CHALMERS

Distribution of
Wind and Solar Energy Resources in Tanzania and Mozambique

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Gothenburg, Sweden, 2011
Report No. 2011:5
ISSN No. 1404-8167

This report is produced within the STEEP-RES (Socio-Technical-Ecological Evaluation of Potential Renewable Energy Sources) research project, supported by the Swedish Futura Foundation. STEEP-RES was initiated in 2009 as a collaboration between Chalmers university of Technology in Sweden, the University of Dar es Salaam in Tanzania, and Universidade Eduardo Mondlane in Mozambique. The project aims to promote enhanced access to electricity in Tanzania and Mozambique through the utilization of locally available renewable energy sources.

OBJECTIVE AND BACKGROUND

This report gives an overview of the resource distribution of wind and solar energy sources in Mozambique and Tanzania. The objectives are (1) to display resource availability of wind and solar energy and (2) to evaluate resource estimations based on remote sensing techniques (NASA Surface meteorology and Solar Energy, SSE) by comparing with local time-series of ground measurement data. The results are discussed from the perspective of energy extraction by modern technologies.

The report is a descriptive synthesis of previously sampled and presented data carried out by researchers, professionals within national meteorology institutes, and by NASA (SSE). The SSE database is a satellite- and model based product, available on the web, in support of resource assessments of renewable energy sources, i.e. solar and wind energy.

The studied region comprises Tanzania and Mozambique, two countries which experience low electrification rates where only 2-3% of the rural population has access to electricity. In both countries economy is growing and governments are stable. Significant policy efforts are launched towards rural electrification and restructuring of the energy sectors aim for a higher influence of private actors and increased use of local energy sources. Moreover, the region are offered additional opportunities through the prognosis of an approaching demographic dividend where the working age part of the population will be larger than ever, as a result of decreased birth numbers (Bloom et al. 2007). The situation opens great possibilities for economic development where the access to modern energy may constitute a key factor (UNDP 2007).

Both countries cover vast areas and extensions of national electricity grids in order to reach remote towns and rural settlements are tremendously costly undertakings. In response, parallel electrification is carried out through decentralized grids and, at the micro-level, autonomous systems. It has been shown that diesel generators, which are often the power sources for the decentralized grids, carries major problems related to the costs and logistics of fuel (Ahlborg and Hammar 2011). Along with micro hydropower, solar photovoltaic and wind power are examples of renewable energy technologies which may provide locally generated electricity. Since recently the use of solar home systems have been growing in both countries, and in particular in Tanzania, while wind power is only represented by one singly turbine in Mozambique and few installations in Tanzania. The growing energy demand and the deficient power distribution in both countries are reflected in an increased interest for renewable sources among the actors in both countries' energy sectors, as was shown in an interview based study (under preparation). Knowledge of the resource distribution is a prerequisite for efficient promotion of these modern fuel-independent power sources.

METHODS

Details on measurement methods and analysis of data are kept short in this synthesis. Information on metadata quality is available in original sources (references).

Wind speed data

Site specific wind speed data (m/s at 10 m) has been compiled from Kainkwa & Uiso (1989), Kainkwa (1999), and Cuamba et al. (unpubl.[1]). These sources present monthly and annual mean values from long term data series of ground measurements. Low resolution wind speed estimations with global coverage has been obtained from the SSE database (NASA 2009) representing estimated average values based on reanalysis of meteorological and satellite data from 1983 to 2005.

Kainkwa & Uiso (1989) analyzed wind measurements from agro-meteorological stations throughout Tanzania and presented seasonal variations of available power and annual means of wind speed at 2 and 10 m height. The data was derived from sources with varying quality; ranging from 7 to 34 years of measurements at 12 a.m. and 6 p.m. From this source annual means of wind speed at 10 m were extracted for 26 locations.

Kainkwa (1999) presented wind speeds from central Tanzania where data has been collected at 9 a.m. and 3 p.m. during ten years (1971-1980). From this source, monthly averages were obtained from published chart for one site (Basuto, measured at 10 m height).

