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SOLAR RADIATION ATLAS IN BANJA LUKA IN THE REPUBLIC OF SRPSKA

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Abstract: The paper presents an atlas of solar radiation for the city of Banja Luka in the Republic of Srpska formed by PVGIS estimation utility. The atlas contains the results of calculating global and direct solar radiation falling on the horizontal surface and global solar radiation falling on the optimally placed surface in Banja Luka in the period from 2007 to 2016. In addition, the intensity of global, direct and diffuse solar radiation falling on the optimally placed surface in Banja Luka is given by months. It was found that 13.89% less solar radiation falls on the horizontal surface and 47.31% less on the vertical surface as compared to the solar radiation that falls on the optimally placed surface. The basic characteristics of fixed, one-axis and dual-axis tracking PV solar power plants power of 1 MWp and the amount of electricity that can be generated by them in Banja Luka, are also given. It was found that with the one-axis tracking solar power plant 30.18% more electricity can be generated, and with the dual-axis tracking solar power plant 33.37% more electricity can be generated as compared to the fixed solar power plant.

Keywords: PVGIS program, solar irradiance, solar energy, PV solar power plants.

1. INTRODUCTION

Quantity of sun radiation intake on the surface of earth is influenced by numerous factors such as: geographical latitude of the given place, season of the year, part of the day, purity of the atmosphere, cloudiness, orientation and surface inclination, etc. These data are very important because of their use in calculations of the cost effectiveness of equipment using sun radiation. Very reliable data can be found in data basis PVGIS (*Photovoltaic Geographical Information System*–PVGIS © European Communities, 2001–2008, http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php).

PVGIS methodology comprises solar radiation data, PV module surface inclination and orientation and shadowing effect of the local terrain features (e.g. when the direct irradiation component is shadowed by the mountains), thus PVGIS represents immensely important PV implementation assessment tool that estimates dynamics of the correlations between solar radiation, climate, atmosphere, the earth's surface and the PV technology used. Several fast web applications enable an easy estimation of the PV electricity generation potential for selected specific locations in Europe [1–8].

The results of investigation of solar radiation and use of solar energy in the Republic of Srpska are given in [9].

This paper provides the results of calculating global, diffuse and direct solar radiation by means of PVGIS estimation utility for the city of Banja Luka. Moreover, the paper contains the results of calculating the electrical energy which can be generated by the fixed, one-axis and the dual-axis tracking solar power plants in Banja Luka.

2. THE GEOGRAPHICAL LOCATION OF BANJA LUKA

Banja Luka (Figure 1) is the administrative, political, economic, cultural and university center of the Republic of Srpska. Banja Luka got the status of a city in 1997.

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The inner city area is located at 160 m above sea level and covers about 80 km^2. The wider urban area is located at 150-500 m above sea level and covers an area of 1239 km^2. Banja Luka is mostly located in the Vrbas valley, which is closed by branches of the Dinaric system from the south and southeast. The valley expands in the east towards the valley of the river Vrbas. In 2013, Banja Luka had 65010 households and 180053 inhabitants [10].

3. GLOBAL SOLAR RADIATION

The energy of global solar radiation falling on the horizontal surface in Banja Luka is given in Figure 2.

The energy of direct solar radiation falling on the horizontal surface in Banja Luka is given in Figure 3.

Figure 1. The geographical location of Banja Luka

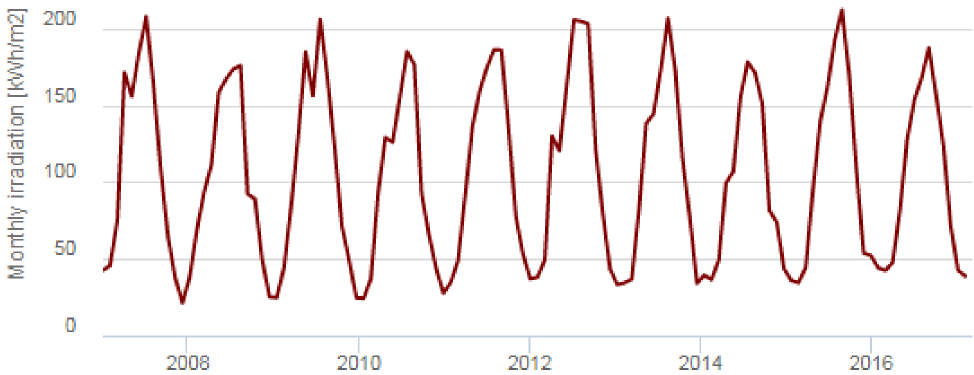

Figure. 2. The energy of global solar radiation falling on the horizontal surface in Banja Luka

