Comparison of Two Solar Potential Methods on Rooftops Using LIDAR Data

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doi: 10.5281/zenodo.11555268

Abstract: This paper presents a comprehensive assessment of rooftop solar potential in the urban environment of Karlovac, Croatia, using LIDAR (Light Detection and Ranging) data. In the midst of increasing demand for sustainable energy solutions, rooftop photovoltaic systems offer a promising opportunity for decentralized energy generation. However, their efficient use requires precise estimation of solar potential at high spatial resolution. This study uses LIDAR data together with Geographic Information System (GIS) techniques to assess the viability of rooftop photovoltaic systems. The methodology involves processing data from LIDAR-derived digital surface models (DSMs) with various software tools to derive key roof characteristics such as slope and orientation. Solar radiation data is then integrated to estimate the solar energy potential of each roof. A GIS analysis is then carried out to visualize and interpret the spatial distribution of solar potential in the study area. Preliminary results show that the solar potential on the individual roofs varies considerably due to differences in orientation and inclination. In addition, the study highlights the impact of urban morphology on the accessibility of solar installations. The results provide valuable insights for urban planners, policy makers and energy stakeholders interested in promoting the use of renewable energy and optimizing urban energy infrastructure. In summary, this study underlines the usefulness of LIDAR data in combination with GIS analysis for the assessment of rooftop solar potential and thus provides an important guidance for sustainable urban energy planning in Karlovac, Croatia, and similar areas worldwide.

Keywords: rooftop solar potential; LIDAR; GIS; DSM.

1 Introduction

Solar energy is a clean and renewable resource that is becoming an increasingly important source of energy due to its availability and long-term viability. Cities will soon be forced to look for new energy sources based on electricity and other renewable energy sources. The use of solar energy is important for energy planning, environmental protection and sustainable development. For this reason, a methodology for estimating solar potential is needed. More accurate methods for estimating solar potential are needed as more and more households and businesses consider the possibility of small photovoltaic (PV) systems. Rooftop systems are practical because they do not take up additional space, but utilize the available space.

Many researchers have studied the solar potential in different areas using several different software. Mujić and Karabegović (2023) used SAGA GIS, GRASS GIS and PVGIS to calculate the solar potential. Dodig and Djapić (2024) used ArcGIS to calculate the solar potential of rooftops in the city of Belgrade. Gulben et al. (2019) used SAGA GIS to create solar energy potential maps, while Bajat et al. (2020) used it to calculate grids for potential solar radiation.

This paper focuses on the analysis and visualization of rooftop solar potential using DSMs (digital surface models) obtained from LiDAR (Light Detection and Ranging) data. LiDAR technology provides high-resolution data that is well suited for the creation of high-precision 3D geometry. A comparison of two methods for calculating the solar potential of roofs was carried out and the results were analysed on a daily and seasonal basis. This work is the first case study in Croatia on solar potential using LIDAR data.

2 Materials and methods

In this study, the calculations of the solar potential of roofs were carried out using the GRASS GIS and SAGA GIS plugins in QGIS. The area of Karlovac and its immediate surroundings were analyzed. Karlovac is a city in central Croatia, located at the interface between the lowlands and the mountainous regions of Croatia.

LiDAR data was collected for this area and used to create a DSM and DTM (Digital Terrain Model). The data was provided by the "DGU" (Croatian State Geodetic Administration). First, the DSM was used to calculate the slope and aspect. Next, GRASS GIS and its function r.sun.insoltime enable the calculation of the total solar potential for a given day of the year. The DTM and the previously determined values for slope and aspect were used as mandatory input parameters together with the number of the day of the year. The daily solar potentials were calculated for four days in 2023 within different seasons, namely: February 15, May 15, August 15 and November 15. The results obtained represent the total daily solar potential of the input grid, expressed in Wh/m², which was divided by 1000 using the QGIS Raster Calculator function to obtain the total daily solar potential in kWh/m². To visualize the solar potential of the roofs, only the roofs from the obtained raster were extracted and displayed.

