U ovom radu se vrši poređenje o tome koliko dobro satelitska merenja i merenja meteoroloških podataka klime predviđaju sunčevu blistavost (irradiance). Vrednovali smo i uporedili podatke o proceni insolacije dobijene od Nasinih satelita sa podacima merenja izvršenih u dve meteorološke stanice u Albaniji. Većina raspoloživih podataka o zračenju zasniva se na satelitskim podacima, koji se izračunavaju na osnovu sunčevog zračenja (satelit). Međutim, postoji dostojstvene nesigurnosti u ovim proračunima. Zbog toga postoje značajne odstupanja između satelitskih podataka i podataka merenih na Zemlji. Poređenje solarnih podataka izmerenih u dve meteorološke stanice koje se nalaze na dve različite lokacije u gradu Tirani, Albanija, pokazalo je prenadevanje satelitskih podataka od oko 14 kWh/m² po mesecu u poređenju sa podacima sa Zemlje. Drugi faktor uticaj utiče oblast uzeta u obzir za podatke. Satelitski podaci se odnose na veće oblasti, a podaci mereni na Zemlji su tačni. Kod dve zemaljske meteorološke stanice razmatrate u našoj studiji, čak iako je njihova godišnja prosečna sunčeva energija ista, njihove distribucije su po mesecima različite. Pretpostavljamo da je to uticaj različitih antropogenih aktivnosti na dve lokacije. Utvrđeno je da su vrednosti mesečne prosečne časovne direktnog solarne iradijacije iz merenja i onih procenjenih iz predložene metode u razumnom saglasju, sa razlikom korena srednjeg kvadrata od 6.5 do 11.7% i srednjim biasom od -11.2%.
This paper compares how well satellite versus weather station measurements of climate predicts solar irradiance. We evaluate and compare solar insolation estimation data provided by NASA satellites with data of measurements made by two ground meteorological stations in Albania. Most of the available radiation data are based on satellite data, which is calculated from sun radiation (satellite). However, there is a lot of uncertainty in these calculations. Thus there are significant deviations between satellite-based data and ground-measured data. Comparison of solar data measured by two weather stations situated in two different sites within the city of Tirana, Albania, showed an annual overestimation satellite data of around 14 kWh/m² month compared with ground data. Another influencing fact is the area, which is considered for the data. Satellite-based data refers to large areas, ground-measured data are exact. Two ground weather stations considered in our study, even their annual average solar energy is the same, their distributions through the months is different. We presume that this is effect of different anthropogenic activity in two sites. It was found that values of monthly average hourly direct normal irradiation from the measurements and those estimated from the proposed method are in reasonable agreement, with a root mean square difference of 6.5 to 11.7% and a mean bias of -11.2%.

Keywords: solar radiation data, satellite data, statistical method, comparison, solar ground data.

INTRODUCTION

Measurement and modeling of broadband and spectral terrestrial solar radiation is important for the evaluation and deployment of solar renewable energy systems. The renewable energy sector depends upon the assessment of resources for planning and selling their energy production technology. For solar based renewable energy technologies such as solar thermal or photovoltaic conversion systems, the basic resource or fuel available is solar radiation. Uncertainties in life cycle savings for solar thermal and photovoltaic (PV) systems are linearly correlated with uncertainty in solar resource data. Assessment of the solar resource for these technologies is based upon measured data, where available. However, the sparse distribution in space, and particularly over time, of measured solar data leads to the use of modeled solar radiation as the basis for many engineering and economic decisions. Most solar radiation models rely on measured data for their development or validation, and often the uncertainty or accuracy of that measured data is unknown. The solar radiation measurement scale is based upon the World Radiometric Reference (WRR) maintained by the World Meteorological Organization (WMO) at the Physical Meteorological Observatory, Davos (PMOD, Davos), Switzerland. The uncertainty in the reference irradiance direct beam component measured with a working reference ACP is 0.45%, or about 5 W/m² at 1000 W/m² direct irradiance [1].
Although weather stations give accurate measures of ground conditions, they entail sporadic observations that require interpolation where observations are missing. In contrast, satellites have trouble measuring some ground phenomenon such as precipitation but they provide complete spatial coverage of various parameters over a landscape. Satellites provide promising measures but ground station data may still be preferred for measuring irradiation especially in rural settings[2]. Traditionally, solar radiation is observed by means of networks of meteorological stations. Costs for installation and maintenance of such networks are very high and national networks comprise only few stations. Consequently the availability of observed solar radiation measurements has proven to be spatially inadequate for many applications. Mapping solar radiation by interpolation/ extrapolation of measurements is possible but usually leads to large errors, except for dense networks. Several authors have shown the potentialities of geostationary satellites for mapping the global irradiation impinging on a horizontal surface at the ground level. [3]. However, due to equipment costs, such measurements are scarce. An alternative solution to this problem is to use a model to derive the direct normal irradiation from satellite data. This possibility comes from the fact that back-scattered solar radiation from earth–atmospheric system captured by a meteorological satellite can be statistically related to the global irradiation at the earth’s surface and the direct component of the global radiation can be extracted from the global radiation by using diffuse fraction models[4]

We evaluate in the present paper the benefit of using space-based observations as an additional information source when interpolating the ground measurements. Finally, the benefit of using satellite information appeared to be the largest in case of highly variable sky conditions over the studied area. In overall, merging ground and satellite data enables to take advantage of both the high accuracy of ground data. More specifically, we consider surface incoming global irradiation derived from NASA in order to improve the spatial resolution of daily surface solar radiation data over Albania.

