Detailed information on irradiance characteristics in Central Africa (Rwanda) from a dedicated network of ground stations for characterizing statistics of the irradiance field and validation of satellite derived data

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Abstract

In Rwanda as in most of the countries in central Africa in-situ empirical data on solar irradiance are sparse. This presents an obstacle for an increased application of solar energy to the coverage of the (increasing) energy needs of the country. These needs are given by both, the wish to increase the share of PV to bulk electricity and the application of PV for off-grid rural electrification. Required for a proper planning of both on- and off-grid applications are information beyond the knowledge of annual or monthly irradiance sums. For the layout of the off-grid systems the respective knowledge of the temporal variability is essential for e.g. the sizing of batteries. For on-grid systems the time and space characteristics of the irradiance field effect the interaction of PV-power plants with the conventional generation park. In Rwanda a new dedicated network of meteorological stations, that are logging the irradiance with a 5min time resolution has been set up to close this gap. For a more comprehensive approach the data from this network can be used to calibrate the satellite derived irradiance data for the continuous coverage of this region. This paper gives a short view on the use of the data for these two fields of application.

Keywords: *irradiance data, irradiance statistics, satellite derived data, ground station network*

1. Introduction

To increase the knowledge of the agro- and energy-meteorological conditions, the government of the Central African country of Rwanda initiated the setup of a fleet of Basic meteorological stations. The map in fig.1 shows the distribution of these stations operated by the Rwanda Environment Management authority (REMA) [Meteo Rwanda, 2014]. In operation since mid of 2013 (stable data delivery since mid of 2014). The stations are equipped with - among others sensors for the registration of the horizontal irradiance. The data are logged with a time resolution of 5min.

Fig. 1: Map of the network of Automatic weather stations setup in in Rwanda (Meteo Rwanda, 2014).

doi:10.18086/eurosun.2016.09.15 Available at http://proceedings.ises.org

This set offers - beyond the countywide information on the general solar potential - on one hand, information on the detailed statistics of the irradiance field in time and space needed as input for the detailed assessment of the performance of both, on-grid and off-grid solar energy systems. In addition these data form a unique basis for the check of the quality of satellite derived irradiance data extracted for this region. In the present paper exemplary applications of this data set should show its usefulness for these two fields of applications.

2. Quality of Data set

As initial analysis, the quality of the ground data set was checked by its consistency to the outcome of a clear sky model. As can be seen in the example given in Fig. 2 , the measured data are well in accordance with a clear sky irradiance calculated (Kasten 1983) for a Linke turbidity of 3.

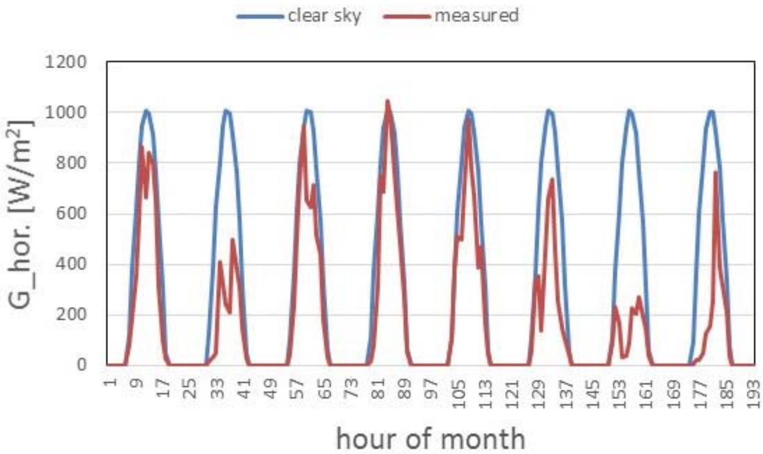

Fig. 2: Data quality from the weather stations in Rwanda, shown by consistency to modelled clear sky data (Linke turbidity:3) . Section of a time series of measured data from Location Gikomera, data from July 2014.

3. Analysis of irradiance statistics

As examples for more in depth analysis of the data sets, two examples are given here. The first concerns the investigation into short term statistics of the irradiance series that effect the performance of both on- and off-grid systems. For on-grid systems the magnitude and persistence of the irradiance fluctuations may challenge the stability of the grid. For off-grid systems the fluctuations cause stress to the storage devices.