The second solar potential was also calculated with SAGA GIS for the same data. The Potential Incoming Solar Radiation function was used to calculate the solar potential. One of the mandatory input data is the Sky View Factor, which indicates the proportion of visible sky above a given observation point and is determined using the Sky View Factor command in SAGA GIS. The input data used are the DSM, the sky view factor raster, the average value for the water vapor pressure in the air, the height of the atmosphere and the solar radiation constant. We used the same parameters as in Gorički et al. (2017), including solar radiation constant 1367 W/ m2, atmospheric height 12 000 m and water vapor pressure in the air 10 mbar. In this case, a raster was created showing the daily solar potential expressed in kWh/m^2. The roofs for the obtained raster were extracted from the rest, as in the previous case, and this representation is further analyzed. The rasters created using different methods were compared visually and using statistical values. The QGIS function "Clip raster by mask layer" was used to extract three roofs from the difference raster, which are analyzed in more detail. The "Zonal statistics" function" was used to calculate the minimum, maximum, arithmetic mean, median and standard deviation for each side of the roof. The R program was used to create a boxplot display for the four analyzed data for both methods. Unlike GRASS GIS, SAGA GIS can select a longer time period in addition to a day. Using the Potential Incoming Solar Radiation function of SAGA GIS and the same input parameters as for the daily solar potential, the solar potentials were calculated for four periods of the year. The first period includes the total solar potential of January, February and March, the second April, May and June, the third July, August and September and the fourth October, November and December. Microsoft Excel was used to create a bar chart showing the mean values of the solar potential for four periods.

3 Results

First, the solar potential was calculated for four days in 2023. The data was analyzed for each day. The daily solar potential values were calculated using the GRASS GIS and SAGA GIS programs (Figure 1).

To observe the influence of orientation on the different methods of determining solar potential, the raster difference was examined for three roofs. As shown in Figure 2, one roof is oriented north-south (Figure 2a), another is oriented east-west (Figure 2b) and the third is a flat roof (Figure 2c). We have divided the first roof into two levels, one facing north and the other facing south. The second roof has one plane facing east and the other facing west. The third roof is a flat roof. In this way, we examine 5 cases: a roof facing north, south, east and west and a flat roof. Depending on this, the difference between the two methods also changes. Table 1 shows the statistical values for each case. To analyze the statistics for each date and method, the statistical values for four dates and both methods are graphically displayed in a boxplot (Figure 3).

In the further analysis, the SAGA GIS was used to calculate the solar potential for four periods of the year. Statistical data were also calculated in order to recognize the dependence of the solar potential on the season. Figure 4