**METHODS OF STUDY**

Source of ground data have been archives of Faculty of Engineering Mathematics and Engineering Physics FEMEFand Faculty of Electrical Engineering FEE of polytechnic University of TiranaPUTin Albania. The data obtained cover a period of 8 to 10 last years with a frequency of half an hour. Instrument used are two Davies meteorological stations installed at the top of respective buildings at the height around thirty meters over the ground and five meters over the roof. These values are statistically sufficient to make a comparison with 22 year monthly average satellite data of solar energy falling on a horizontal surface of one square meter area provided by NASA. Source of satellite data is site of meteorological data of NASA [5, 6].

In the literature, several statistical test methods are used to evaluate the performance of the models of solar radiation estimations. Among these, correlation
mean bias error (MBE), root mean square error (RMSE), and the t-statistic (t-stat) errors are the most widely used ones. [7, 8, 9].

The mean bias error (MBE) provides information on the long-term performance of the correlations by allowing a comparison of the actual deviation between calculated and measured values term by term.

\[
MBE = \frac{1}{n} \sum_{k=0}^{n} (J_k - X_k) / n
\]  

Where \( J_k \) is the estimate of one of the methods and \( X_k \) is the estimate of other method for the same event. In our case \( J_k \) stands for ground estimation and \( X_k \) stands for NASA estimations. The root-mean-square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the quantity being modeled or estimated. RMSE is a good measure of precision. The value of RMSE is always positive, representing zero in the ideal case.

\[
RMSE = \sqrt{\frac{1}{n} \sum_{k=0}^{n} (J_k - X_k)^2}
\]  

MBE detect and evaluate any systematic difference between two sets of data, it is a parameter that can be used to convert estimates given by each of the methods to each other. A low value of MBE indicates that both methods give equivalent estimates (systematic error is small). On the other hand, RMSE evaluate statistical distribution of value of systematic difference between two sets of data.

In order to determine if two measuring methods provide estimations that can be considered statistically different we used the t-statistic, a test of the null hypothesis that the difference between two responses measured on the same statistical unit has a mean value of zero [10].

\[
t - \text{stat} = \frac{\sqrt{(n-1) \cdot MBE}}{RMSE}
\]  

Data of solar radiation on horizontal surface used for comparison are data taken from two different meteorological stations in city of Tirana situated around one kilometer apart, one at the Faculty of Mathematical and Physics Engineering (FEMEF) and other at the Faculty of Electrical Engineering (FEE). Two sites differ very much by intensity of traffic air pollution in certain periods of the year. Comparison satellitedata are taken by NASA satellite based models. Data are illustrated in charts for monthly averaged values.
RESULTS AND DISCUSSION

In Table 1 are shown monthly total amount of energy falling on unit horizontal area of total (kWh/m²/month) as measured by ground station of FEE, FEMEF and estimation of NASA for city of Tirana, together with corresponding differences between monthly solar energy. In table 2 are shown statistical indicators calculated for each set of differences, it is MBE, RMSE, degree of freedom, t-statistic and its critical value of level of significance 5% for differences between monthly solar energy data (NASA-FEMEF), (NASA-FEE) and (FEE-FEMEF). Figure 1 and 2 visualize the data shown in Table 1.

TABLE 1. The monthly total amount of energy falling on unit horizontal area of (kWh/m²/month) as measured by ground station of FEE, FEMEF and estimation of NASA for city of Tirana, together with corresponding differences between monthly solar energy

