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Energy Procedia 57 (2014) 1266 – 1274

Energy Procedia

2013 ISES Solar World Congress

Solar Energy Resource Assessment of the Geba Catchment, Northern Ethiopia

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Abstract

The global shift towards renewable energy is manifested in developing countries such as Ethiopia primarily because of continuous economic growth in the last two decades and secondly due to the vast untapped potential resources. In addition to other factors, the lack of accurate data of the resources has, however, hampered the development of solar energy technologies. The aim of this paper is to investigate the resource estimation by undertaking direct measurements at selected sites in the Northern part of Ethiopia.
This paper presents an assessment of the solar energy resource based on the primary data collected between January 2011 and December 2012. The daily and monthly average global solar radiation is analyzed based on the 10 minute interval measurement retrieved from the data loggers.
From the analysis it is seen that the measured values give a better accuracy and distribution of the global solar radiation than earlier Fig.s that were based on satellite images and model calculations. Furthermore, these results can be used to determine the solar resource potential of Northern Ethiopia for further energy development.

Selection and/or peer-review under responsibility of ISES.

Keywords: solar radiation, assessment, resource potential

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1876-6102
Selection and/or peer-review under responsibility of ISES.
doi:10.1016/j.egypro.2014.10.116

1. Introduction

The backbone of Ethiopia's energy supply remains to be hydroelectric power supplying a staggering 90% of the total electricity while the newly emerging wind energy comprises 3.7% with further wind parks under commissioning. With only 6.1% of electricity derived from fossil (diesel) generators [1], Ethiopia's electric energy source can be dubbed a clean one. Nonetheless, despite the remarkable improvements, more than half of the population is not connected to the grid and has little or no access to electricity [2]. This segment of energy demand is met by traditional means of biomass energy where by it contributes to the degradation of the environment through deforestation.

The global shift towards renewable energy is gaining momentum as the technology to harness those resources further matures. Recent researches in the areas of solar technology continue to produce promising innovative technologies that not only could bring the costs down but also do increase system efficiency [3]. These factors certainly boost the initiatives by which developing countries like Ethiopia could benefit by utilizing their untapped renewable energy resources, albeit indirectly. This is a good news for a country whose economy has experienced a strong and broad based growth over the past decade, averaging 10.6% per year in 2004/05 - 2011/12 compared to the Sub-Sahara Africa (SSA) that stood at an average of 5.2% as indicated in the Fig. 1. [4].

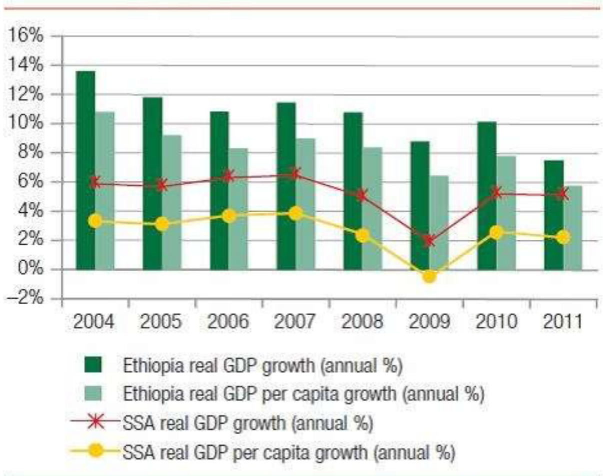

Fig. 1 Ethiopia GDP Growth Rates, 2004 to 2011 [4]

In addition to its double digit economic growth, Ethiopia is the second most populous country in the SSA region (estimated 84.73 million in 2011) with an annual growth of 2.2%. These factors add up in looking for alternative ways to supply the ever increasing of energy demand estimated to be growing at 25% annually for the last five years [5]. It is thus significantly relevant to seek alternative means of satisfying the energy supply of the rural community that is distributed across a wider range of area in a country known for its rugged plateaus and mountains. Even with the Ethiopian Electric and Power Corporation's (EEPCo) continued effort to more than double the generation capacity, addressing the energy demand of the rural community will continue to be a challenge for which there should be an alternative other than the grid system. Further issues that are related to the supply and demand of energy in the country have been discussed in other works [6], [7].