Cuamba et al. (unpubl.[1]) assessed the wind regimes in Mozambique by analyzing wind data measured (partly intermittently) by the National Institute of Meteorology from 1971 to 1990. From this source, monthly values of wind speed at 10 m height have been extracted for 6 locations.

The SSE estimation of wind speed is based on satellite and meteorological data (1983-2005) which have been reanalyzed by NASA to produce a global estimation of wind speed at 10 m height for terrein similar to airports. Since the estimation represents airport conditions the given wind speeds are expected to overrate the actual wind speed at 10 m from ground while represent the wind speed at about 10 m above vegetation (NASA 2009). Globally, SSE data has been validated through reference stations on ground, using a 10 year average, showing a 20-25% level of uncertainty (NASA 2009). The SSE estimations are provided with a geographical resolution of 1° and global coverage.

Insolation data

Site specific insolation data (global solar radiation, kWh/m^2) were extracted from Alfayo & Uiso (2002) and Cuamba et al. (unpubl[2]), which both present time series of ground measurements, and Nijegorodov et al. (2003) who presents simulated insolation data. Low resolution global coverage insolation data has been extracted from the SSE database (NASA 2009) based on reanalysis of meteorological and satellite data from 1983 to 2005.

Alfayo & Uiso (2002) presented insolation data from the Directorate of Meteorology and other meteorological stations, covering the time period 1965-1990. This work includes a modelling of solar radiation isobars throughout Tanzania. From this source, insolation (global solar radiation) monthly values were extracted for 4 locations in Tanzania.

Cuamba et al. (unpubl.[2]) compiled recorded sunshine hours from the period 1970-2000, derived from the National Institute of Meteorology, and recalculated the data to estimated global solar radiation; assessing the solar energy potential in Mozambique. From this source, insolation monthly values were extracted for 6 locations in Mozambique.

Nijegorodov et al. (2003) used data from various ground measurement stations to simulate the solar radiation distribution throughout Mozambique, using an algorithm developed by Nijegorodov (1999). Simulated annual means of global solar radiation for 21 locations in Mozambique was extracted from this source.

The SSE estimation of insolation is based on satellite derived electromagnetic energy incident on earth surface which has been reanalyzed together with meteorological data by NASA to produce a global estimation. The data includes the period 1983-2005. The SSE insolation data has further been validated through globally distributed ground reference stations, showing an adequate accuracy which is highest for equatorial regions (NASA 2009). As for wind speed, the SSE estimations of solar radiation are provided with a geographical resolution of 1° and global coverage.

Preparation of data

Acquired resource data were compiled and transferred into shape files in the ArcGIS software. Where annual mean value of wind speed and insolation was not shown in original source it was calculated from monthly values. Geographical positions were extracted from the original data source when available, and from Google™Earth when coordinates where not given in the original source (using the local name of sampling site). Hereby, the geographical positioning of some data points is only valid at a large geographic scale (kilometers). Data positions were further transferred into the projected coordinate system UTM 37s. Ground measurement data were displayed without further rearrangement. The satellite modeled data downloaded from NASA SSE website were interpolated from a grid of mean values with a spatial resolution of 1°. For interpolation the spline (regularized) function was judged to be the most accurate method. The method implies that the interpolation curve is allowed both to exceed and fall below actual mean values. Finally, geographically determined single data points were extracted from the interpolated SSE data raster to be compared with respective ground measurement data from the same position.

RESULTS

Wind speed

The ground measurements of wind speed at 10 m height show annual mean values between 1.8 m/s (Lyamungo) and 6.6 m/s (Sao-Hill and Mtwara) (Kainkwa & Uiso 1989), Figure 1. The variations in wind speed are high as some measurements are carried out at specifically windy locations; wind hotspots. The interpolated SSE estimations indicate somewhat lower annual mean wind speeds, ranging from 1.6 to 5.1 m/s. According to SSE data, only coastal Tanzania and north eastern Mozambique have annual averages of wind speed reaching 5 m/s. A larger caption of southern Tanzania and northern Mozambique, along with north western Tanzania and southernmost Mozambique show indications of wind speeds from 4 m/s. However, the ground measurements add several hot-spots of wind speed which are not reflected by the SSE data. In Tanzania 10 out of 26 ground measurement sites show annual wind speeds exceeding 5 m/s. In Mozambique only the Maputo station reports wind speeds above 5 m/s.