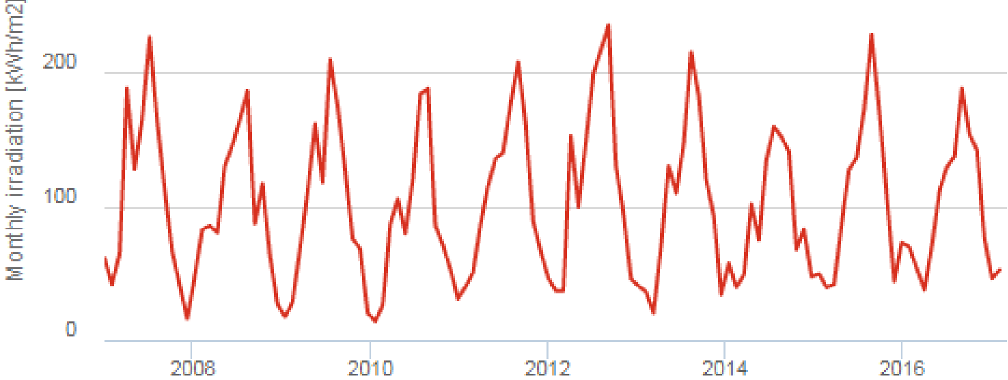

Figure 3. The energy of direct solar radiation falling on the horizontal surface in Banja Luka

The energy of global solar radiation falling on a surface set at an optimal angle of 34º in Banja Luka is given in Figure 4.

Based on the previous figures, it can be concluded that in the period 2007-2016 there was no significant deviation of the energy of global and direct solar radiation falling on the horizontal and optimally placed surface.

4. GLOBAL, DIRECT AND DIFFUSE SOLAR RADIATION FALLING ON AN OPTIMALLY TILTED SURFACE

The intensity of global, direct and diffuse solar radiation that falls on the optimally placed surface by months, during the year in Banja Luka is shown in Figures 5–16.

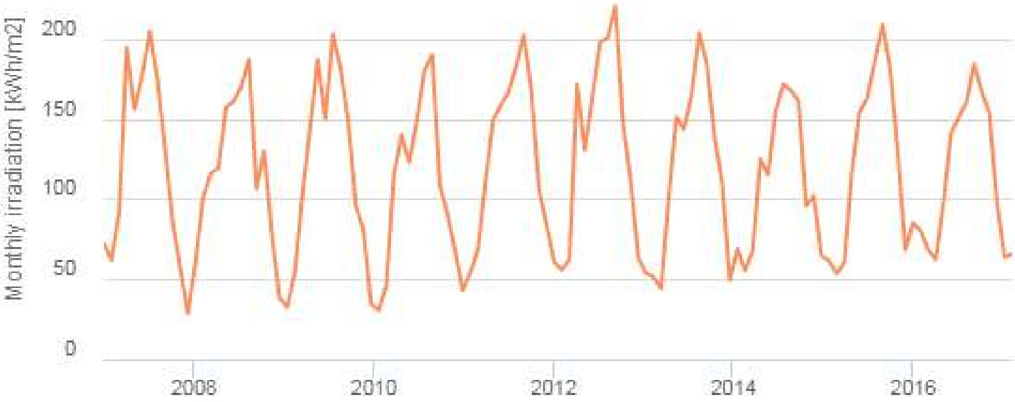

Figure 4. The energy of global solar radiation falling on a surface set at an optimal angle of 34º in Banja Luka