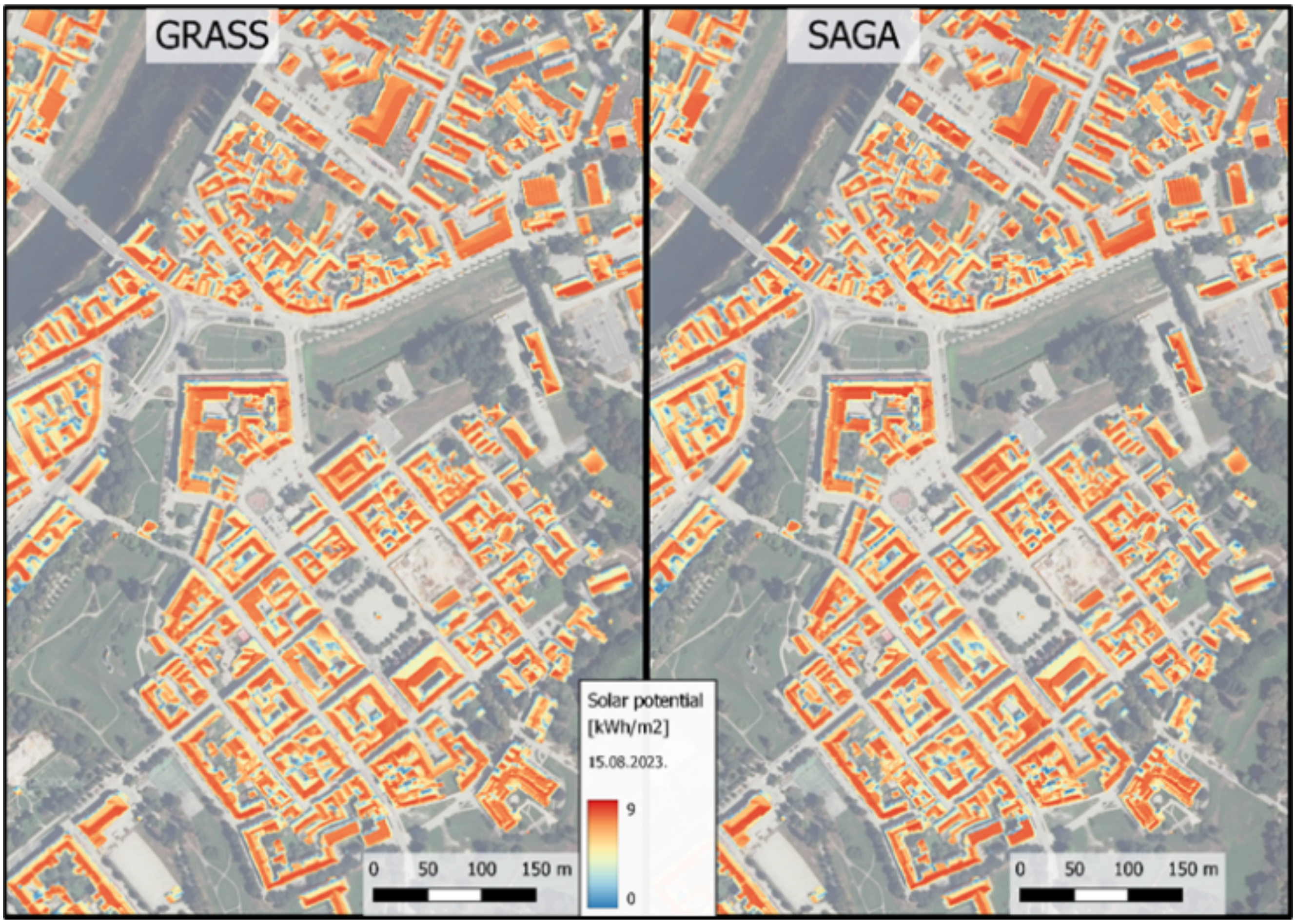

Figure 1. Solar potential values obtained using GRASS GIS and SAGA GIS for August 15, 2023.

shows the mean value of the solar potential as a function of the season.

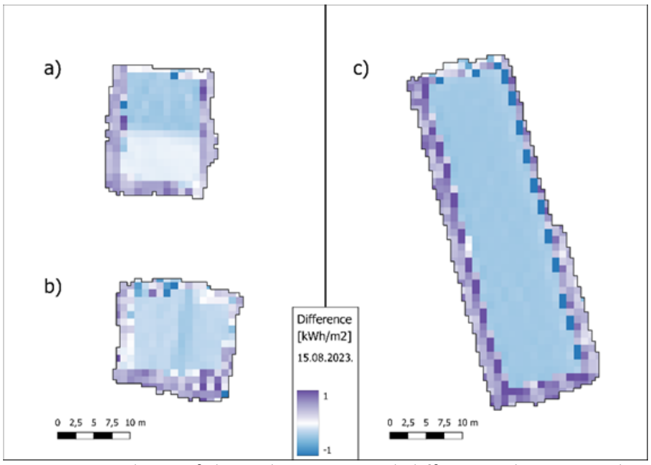

Figure 2. Values of the solar potential difference between the GRASS and SAGA calculation methods for August 15, 2023.

Table 1. Statistical values for roofs in difference raster.

DIFFERENCE	MIN	MAX	MEAN	MEDIAN	ST. DEV.
North roof	-1,31	1,34	-0,11	-0,34	0,43
South roof	-0,42	0,90	0,11	-0,07	0,33
West roof	-1,47	1,07	-0,02	-0,21	0,39
East roof	-1,54	1,38	-0,01	-0,23	0,42
Flat roof	-2,12	1,38	-0,11	-0,37	0,56

The processing time was also examined. The processing time for the daily calculation of the solar potential with GRASS GIS was about two hours and with SAGA GIS about 20 minutes. In addition, the processing of SAGA GIS took three days for each of the four time periods.

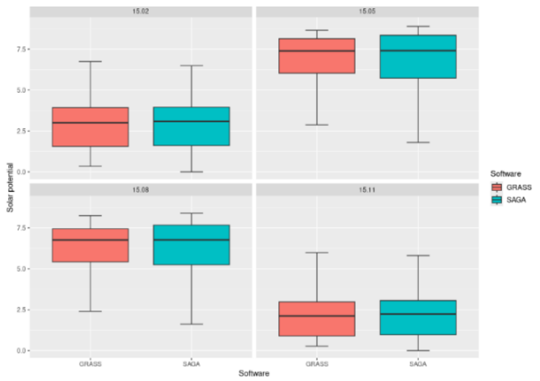

Figure 3. Statistics for each day and method.