Although the government of Ethiopia (GoE) has yet to ratify an updated energy policy, various developers are showing their interest to invest in the energy sector. To cater the demands in this sector, the Ministry of Water and Energy (MoW&E) has prepared a national master plan on the wind and solar energy resources[8]. The MoW&E in its recent assessment report of solar and wind resources has indicated significant improvements to the previous estimates from satellite data including that of the Solar and Wind Resource Analysis (SWERA) conducted and was jointly sponsored by Global Environment Facility (GEF) and United Nations Environment Programme (UNEP) to about 1,350GW potential, up by about 30% [9].

However, there is limited study of solar energy resource assessment in Ethiopia that is based on a consolidated in-situ measurement of the wind and solar resources. Meteorological stations in the country lack radiation data measurement equipment and as a result radiation data was only available for the capital city, Addis Ababa [6]. Most of the studies were based on meteorological data of specific locations estimating total daily or monthly solar irradiance with the help of different solar radiation models. Mekonnen [10] has used Simple Model of Atmospheric Radiative Transfer of Sunshine (SMARTS) that predicts solar irradiance high spectral resolution, and under variable atmospheric conditions and Vapour Pressure Radiation Model (VP-RAD) which uses average relative humidity. Drake and Mulugetta [11] on the other hand, have developed a localized radiation-sunshine regression equation based on the data from seven meteorological stations. Schillings, Meyer and Treb also performed high resolution solar radiation assessment based on data of the geostationary satellite Meteosat [12].

It is therefore the main objective of this paper to contribute towards establishing an accurate and actual ground-level data of the renewable energy resources. The scope is, however, limited to sites in the Northern part of Ethiopia where four sites were selected and studied for their wind and solar energy potential. Hence, the results will be useful to understand the long-term spatial and temporal distributions of available the solar resources which is fundamental to determining the potential and feasibility of any solar energy application. Information derived from historical solar resource data can be used to make energy policy decisions, select optimum energy conversion technologies, design systems for specific locations, and operate and maintain installed solar energy conversion systems [13].

1.1. Geographical locations of study area

Ethiopia is geographically located between 33° and 48° East longitudes and between 3° and 15° North which is within the solar belt. This study further investigates the resource estimation by undertaking a direct measurement of the global horizontal irradiation (GHI) in selected sites on Northern part of the country. These sites are located in the area called the Geba catchment in Tigray Region, Northern Ethiopia. The catchment covers an area of 5133 sq. km with an elevation ranging from 955 m to 3295 m with a mean elevation of 2164 m above sea level [14]. The catchment's geographical coordinates are 38°38' to 39°48' E (longitude) and 13°18' to14°15 N (latitude) [15]. The raining season of this catchment is from end of July to beginning of September the remaining of the year with clear sky. In the region more than 80% of the population is engaged in agricultural sector. Fig. 2 shows the base map of Geba catchment. Even though there is no study to date about the energy utilization of this catchment, it is believed that the 80% of population, dependent on agriculture, has little access to modern energy.