<table>
<thead>
<tr>
<th>Month/Source</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEE</td>
<td>60.97</td>
<td>72.79</td>
<td>103.5</td>
<td>130.6</td>
<td>172</td>
<td>194.8</td>
<td>207.3</td>
<td>189.7</td>
<td>142.2</td>
<td>102.1</td>
<td>67.98</td>
<td>60.12</td>
<td>1500</td>
</tr>
<tr>
<td>FEMEF</td>
<td>43.51</td>
<td>62.64</td>
<td>121.96</td>
<td>148.61</td>
<td>200.25</td>
<td>207.01</td>
<td>193.82</td>
<td>136.95</td>
<td>91.33</td>
<td>55.39</td>
<td>47.10</td>
<td>1505</td>
<td></td>
</tr>
<tr>
<td>NASA</td>
<td>59.52</td>
<td>77.0</td>
<td>128.7</td>
<td>157.5</td>
<td>204.3</td>
<td>229.2</td>
<td>239</td>
<td>205.8</td>
<td>152.7</td>
<td>105.1</td>
<td>61.2</td>
<td>48.05</td>
<td>1668</td>
</tr>
<tr>
<td>FEE-FEMEF</td>
<td>17.46</td>
<td>10.15</td>
<td>-18.11</td>
<td>-18.00</td>
<td>-18.51</td>
<td>-5.42</td>
<td>0.30</td>
<td>-4.15</td>
<td>5.21</td>
<td>10.78</td>
<td>12.59</td>
<td>13.02</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2. MBE, RMSE, degree of freedom, t-statistic and its critical value of level of significance 5% for differences between monthly solar energy (NASA-FEMEF), (NASA-FEE) and (FEE-FEMEF)

<table>
<thead>
<tr>
<th>Location Station</th>
<th>MBE in kWh/m² month</th>
<th>RMSE in kWh/m² month</th>
<th>t-stat</th>
<th>Degree of freedom</th>
<th>Critical Values t-statistics Significance level 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA-FEMEF</td>
<td>-14.05</td>
<td>8.984</td>
<td>5.42</td>
<td>12</td>
<td>1.796</td>
</tr>
<tr>
<td>NASA- FEE</td>
<td>-13.61</td>
<td>16.28</td>
<td>2.90</td>
<td>12</td>
<td>1.796</td>
</tr>
<tr>
<td>FEE - FEMEF</td>
<td>0.44</td>
<td>13.20</td>
<td>0.12</td>
<td>12</td>
<td>1.796</td>
</tr>
</tbody>
</table>

Estimations of NASA of monthly total solar energy falling on unite area are always over estimated with ground measurements offered by two ground meteorological stations situated in two different sites of Tirana. MBE for meteorological stati-
ons situated at FEMEF and FEE are (-14.05 kWh/m²/month) and (-13.61 kWh/m²/month), respectively. The average yearly overestimation of data offered by NASA compared with data of measurements carried by both ground stations is around 11.2 %, with a root mean square difference of 6.5 to 11.7%. It was found that values of monthly average hourly direct normal irradiation from the measurements and those estimated from the proposed method are not in reasonable agreement. Differences between data of solar energy taken from two ground meteorological stations at FEE and FEMEF, even the total yearly value results to be very small, show an interesting variation from one month to the other. During autumn-winter (October till February) energy data measured by meteorological station situated at FEMEF are greater than data of energy measured by meteorological station situated at FEE. During the remaining period of the year the situation is reversed. (See Figures 1 and 2) A probable explanation for this observation, as shown by Buzra et al, is differences on effect of anthropogenic activity in two sites of city of Tirana [11].

**Figure 1.** Monthly total amount of energy falling on unit horizontal area (kWh/m²/month) as measured by ground station of FEE, FEMEF and estimation of NASA for city of Tirana

Considering calculated values of RMSE and t-stat, MBE calculated for city of Tirana is statistically relevant (t-stat = 5.42 and 2.90 for meteorological stations situated at FEMEF and FEE respectively) are much greater than critical value of t-stat = 1.796, for a confidence 95%), which is an evidence of the significance of the difference between ground estimates and NASA estimates. However, we cannot confirm the same thing for other two ground stations. Apart their specificities, the yearly average solar energy data are statistically identical. (t-stat 0.12 much smaller than critical value of t-stat = 1.796, for a confidence 95%). Nevertheless if we consider monthly distribution of data, effect of anthropogenic activity in different sites of the city must not be neglected.
CONCLUSION

In this study we evaluate and compare solar insolation estimation data provided by NASA satellites with data of measurements made by two ground meteorological stations in Albania. Most of the available radiation data is based on satellite data, which is calculated from sun radiation (satellite) as well as temperature and wind speed (weather stations). However, there is a lot of uncertainty in these calculations. Thus there are significant deviations between satellite-based data and ground-measured data. Comparison of solar data measured by two weather stations situated in two different sites within the city of Tirana, Albania, showed an annual overestimation satellite data of around 14 kWh/m² month compared with ground data. Another influencing fact is the area, which is considered for the data. Satellite-based data refers to large areas of approx. 1km², ground-measured data are exact. Two ground stations considered in our study, even their annual average solar energy is the same, their distribution through the months is different. We presume that this is effect of different anthropogenic activity in two sites. Only with measurement stations on the ground you get accurate measurement data, which can be used to calculate the annual energy yield at the site. It was found that values of monthly average hourly direct normal irradiation from the measurements and those estimated from the proposed method are not in reasonable agreement, with a root mean square difference of 6.5 to 11.7% and a mean bias of -11.2%.

REFERENCE