A comparison between ground measurements and SSE estimations shows that SSE data underestimates the annual average of wind speed with a mean bias of -0.42 m/s and a RMSE (root mean square error) of ±1.5 compared to ground measurements (n=28). In comparison, the global bias and RMSE (based on monthly means) for SSE estimations are -0.2 m/s ±1.3, for values at sites similar to airports (NASA 2009). This means that the SSE estimations on annual basis are less accurate in the analyzed region compared to global estimations. It is somewhat unexpected that SSE data underestimate wind speeds even though the SSE data are estimated for winds over flat open (airport) surfaces which are more wind prone than the vegetated natural landscape. However, several ground measurement sites are situated in particularly windy locations (mountainous areas) which may explain part of the difference. Another potential source of error is the interpolation process. The comparison show that the SSE data does not concur satisfactorily with ground measurements and consequently the use of SSE wind estimations should be restricted to overview approaches in this region.

Monthly wind speed data are of certain importance for decentralized electricity grids since seasons with low winds may imply long periods without electricity generation. Monthly wind speed data from ground measurement at 10 m were only found for one area in central Tanzania, Basuto (Kainkwa 1999), but for 6 locations in Mozambique (Cuamba et al. unpubl.[1]). The SSE interpolations (displayed for every second month in Figure 2) indicate high seasonal variations and annually continuous wind speeds above 4 m/s in northern and coastal Tanzania, and in southernmost coastal Mozambique. The general pattern is an increased wind speed in the southern hemisphere winter, from May to October.

As illustrated in Figure 2 the comparison between SSE and ground measurement monthly values reveal large spatial variations in wind speed with particular peaks in Sao-Hill, Basuto, and Tabora in central Tanzania.