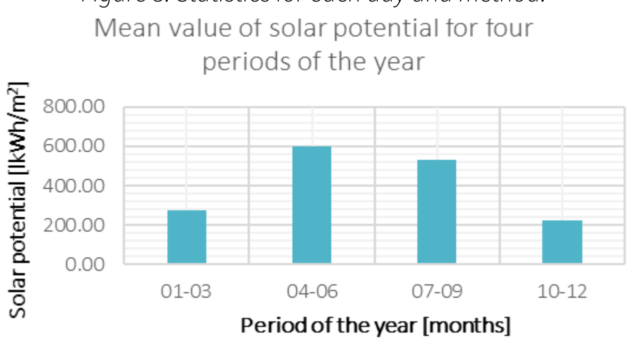

Figure 4. Mean value of solar potential for four periods of the year.

4 Discussion

Figure 1 shows that the representation obtained by SAGA is slightly, but not significantly, darker than that obtained by GRASS. It is therefore to be expected that the solar potential values of SAGA are higher than those of GRASS. However, the relationships between the solar potentials of the roofs within the same grid look the same for both results. Their relationship can be determined more precisely using the GRASS and SAGA difference grid. The negative result is where SAGA has higher values than GRASS, and it is obvious that they predominate at all roof levels. There is a positive result where GRASS values are higher, and we can see this on the edges of the roofs. The predominance of the blue color confirms to us that the result obtained by SAGA indicates slightly higher values for solar potential. We looked at the three roofs in detail and examined the difference in raster values, especially in their case. On each roof we can see that the edge values are positive and mostly between 0 and 1. The interior of the roofs is mostly between 0 and –1. It is visually apparent that the north side has a darker shade of blue than the south side. The solar potential difference values are closer to zero on the south side. In this case, it is best represented by the median, which is –0.34 for the north side and –0.07 for the south side. Therefore, the two methods for calculating the potential differ only slightly when representing the south side of the roof and more when representing the north side. The east and west sides of the roof are obviously the same. The shade of blue is darker than that on the south side, but lighter than that on the north side. This is also confirmed by their median, which is –0.21 for the western and –0.23 for the eastern part of the roof. It can also be seen that the differences between the eastern and western orientations are equally large. The differences are greatest at the edges of the roofs, regardless of the orientation. The greatest difference can be seen on a flat roof. This is best confirmed by the greater intensity of blue and the median, which deviates the most from zero and is –0.37. It is therefore noticeable that GRASS and SAGA differ the most on the flat roof and the least on the south side of the gable roof. The daily values of the solar potential were calculated for a further three days in different seasons. We compared the differences in the results using the statistical values shown in the graph (Figure 3). For each day and method, there is a boxplot showing the median, quartiles and range of values covered by the data; outliers are not shown. We can see that the medians for both methods are remarkably close to each other and almost the same. The minimum and maximum differ slightly, as do the quartiles. However, the differences are not very pronounced. From Figure 4, we can conclude that GRASS GIS and SAGA GIS provide very similar results, which is in line with Mujić and Karabegović (2023), who concluded that the results between GRASS and SAGA GIS have maximum deviations of up to 0.96%. From all this, we can conclude that the charts are not very different and we can consider them both credible. However, one notable difference is the time it takes to calculate the results, with SAGA proving to be faster, confirming the statement by Gulben et al. (2019) that SAGA GIS is much faster than GRASS GIS.

Figure 5 also shows that the highest value of solar potential is reached in the summer months, especially from April to June. It is similar to the boxplot, where all values are highest on May 15. August 15 shows slightly lower values, which also applies to the period from July to September. The lowest values for solar potential are in the period from October to December, which is also confirmed by the statistical values for November 15. This is consistent with the findings of Gorički et al. (2017), who concluded that solar radiation is highest in July and lowest in December.

5 Conclusions

Solar energy is a clean and renewable resource that is becoming an increasingly important energy source due to its availability and long-term viability. More accurate methods of estimating solar capacity are needed as more homes and businesses consider the possibility of small photovoltaic (PV) systems. Rooftop systems are practical because they do not require additional space, but utilize existing space. This paper presents a comprehensive assessment of the solar potential of rooftops in the urban environment of Karlovac, Croatia, using LiDAR data. The difference in the rasters between GRASS and SAGA shows that SAGA has higher values on all roof levels, while GRASS has higher values on the roof edges. It is noticeable that GRASS and SAGA differ most on the flat roof and least on the south side of the multi-gable roof. Although there are some differences in the statistical values with an average difference of 0.01 kWh/m^2, it can be concluded that GRASS GIS and SAGA GIS deliver equivalent results. The solar potential reaches the highest value in the summer months and the lowest in the period from October to December.

Acknowledgment: This research was funded by the Croatian Science Foundation under the Grant. No. IP-2022-10-2639: “Fusion of multitemporal optical and radar microsatellite data for land cover change detection” (FORMAT).

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