3.1. Temporal statistics of short term data

From the 5min ground station data, the temporal variability of the irradiance re analysed. This is done here by extracting the daily standard deviation of the 5 min clear sky index (csi). Fig.3 gives for the location Kigali the daily standard deviation of the csi in dependence of the daily mean csi for the month of December 2013 and July 2014. It can be observed that there is no unique coupling of the daily standard deviation to the daily mean. This may call for a revisiting of both, schemes for the generation synthetic data sets based on daily averages (see e.g. Remund, Kunz 2004) and respective tools for the analytics system design (see e.g. Beyer, Langer 1996). In addition the autocorrelation coefficient of these csi series are inspected, indicating a general high correlation of the fluctuations on this time scale (Fig.4) which e.g. effects the cycling characteristics of the storages.

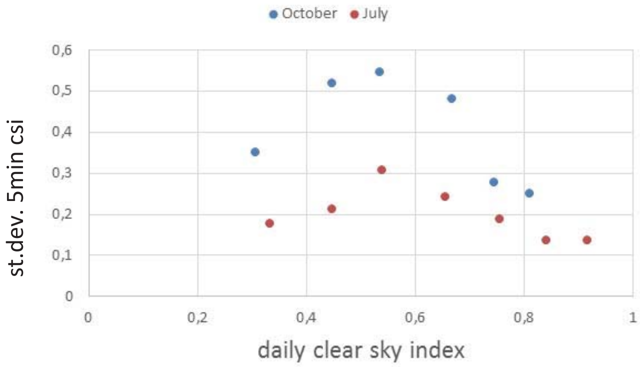

Fig. 3: Standard deviation of the 5 min clear sky indices csi, depending on the daily clear sky index for the location Kigale, month December 2013 and July 2014.

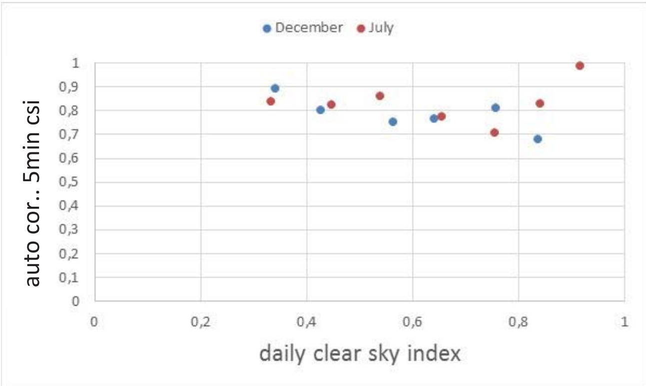

Fig. 4: Temporal correlation of 5 min. clear sky indices csi auto- correlation depending on daily clear sky index location Kigali, July and December - similar structure for both month indicate persistence of cloud situation for periods > 5min. Same data base data as Fig.3.

3.2. Spatial statistics of daily and hourly data

A second approach to investigate the details of the variability of the irradiance field with relevance for the large scale country wide integration of photovoltaics focusses on the large scale spatial correlation. Fig. 5a and 5b give a first qualitative view on the homogeneity of the irradiance field by showing the monthly time series of the daily clearness index for the months of July and December for 4 stations dispersed over the country (see map in fig.1).

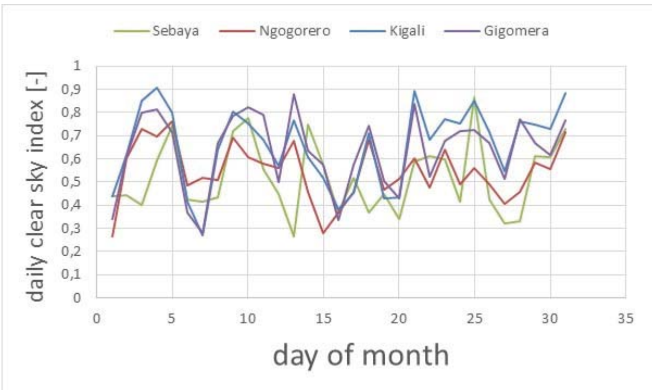

Fig. 5a:. : Monthly time series of the daily clear sky index at 4 stations (see map in fig.1). Given are the data for (July 14 5a)