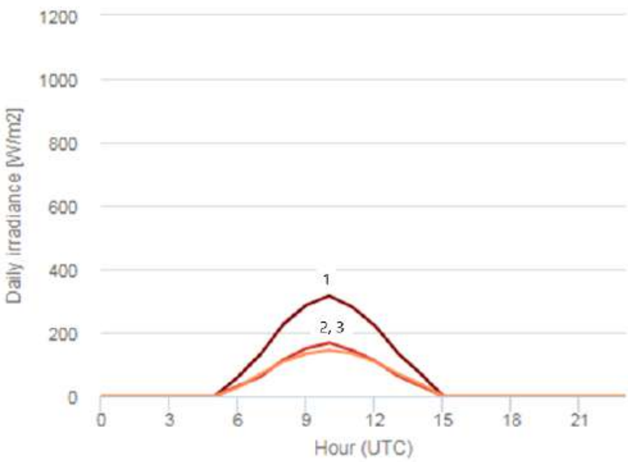

Figure 5. Intensity of global (1), direct (2) and diffuse (3) solar radiation in January in Banja Luka (34º)

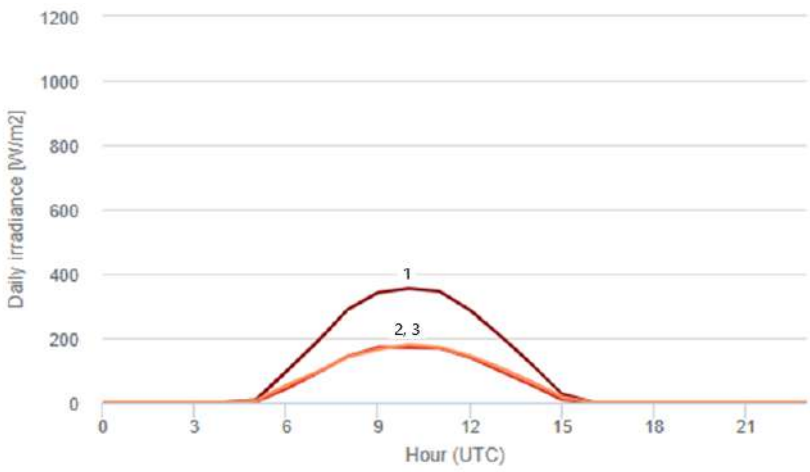

Figure 6. Intensity of global (1), direct (2) and diffuse (3) solar radiation in February in Banja Luka (34º)

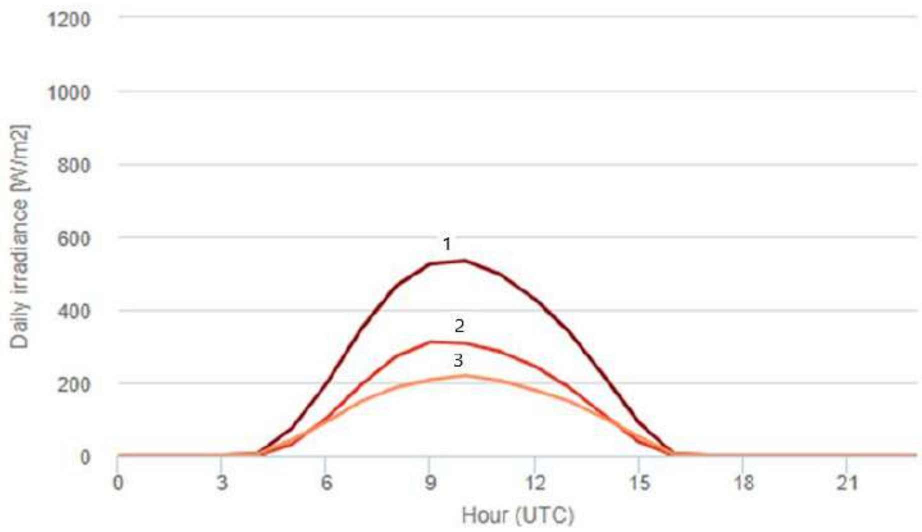

Figure 7. Intensity of global (1), direct (2) and diffuse (3) solar radiation in March in Banja Luka (34^o)