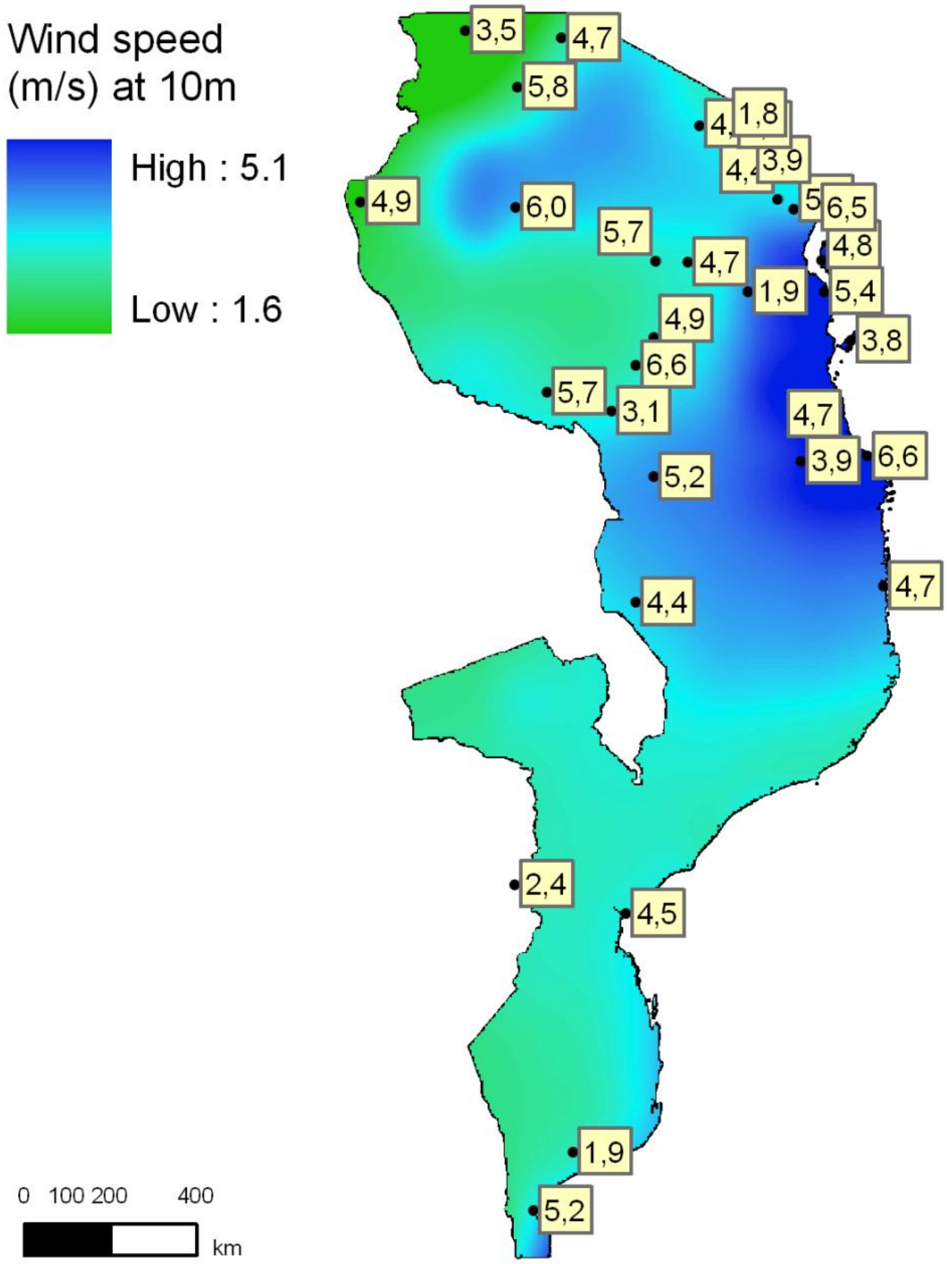

Figure 1. Annual averages of wind speed (m/s) in Tanzania and Mozambique. Labels show ground measurements and colour gradient represent interpolation of SSE data.