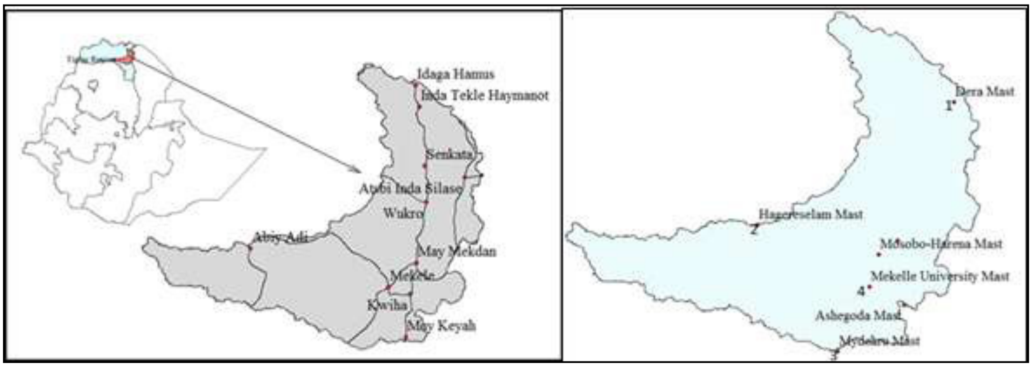

Fig. 2 Base map of Geba Catchment (a) situation map [15]; (b) measurement sites

The measurements were taken at four selected sites of the Geba catchment using pyranometers mounted on wind masts at a height of 2m above the ground. This article assesses the solar energy resource based on data collected for two years between Jan 1, 2011 to Dec 31, 2012. The daily and monthly average global solar radiation is analyzed from the 10 minute interval measurement retrieved from the data loggers. The four measurement sites are located far away from industrial towns and are all considered to be pollution free. With limited budget for instrumentation, the selection of sites had to consider numerous factors. After identifying potential sites with good solar resource estimates from the 3TIER, extensive site visits were undertaken to make on ground assessment for deploying the instrumentation. Eventually, four sites were selected that were considered as representative of the geographic and meteorological variations as possible while following recommendations and practices of the National Renewable Energy Laboratory (NREL) for measurement sites [13].

Table 1 Name of the measurement sites, location and altitude and duration of measurement

Site No	Site Name	Location		Altitude (m)
		Latitude	Longitude	
1	Dera	13°59.377'N	39°43.849'E	2870
2	Hagereselam	13°39.623'N	39°11.530'E	2632
3	Mayderhu	13°17.670'N	39°23.885'E	2512
4	Mekelle University (MU) Campus	13°28.694'N	39°29.244'E	2208

2. Materials and Methods

2.1. Materials

The instruments were mounted on wind masts that also had anemometers, wind vanes and temperature sensors in addition to data loggers powered by alkaline battery. The pyranometers used are of type Si-photodiode pyranometers DS6450 of ®Davis Instruments Corp, USA. The accuracy of the instrument is ±5% of full scale and its sensitivity is 1 W/m^2, it has operating temperature of -40° to +65°C and range of measurement from 0-1800 W/m^2. These sensors have been a relatively low-cost alternative for irradiance measurements and nowadays are widely used. They are used to measure global radiation, the sum at the point of measurement of both the direct and diffuse components of solar irradiance. The readings were logged into a data logger of type ®EKO21 N Data logger. Frequent site visits were conducted periodically to perform inspections for the overall care and maintenance.

2.2. Methods

Measured data logged every ten minutes including the minimum, average and maximum during the interval in the data logger is stored in a memory card which is retrieved periodically and backed up to a laptop. The data exported in text format were further processed using statistical tools and spreadsheet. The collected data from each measurement site was subjected to validation and filtering. Furthermore, daily and monthly average global solar radiation is calculated and compared for each measurement site to get the temporal as well as spatial distribution of the global solar radiation in the catchment. Measurements have been conducted since June 2010 and the analysis covers the time between June 2011 till May 2012. The average daily solar radiation for each month is then plotted as shown in subsequent figures.

3. Results and Discussion

The daily average solar energy is obtained from the ten minutes average data recorded from the pyranometers. The solar radiation in W/m^2 in each ten minute interval for each day is added and converted in to $kWh/m^2/day$. The daily average solar radiation of the four sites is discussed in subsequent sections. It is worth to note that Ethiopia lies in the tropical zone laying just above the Equator and below the Tropic of Cancer having four climatic seasons where the summer months of June, July and August are characterized by heavy rain falls and clouds while in contrast, in the winter dry season that falls in the months between December, January and February is known for its clear sky and hot temperatures.

3.1. Spatial Distribution

Apart from the temporal variation, it is quite important to investigate the spatial distribution of the global solar radiation across the region. Previous works did lack that accuracy through employing approximate models and coarse satellite resolution resulting in poor estimates.