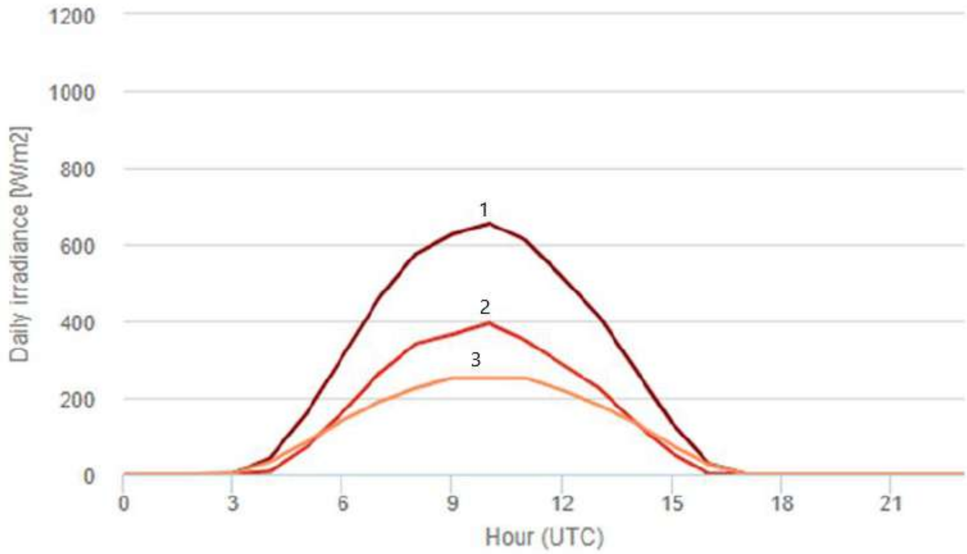

Figure 8. Intensity of global (1), direct (2) and diffuse (3) solar radiation in April in Banja Luka (34^o)

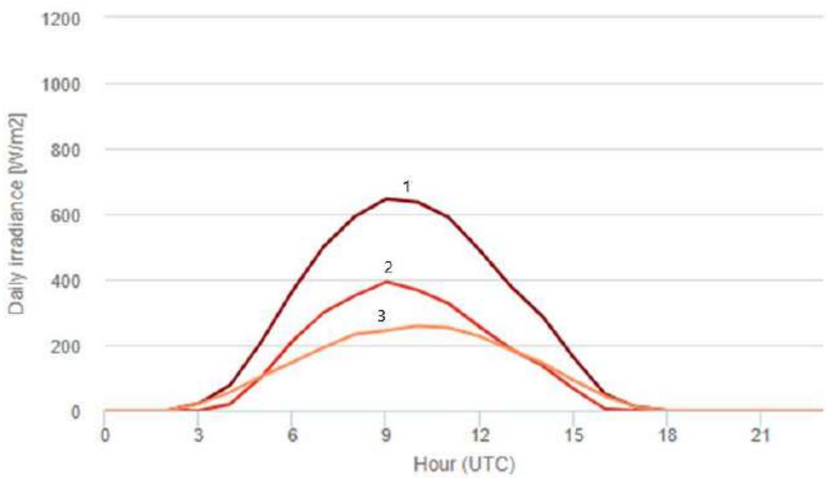

Figure 9. Intensity of global (1), direct (2) and diffuse (3) solar radiation in May in Banja Luka (34^o)

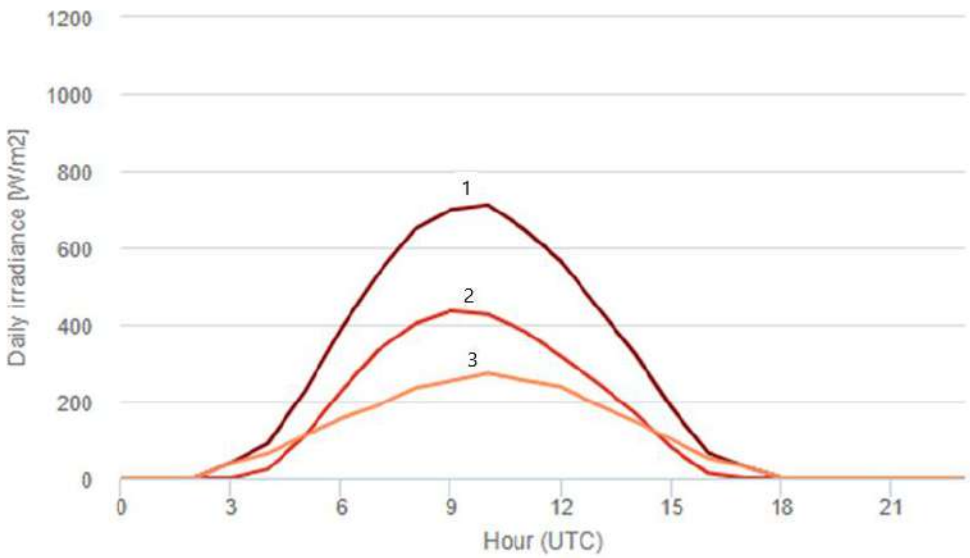

Figure 10. Intensity of global (1), direct (2) and diffuse (3) solar radiation in June in Banja Luka (34^o)