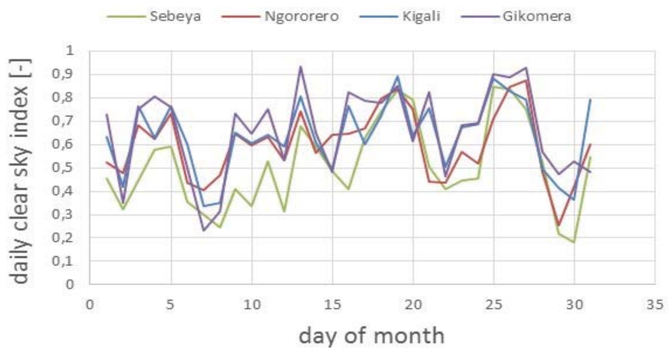

Fig. 5b: Same as fig.5 but for December 14 (5b)

It can be observed that days with an either completely clear of completely covered sky at all of the stations are rare. Thus it has to be expected, that a county wide PV-fleet will only rarely challenge the grid by delivering the rated power of all systems at one. The more fractures spatial structure of the irradiance field in Rwanda is also visible when looking at the cross-correlation of the hourly clearness index for pairs of stations.
Fig. 6 gives the correlation coefficients for pairs of stations in dependence of the interstation distances. Data for the month of July and December are analyzed. The strong decay with distance can be observed. For comparison, the characteristic of the decay of the interstation correlation (annual average) extracted from data sets for Germany (Wiemken et. al. 2001) are given. This indicates, that the fluctuations of the irradiance field in Rwanda show less spatial coherence that in northern Europe – leading to a more pronounced smoothing of the relative fluctuations of lumped power output from dispersed stations as compared to the fluctuations in single station data.

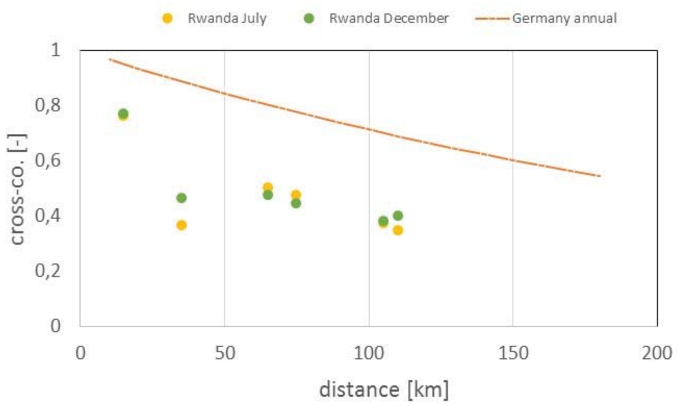

Fig. 6: Cross correlation of hourly clear sky indices compared to the correlation derived from a respective set from stations in Germany (Wiemken et al. 2001).

4. Application for the quality check of satellite derived data

A first qualitative assessment of the quality of satellite derived data for Rwanda had been done by Habyarimana, Beyer 2015. With the by then absence of time parallel ground and satellite data there was a comparison of the trace of monthly means for 5 years of satellite data (Geomodell 2013) with the 2014 ground data for the station of Kigali. It can be remarked that the satellite derived data are for most of the month clearly superior to that ground data.

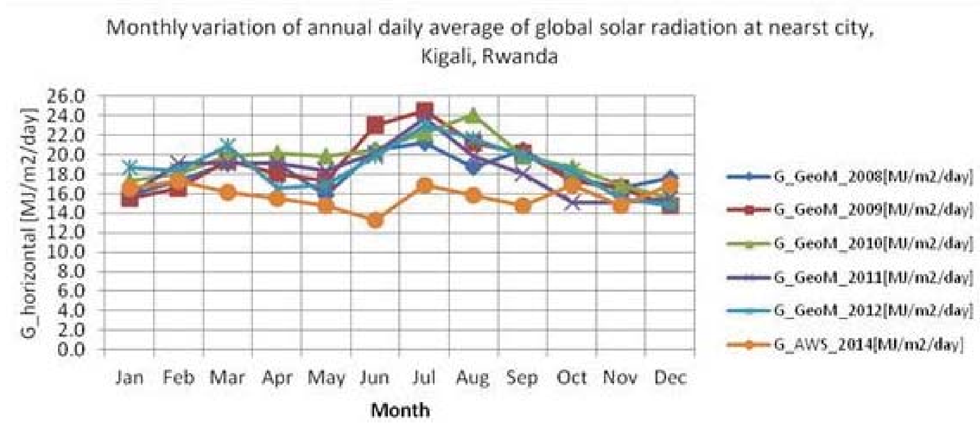

Fig. 7: Comparison of yearly traces of the monthly irradiance sum for Kigali from the 2014 ground data and 2008-2012 satellite derived data from Geomodel 2013.