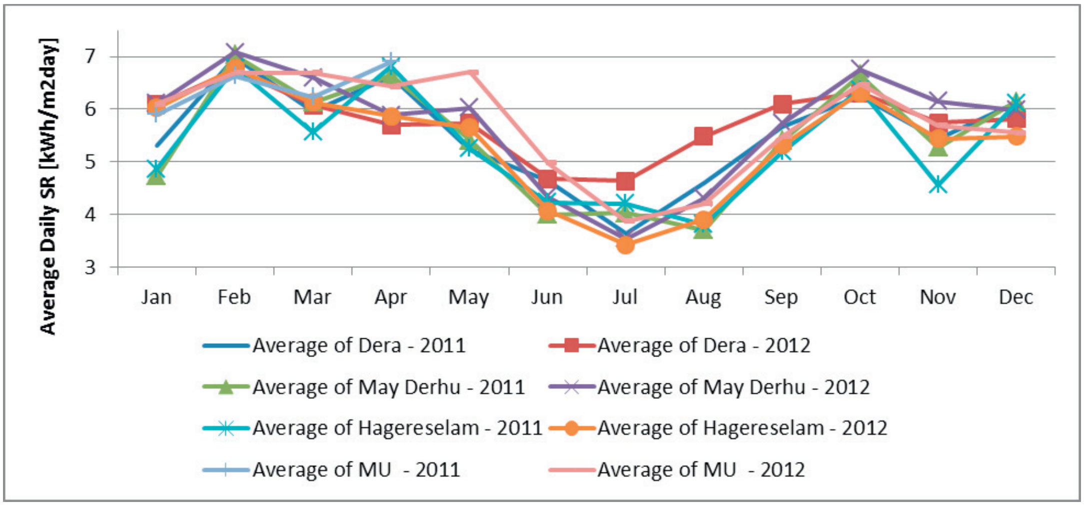

Fig. 3 Solar Radiation Measurements of 4 sites for years 2011-1012

It can be seen from Fig. 3 that the measurements for the sites of Hagereselam and May Derhu exhibit a relatively similar trends than the remaining two. Generally higher average measurements are observed during the dry season with maximum values (>6.5kWh/m^2/day) for the month of February for all the sites. During the rainy season and more specifically in the month of July, the solar radiation measured is the lowest for all sites, as expected. MU campus has relatively higher radiation during the dry season while Dera site's measurements are on the upper end during the summer (rainy) season with a measurement of 4.634kWh/m^2/day. Overall, although the average daily values are very close, their variation across the sites is not quite predictable in every month. This a rather important point when considering utilization of the resource for concentrated solar power (CSP) and Photovoltaic (PV) application.

3.2. Temporal variation

Although there is only a two years data of the catchment, the variation of the solar radiation with respect to time for each site gives an insight about the trend of solar radiation distribution in addition to the spatial distribution among the various sites.