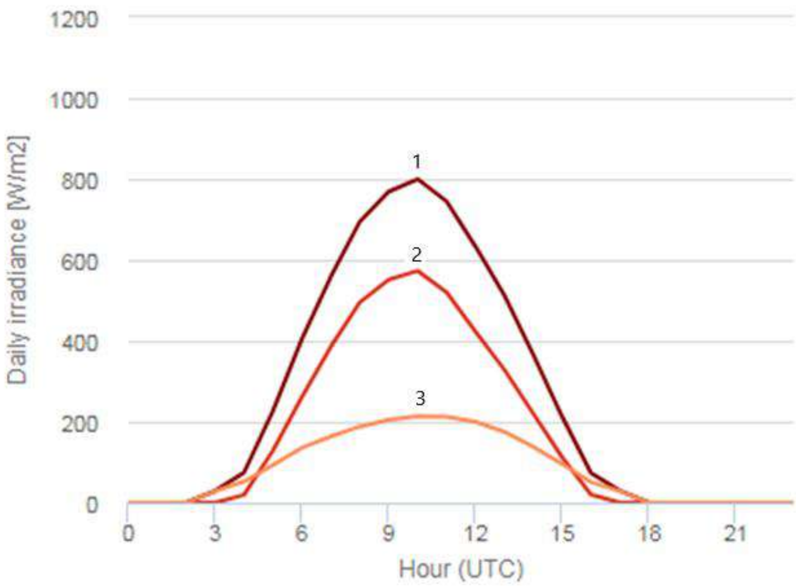

Figure 11. Intensity of global (1), direct (2) and diffuse (3) solar radiation in July in Banja Luka (34^o)

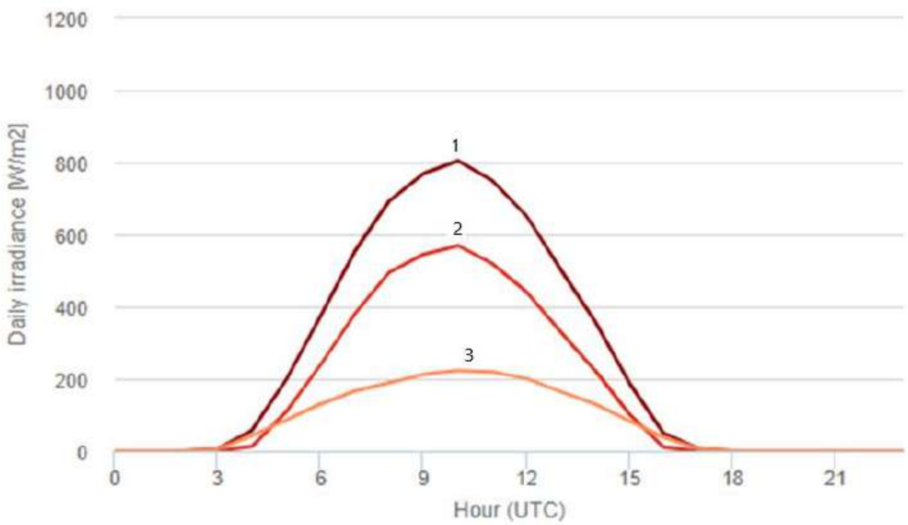

Figure 12. Intensity of global (1), direct (2) and diffuse (3) solar radiation in August in Banja Luka (34^o)

