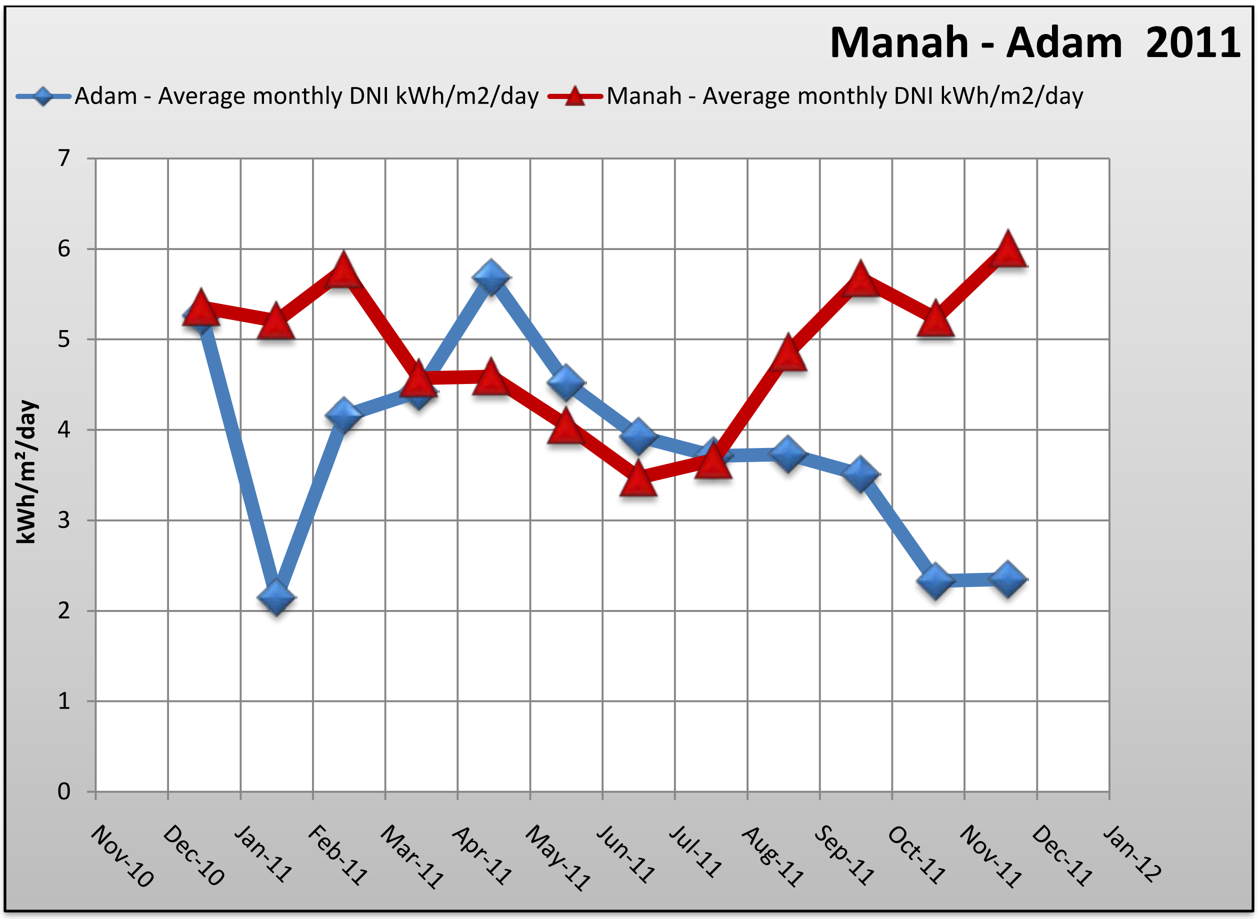

Figure 4-1 Graph displaying monthly average for DNI obtained from Manah and Adam meteorological stations.

The graph shows a comparison of DNI data measured at Adam and Manah. Initial review shows the measured DNI results are lower than would be predicted from the satellite data, and the inconsistency of data between the two sites indicates some problems of quality data capture, probably due to instrument fouling. Work to improve the quality of data capture continues for these remote sites, however there is also question of whether the data is actually showing lower solar insolence than predicted. The satellite data is an averaged data set of 10 years and is not a direct comparator to one year's worth of data,however it does raise a question on the quality of the satellite data.

These questions do prompt publication of the data to receive comment from a wider audience.

5 References

Kipp and Zonen (2008) *CHP1 Pyrheliometer Instruction Manual.* Manual version: 1007

Kipp and Zonen (2008) *CMP CMA series PyranometersAlbedometers V1 Manual.* Manual version: 1007 [1]

WorleyParsons (2011) *Oman Solar Power Project, Solar Sensor Maintenance and Data Quality Guidelines*

WorleyParsons(2010) Implementation *of Large Scale Solar Project in Oman, Solar Power Project*, Site Selection Report.Revision 3

Please see the following links for more information on each of the installed equipment at the monitoring stations (1):

- Falcom TANGO864 modem:
  http://www.falcom.de/fileadmin/downloads/documentation/TANGO/tango864_flyer_v1.0.2.pdf

- Kipp&ZonenPyranometer CMP 21
  http://www.kippzonen.com/?download/7071/CMP+Pyranometers+-+Brochure+(CMP+3,+CMP+6,+CMP+11,+CMP+21+and+CMP+22)+-+A4+format.aspx

- Kipp&Zonen Normal Incidence Pyrheliometer CHP 1
  http://www.kippzonen.com/?download/43102/CHP+1+Pyrheliometer+-+Brochure.aspx

- Kipp&ZonenSolys 2 Sun Trackers
  http://www.kippzonen.com/?download/551/Sun+Trackers+-+Brochure+(2AP+and+SOLYS+2).aspx

- MicroStep MIS Automatic Weather Station IMS AMS 111
  http://www.microstep-mis.com/src/products/meteorology/automatic/ams111/AMS111_II_en_REVB.pdf

- MicroStep MIS Thermometer PT100
  http://www.microstep-mis.com/src/products/sensors_and_accessories/sensors/thermometer_pt100/PT_100_thermometer_mail.pdf

[1] Consent was attained from each of the manufacturers to publish links to their corresponding products.

- TSI Inc. DustTrak Dust Monitor Model no. 8533
http://www.tsi.com/uploadedFiles/Product_Information/Literature/Spec_Sheets/DustTrak-DRX-6001981_USA-web.pdf

- Vaisala BAROCAP® Digital Barometer PTB 330
http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/PTB330-Datasheet-B210708EN-C-LOW-v2.pdf

- Vaisala Humidity and Temperature Probe HMP 155
http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/HMP155-Datasheet-B210752EN-D-LOW-v4.pdf

- Vaisala Rain Gauge RG13
http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/RG13-RG13H-datasheet-B010195EN-D-low.pdf

- Vaisala Wind Set WA15
http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/WA15-Datasheet-B210382EN-B-LoRes.pdf

- Vaisala Visibility Sensor PWD10/20
http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/PWD20W-Datasheet-B210879EN-A-LoRes.pdf