3.2.1. Dera Site

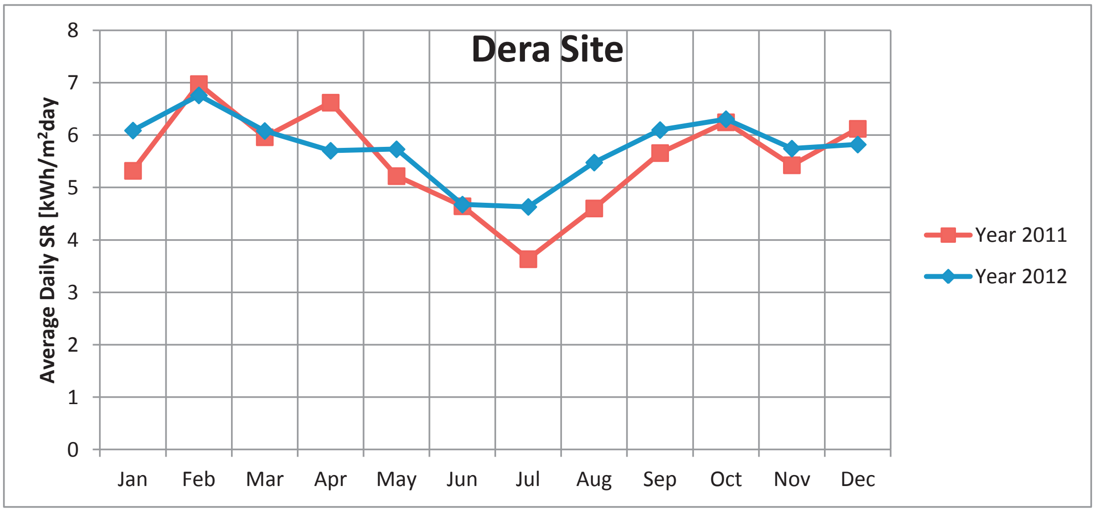

Fig. 4 Solar Radiation Measurements for Dera Site

Dera site located at an elevation of 2870m above sea level is considered to lay in the *Dega* (cool) region of the climatic zone of Ethiopia. Yet the measurement results indicate that it is still endowed with a considerable solar energy resource scoring as high as 7 kWh/m^2-day daily average solar radiation. Except for the months of June and July, which are two of the three months of the rainy season, all the daily average values of the remaining months exceed 5 kWh/m^2-day.

During 2011, the site recorded a minimum temperature of 1.6°C and a maximum temperature of 27.2°C. In the meantime, the incident global solar radiation was maximum on March 11 shortly before noon at 11h51 local time with 1202 W/m^2 while the average yearly daily solar radiation is 230.1 W/m^2 (including 24Hr data).

The corresponding values for the year 2012 have a minimum temperature of 2.45°C and a maximum temperature record 24.96°C. Measurements of incident global solar radiation indicate that the maximum value over the year occurred on March 4 in the afternoon at 12h31 with a value of 1159 W/m^2. The overall average yearly solar radiation is found to be 239.83 W/m^2.

Variations are also observed in average values for similar months in both years. Higher values of solar radiation increments observed for months of July while April sees the highest decrease. It is worth to note that while the overall trend seem similar, increments are observed for lower radiation values while higher values saw no significant increments. Although it is too early to conclude on the trends, however, overall average values of year 2012 are observed to be higher than that of the year 2011 for this specific site.

3.2.2. Hagereselam Site

The daily average measurements of 2012 are higher than the corresponding values of year 2012 for most of the months except for the months of April and July. July 2012 also was the month with the least daily average radiation of less than 4 kWh/m^2/day. The site's maximum temperature occurred in April 15, 2012 in the afternoon reaching a value of 31.79°C while the minimum was in February 10, 2012 early morning recording 6.87°C. Whereas the readings of average daily radiation throughout the year was found to be 223.82 W/m^2 with the single highest incident radiation measuring 1137 W/m2 recorded in December 9 afternoon.