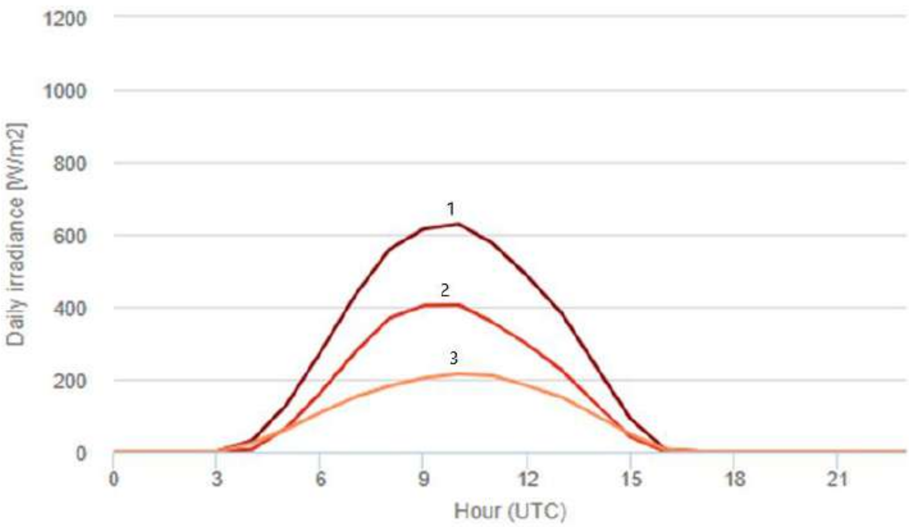

Figure 13. Intensity of global (1), direct (2) and diffuse (3) solar radiation in September in Banja Luka (34º)

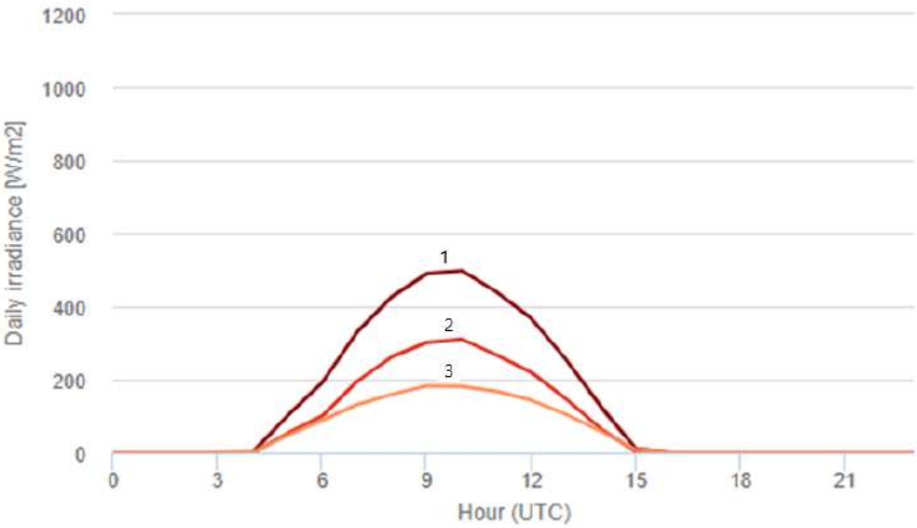

Figure 14. Intensity of global (1), direct (2) and diffuse (3) solar radiation in October in Banja Luka (34º)

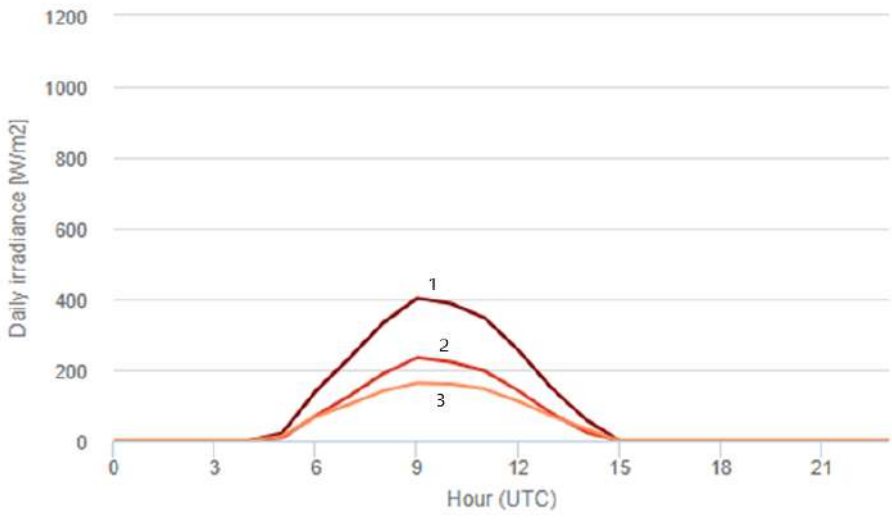

Figure 15. Intensity of global (1), direct (2) and diffuse (3) solar radiation in November in Banja Luka (34º)