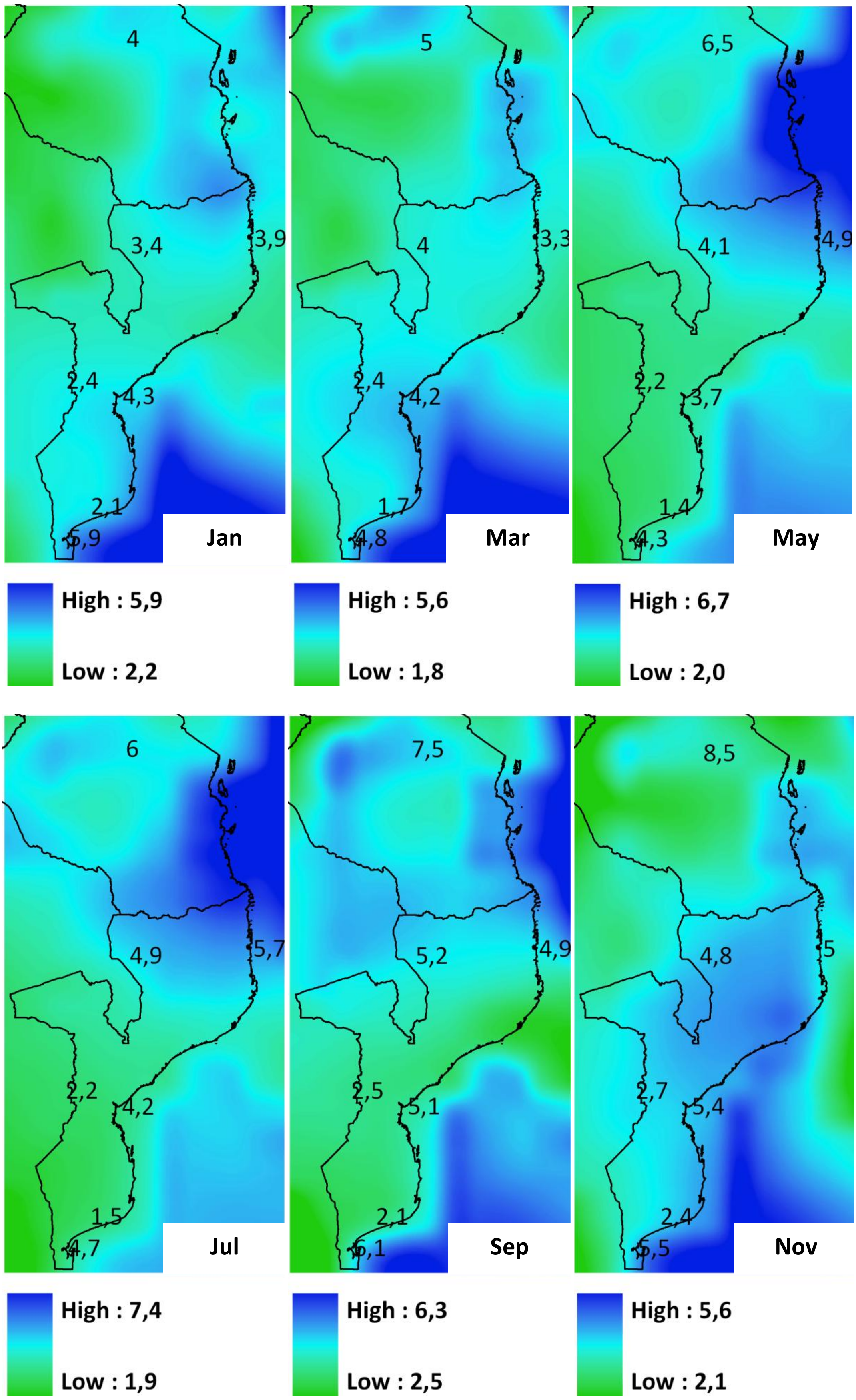

Figure 2. The interpolations illustrate monthly averages of wind speed (m/s) in Tanzania and Mozambique based on SSE data, with ground measurement data overlaid. The graphs indicated that northern and coastal Tanzania, and southernmost coastal Mozambique, have relatively continuous winds above 4 m/s.

Solar radiation

According to ground measurements the insolation varies from 4.5 kWh/(m^2 day) in Morogoro, Tanzania, and 6.0 kWh/(m^2 day) in Pemba, Mozambique (Alfayo & Uiso 2002; Cuamba et al. unpubl.[2]) (Figure 3). According to the interpolation of SSE data the insolation ranges from 4.9 to 6.3 kWh/(m^2 day). In both cases, the insolation corresponds to good solar energy potentials. In comparison, the insolation in the Sahara desert is approx. 6-7 kWh/(m^2 day) and the Mediterranean coast receive about 4.5 kWh/(m^2 day).

The accuracy of interpolated SSE data in comparison to ground measurements is relatively good, with a bias of -0.01 kWh/(m^2 day) and RMSE of ±0.55 (n=10) for annual average of insolation. With this accuracy, the SSE estimation may be a useful indicator of insolation in the region; however, good modelling works on solar radiation are also available for the region (Alfayo & Uiso 2002; Nijegorodov et al. 2003).

The SSE data and previous modelling indicate substantial differences in insolation within the region, with highest values in a broad stretch throughout central Tanzania (as shown by Alfayo & Uiso 2002). The SSE further indicate a higher insolation along the northern coast, however this pattern is not evidently in other assessments.

Monthly values are of particular importance for decentralized electricity grids or home solar systems since seasons with reduced insolation may imply long periods with low availability of electricity. The seasonal variations, as interpreted from SSE estimations in two-month intervals (Figure 4), indicate that central-western Tanzania gains substantially more insolation during May to October, while most other areas of the region, including Mozambique, receive the least insolation during this period (southern hemisphere winter).