This comparison is taken up here with the use of now available datasets with worldwide coverage offered by the SARAH service (Müller et al 2015). The following results refer to that source.
Fig.8 gives data for the station. Here the increase of the cumulative irradiance sum for the month of October is given. It can be observed that the satellite derived data give an overestimation of ~20%. A pattern that is qualitatively repeated for the month of November and December (fig. 9 and fig. 10).
For an explanation of this overestimation a first guess would call for an inspection of the assumptions taken for the estimation of the clear sky irradiance used in the calculation scheme for the satellite derived data. To get a qualitative impression of the influence of the assumptions on clear sky irradiance, it is assumed that a tuning of the clear sky irradiance may result in but a scaling of the modelled irradiance. Applying this assumption, one may test the use of a scaling to matching the final monthly irradiance sum.
The results of this procedure applied to the monthly sets are added in the figs.8-10.

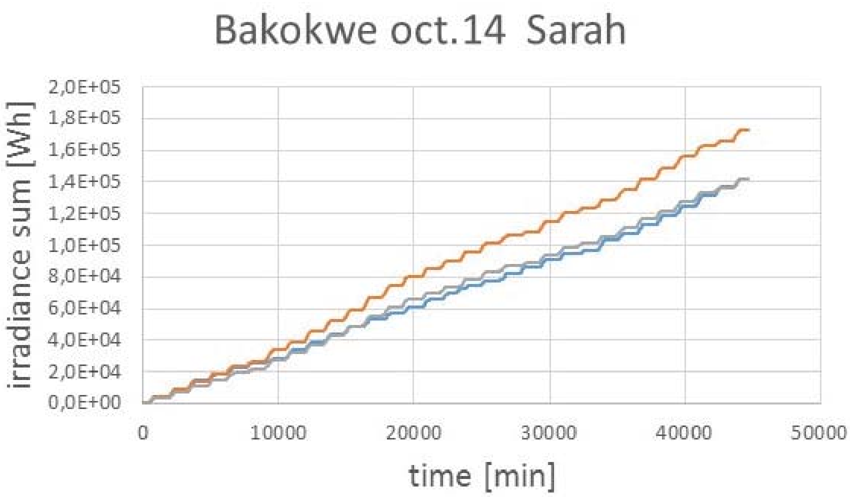

Fig. 8: Cumulative irradiance sum for the data from the station Bakokwe, month of October14 - Red line: satellite derived data, blue line: ground data, grey line: satellite derived data matched to meet the final monthly irradiance sum (see text).

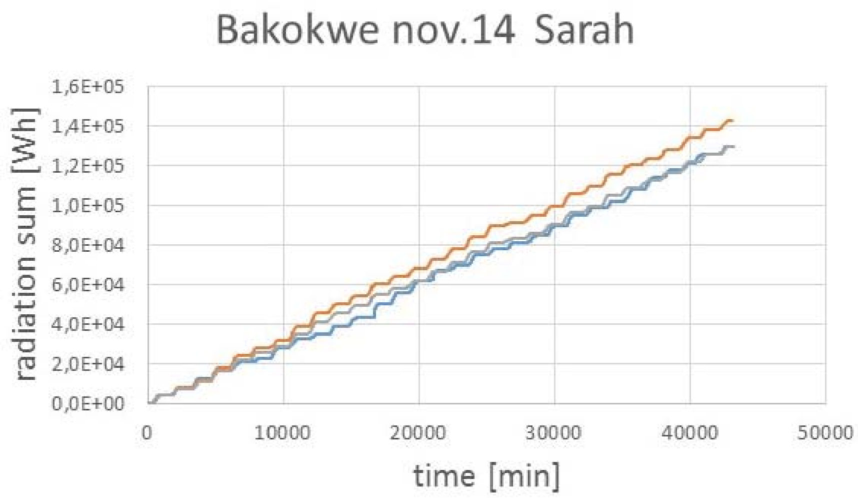

Fig. 9: Same as fig.8, but for the month of November 14.