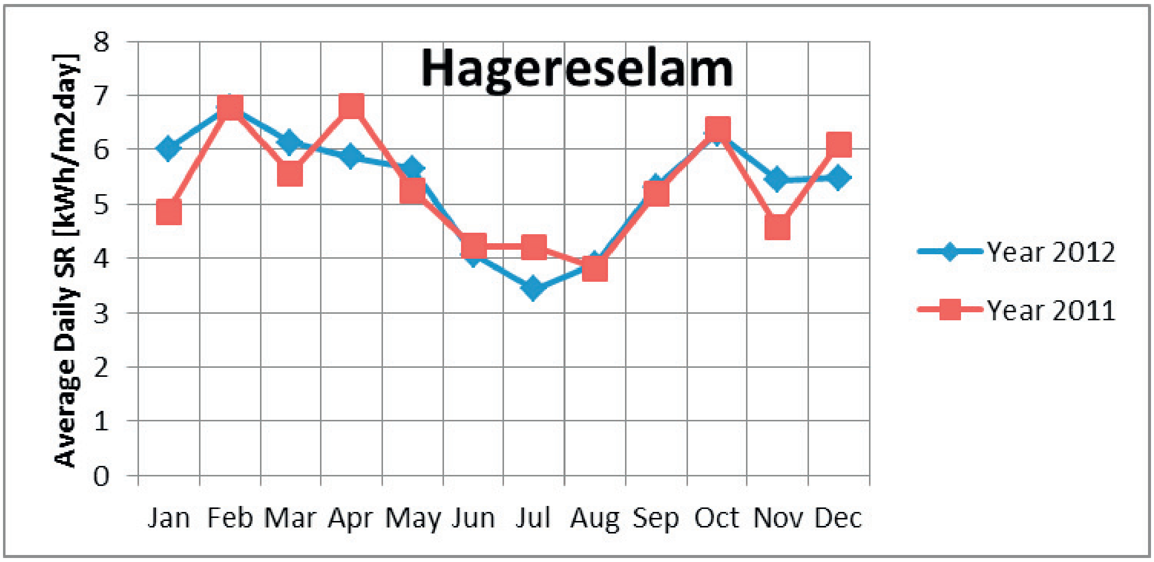

Fig. 5 Solar Radiation Measurements for Hagereselam Site

3.2.3. May Derhu Site

Measurement values at May Derhu site for both the years exhibit a very close resemblance. With the exception of January and November, the radiation values seem to have less temporal variation. Accompanying temperature measurements indicate that the site had a maximum reading of 32.44°C during April while the minimum was 6.03°C in late January (In 01/25/2012 at 7:49). The average daily global radiation was found to be 237.67 W/m^2 while the maximum incident radiation was 1194 W/m^2 in the month of September (in 17/09/2012 at 13:17). This site also has low radiation measurements during the months of the rainy season between June and August with average reading of less than 4 kWh/m^2/day.

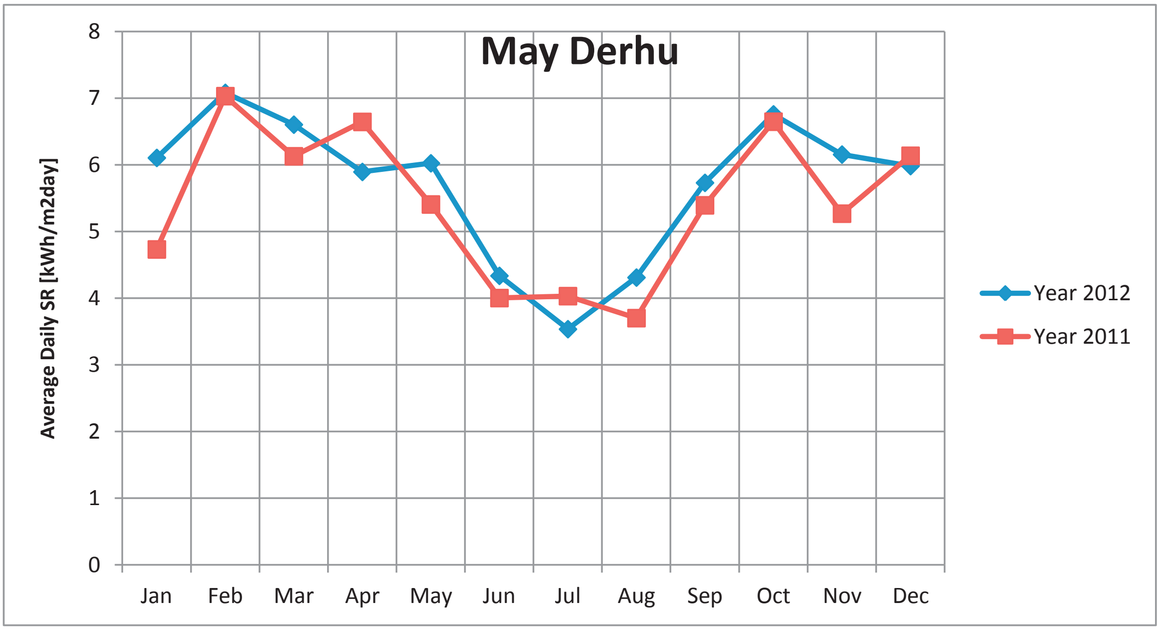

Fig. 6 Solar Radiation Measurements for May Derhu Site

3.2.4. MU Main Campus

The measurements for the MU campus site includes 4 months of recording from 2011 and full data for 2012. Due to meintenance needs of the data logger in this site, no measurements were taken during the period between May to