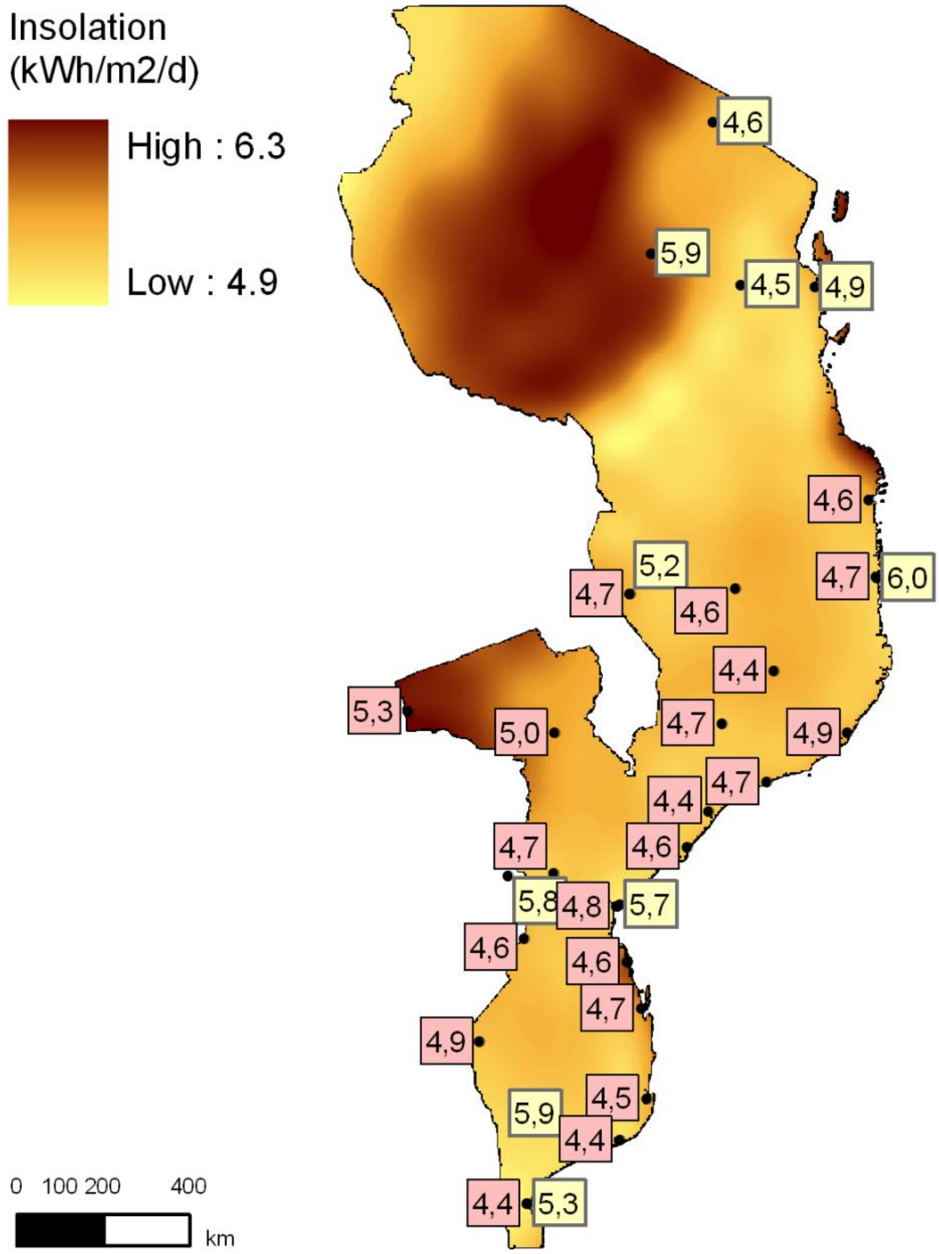

Figure 3. Annual averages of insolation kWh/(m^2 day) in Tanzania and Mozambique. Yellow labels represent ground measurements values and red labels show simulation-based values from Nijegorodov et al. (2003). Colour gradient represent interpolated values from SSE data.