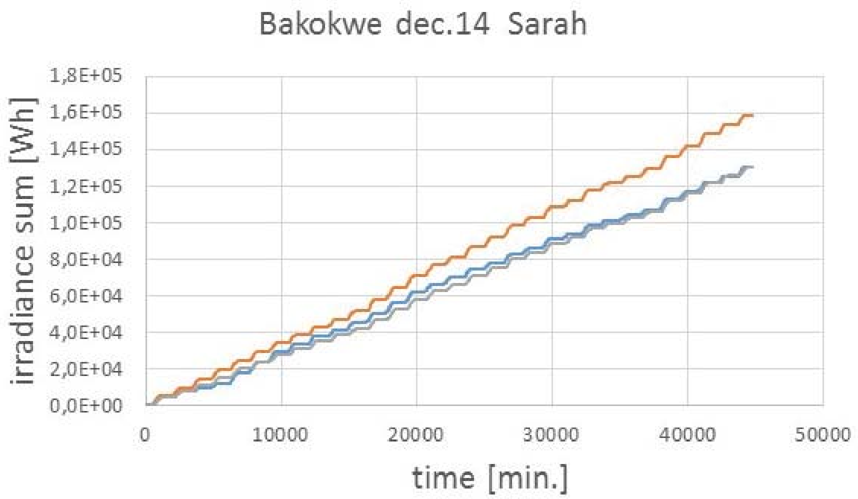

Fig. 10: Same as fig.8, but for the month of December 14.

In the figures 8-10 the grey lines present this adopted irradiance sums - a perfect match with the line for the ground data would indicate that errors are due to but a faulty scaling, i.e. incorrect assumptions on clear sky irradiances. As can be observed this is most likely the case for the December and October data. For November further inspection would be needed.

5. Conclusions

In view of the general lack of detailed irradiance data in central Africa, the opportunities offered by a network of meteorological stations in Rwanda logging highly time resolved respective data sets are obvious. This could be discussed for both, the application for the layout (e.g. sizing of storage) of small stand-alone PV systems and the assessment of large scale application of grid-connected PV-power stations with repercussion in the country wide power grid. An additional benefit of the set discussed is given by its applicability for the quality assessment of satellite derived information on irradiance. Here, a need for improved information on the local atmospheric turbidity could be identified.

6. Acknowledgement

Thanks are due to Meteo Rwanda for granting access to the ground data. The SARAH data are kindly supplied by Thomas Huld from JRC, Ispra, Italy.

7. References

Beyer, H.G. Habyarimana, F. 2015, Assessment of the quality of satellite derived irradiance data for Rwanda by comparison with data from a fleet of automated ground stations

Beyer, H.G., Langer, C., 1996, A method for the identification of configurations of pv/wlnd hybrid systems for the reliable supply of small loads, Solar Energy, 98, 381-391

GeoModel, 2013. http://geomodelsolar.eu/home as of 15.05.2014

Kasten, F., 1983, Parametrisierung der Globalstrahlung durch Bedeckungsgrad und Trübungsfaktor, Annalen der Meteorologie, Neue Folge 20

Meteo Rwanda, 2014. http://www.meteorwanda.gov.rw

Müller, R.; Pfeifroth, U.; Träger-Chatterjee, Ch; Cremer, R.; Trentmann, J.; Hollmann, R.. 2015: Surface Solar Radiation Data Set - Heliosat (SARAH) - Edition 1. Satellite Application Facility on Climate Monitoring. DOI:10.5676/EUM_SAF_CM/SARAH/V001. http://dx.doi.org/10.5676/EUM_SAF_CM/SARAH/V001

Remund, J., Kunz, S., 2004. METEONORM Version 5.1, http://www.meteonorm.com

Wiemken, E. et.al, 2001, Power characteristics of PV ensembles: experiences from the combined power production of 100 grid connected PV systems distributed over the area of Germany, Solar Energy, 70