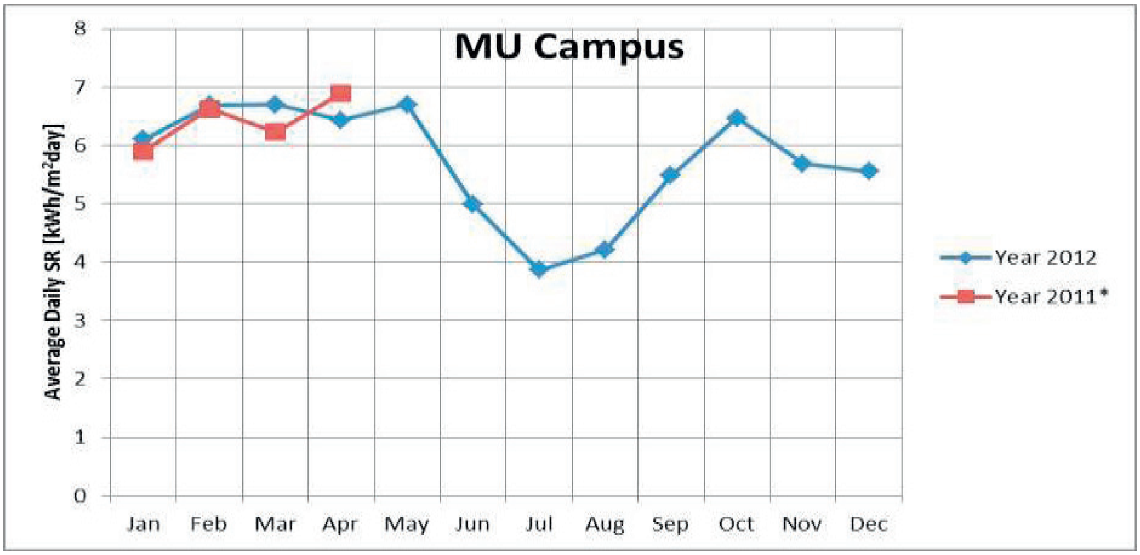

Fig. 7 Solar Radiation Measurements for Main campus Site

December 2011. However, after replacing the data logger, recordings of measurements continued as of January 2012.

With the exception of the months of July and August, the average daily solar radiation is observed to be greater than 5kWh/m^2/day. In fact, this site exihibits measurements greater than 6 kWh/m^2/day for half of the year in the months between October and May. As far as the yearly average solar radiation is considered the average value is found to be 236 W/m^2 while the single maximum incidence of solar radiation was 1209 W/m^2 recorded on the May 5, 2012 at 13h13 local time.

This site is the nearest one to Mekelle whose solar radiation estimates has been one of the few locations previously investigated. In its final report the SWERA [9] , [16] has estimated Mekelle's Average Daily Global Radiation on Horizontal Surface to be 2.27 kWh/m^2/day which is considerably lower than the 2012 yearly average of 5.7412 kWh/m^2/day. Yet, NASA's estimates are found to be the closest with a value of 5.86 kWh/m^2/day while results of CESEN estimates [8] , [16] indicated higher etimates of 6.59 kWh/m^2/day.

4. Conclusion

The measurements indicate and justify that the global horizontal radiation of the sites is far greater than the previous estimates of SWERA. The MoW&E in its recent national master plan report correctly indicates that the Northern part of the country receive higher radiation due to the movement of high-radiation zone northwards. However, the conclusion of low solar radiation over the country during the dry season between October to January is not corroborated by results of the measurements in all four sites. This indicates that there is a strong need for previous estimates mostly based on models and geostationary satellites reliability to validate their estimates using long term and in-situ measurements. Based on the two years measurements, the results indicate that Geba Catchment is endowed with a considerable amount of horizontal solar radiation with an average of 5.59 kWh/m^2/day. This considerable potential could a good alternative source of energy for the rural community. The results can also contribute to studies and developments that are aimed to develop large-scale Photo-voltaic and CSP systems. In conclusion, the measured values give a better accuracy and distribution of the global solar radiation than earlier Fig.s that were based on satellite images and model calculations.

Acknowledgements

The authors would like acknowledge The authors acknowledge the financial support of the Flemish Interuniversity Council (VLIR) under the framework of 'VLIR & Mekelle University Inter University Partnership Programme, 2003–2013; subproject Farm Technology', the National Agricultural Research Fund (NARF) of Ethiopian Institute of Agricultural Research (EIAR), the Norwegian Programme for Development, Research and Education (NUFU) and Norad's Master Programme for Energy and Petroleum (EnPe).

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