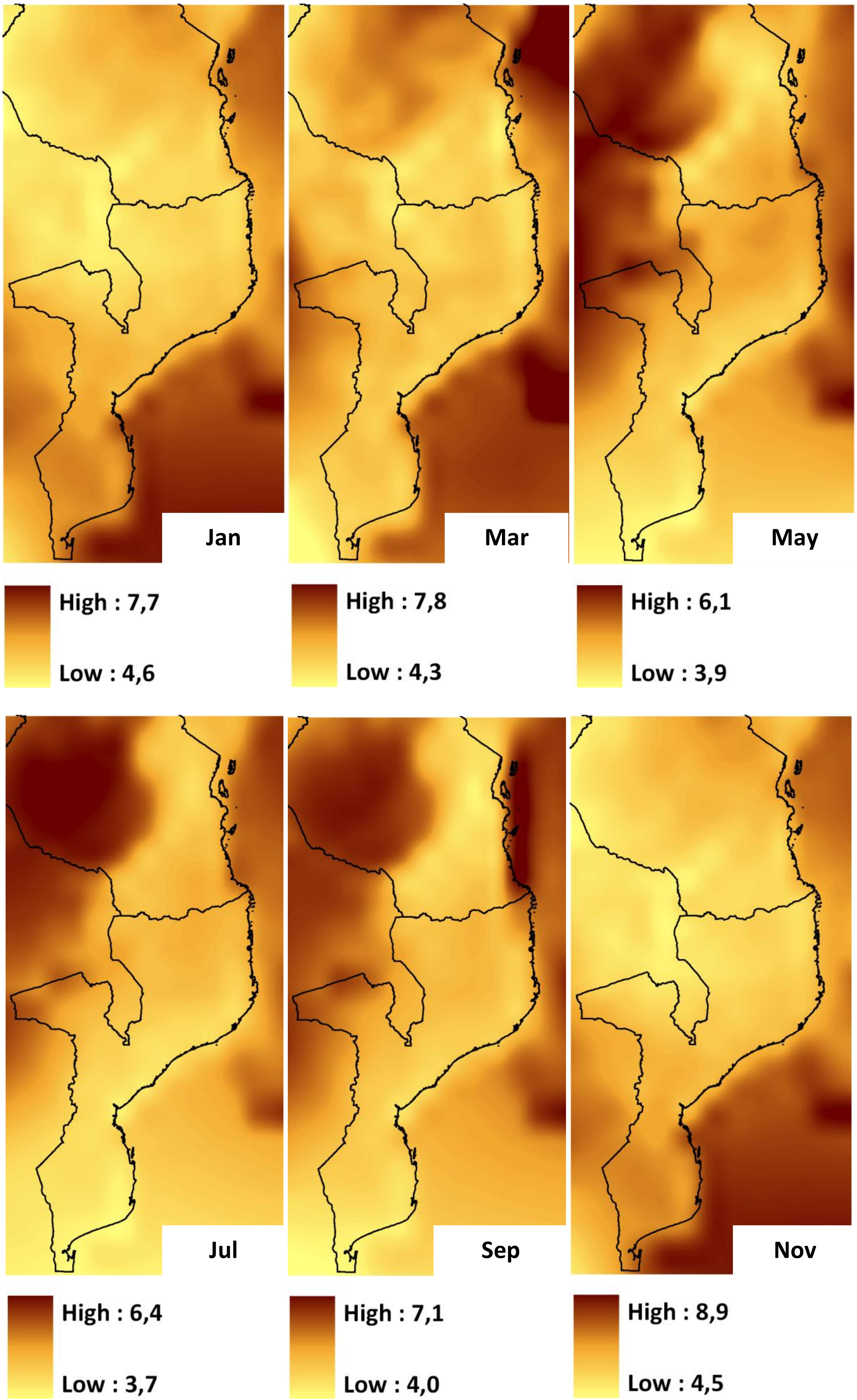

Figure 4. Monthly averages of insolation kWh/(m^2 day) in Tanzania and Mozambique derived from interpolation of SSE data. The result indicates persistent high insolation in western Tanzania but the whole region receives adequate insolation throughout the year. The lowest insolation occur during the southern hemisphere winter.

DISCUSSION AND CONCLUSIONS

Wind resources

The annual mean values of wind speed at 10 m height range from 1.8 to 6.6 m/s (ground measurements) within the region. Wind speeds from 5 m/s has been proposed as feasible for energy extraction (Kainkwa 1999; Cuamba et al. unpubl.1). However, small-scale converters adapted for lower wind speeds are now available and even wind speeds around 4 m/s may be found of interest for remote decentralized grids. Under such conditions small turbines can be valuable and a higher cost of energy may be acceptable as the alternative generally is fuel-dependent diesel generators. Furthermore, measurements and modelling refer to 10 m height and knowledge about wind speed at higher levels are less known.

Promising wind conditions are indicated for South-East Tanzania and North-East Mozambique, along with several hot-spots in the highlands of central Tanzania as has been shown by Kainkwa (1989). Within these areas it is likely to find sites suitable for large scale wind power.

The seasonal variations leave few suitable areas for stand-alone wind power in small grids (where continuity in generation throughout the year is vital). However, in particularly windy areas even sites with seasonal changes a combination of energy sources, such as micro hydro and wind, may complement each other well and open for hybrid systems, as was suggested by Kainkwa (1999). The seasonal variations derived from SSE data indicate that northern and coastal Tanzania, along with southern coastal Mozambique, have relatively continuous winds above 4 m/s (and higher wind speed during the southern hemisphere winter).

To be noted is that the SSE estimations provided by NASA are not fully correlated with ground measurements and should therefore only be used for overview purposes. The spatial variations over short distances are particularly high in the mountainous areas. Hence, further efforts of site-specific sampling are necessary in any areas of interest; such detailed measurements are currently carried out in Tanzania and a national wind Atlas is under preparation on commission of the Tanzanian Government.

In summary, good potential for wind energy extraction in Tanzania is indicated for coastal areas and for certain highland hot-spots. Most parts of Mozambique have relatively low wind speeds, with exception of the North-East (Cabo Delgado) and the southernmost coast (Maputo area) where significant wind speeds are indicated. Several wind power resource assessments have been carried out in the region but local variations are high and the potential of wind energy is not well known.

Solar resources

The annual means of global solar radiation (insolation) range from 4.5 to 6.0 kWh/(m^2 day) according to ground measurements, and reaches 6.3 kWh/(m^2 day) according to interpolation of SSE estimations. This reflects a good potential for solar energy conversion throughout the region. Small-scale use of solar photovoltaic technologies is expected to be adequate from approx. 4 kWh/(m^2 day) while larger installations such as solar thermal power plants require about 5 kWh/(m^2 day) (Alfayo & Uiso 2002). The highest insolation in the region is found in central Tanzania, but local peaks occur elsewhere.

According to SSE data, the seasonal variations are high in western Tanzania. In this area the highest insolation occurs during May–September, while most other areas including most of Mozambique peaks during November–March.

The interpolations of SSE data provided by NASA correlate well with ground measurements, and the estimations of insolation is more accurate than the wind speed estimations. The SSE estimations can consequently be considered as an adequate source for assessing solar power within the studied region. Comprehensive modelling of solar radiation has also been published by Alfayo & Uiso (2002) for Tanzania and by Nijegorodov et al. (2003) for Mozambique.

In summary, the whole region receives adequate insolation for small-scale solar power. Furthermore, several areas, most profoundly central Tanzania, receive insolation high enough for large scale energy extraction. Most areas peak in insolation during the southern hemisphere summer. Previous resource assessments have been conducted and the solar energy potential is relatively well known in the region.

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