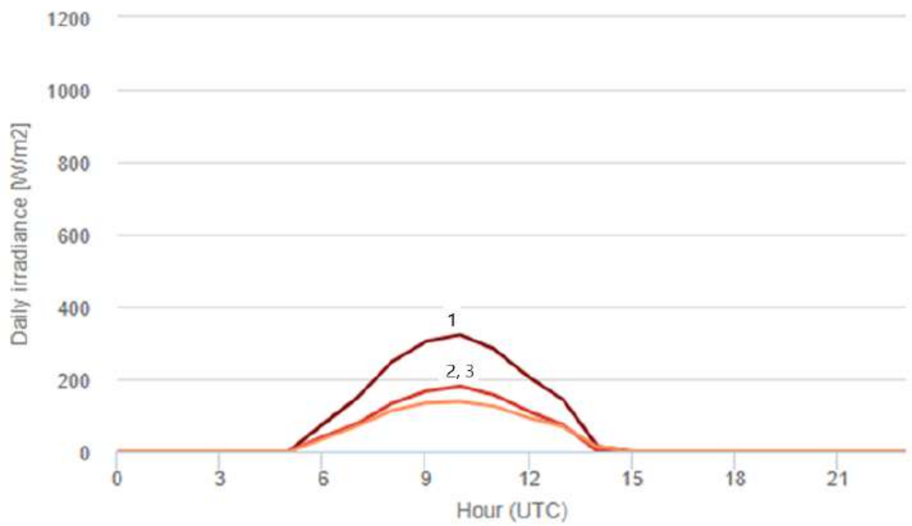

Figure 16. Intensity of global (1), direct (2) and diffuse (3) solar radiation in December in Banja Luka (34°)

Figures 5–16 show the following:

– the intensity of global solar radiation increases from 320 W/m^2 in January to 800 W/m^2 in August and it decreases from August to December when it is 320 W/m^2;

– the intensity of direct solar radiation increases from 180 W/m^2 in January to 580 W/m^2 in August and it decreases from August to December when it is 190 W/m^2;

– the intensity of diffuse solar radiation increases from 170 W/m^2 in January to 220 W/m^2 in August and it decreases from August to December when it is 130 W/m^2;

– the values of the intensity of direct and diffuse solar radiation are almost the same in January, February, November and December;

– in the period from March to November, the curves of direct and diffuse radiation intensity do not coincide, whereby the intensity of direct radiation is always higher than the intensity of diffuse radiation.

The geographical position, optimal angle and the energy of the solar radiation falling on the horizontal, optimally tilted and vertically placed surface in Banja Luka are given in Table 1.

Table 1. Geographical position, optimal angle and the energy of the solar radiation falling on the horizontal, optimally tilted and vertically placed surface in Banja Luka

Location	Geographical position	Optimal angle (°)	Energy of solar radiation falling		
			on the horizontal surface (Wh/m^2)	on the optimally tilted surface (Wh/m^2)	on the vertically placed surface (Wh/m^2)
Banja Luka	44°46’0’’ North latitude 17°10’59’’ East longitude	34	3449.92	3929.42	2667.42

Based on the data shown in Table 1 it can be seen that the largest amount of solar radiation energy falls on the optimally placed surface, slightly less on the horizontal, and the lowest on the vertically placed surface. The horizontal surface receives 13.89%, and the vertical 47.31% less energy of solar radiation in relation to the optimally placed surface.

5. SOLAR POWER PLANTS

The calculation results of the amount of electricity that can be generated using the fixed, one-axis and dual-axis tracking PV solar power plants in Banja Luka, using the PVGIS program are given below.

Fixed solar power plant

PVGIS characteristics of a fixed solar power plant power of 1 MWp that would be installed in Banja Luka are given in Table 2.

PVGIS data for monthly electricity production by a fixed solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka are shown in Figure 17.

Table 2. PVGIS characteristics of a fixed solar power plant power of 1 MWp that would be installed in Banja Luka

Location	Banja Luka
Power of photovoltaic solar power plant (MWp)	1
Power plant losses (%)	14
Tilt angle (º)	34
Azimuth angle (º)	0
Annual electricity production (kWh)	1112301.85

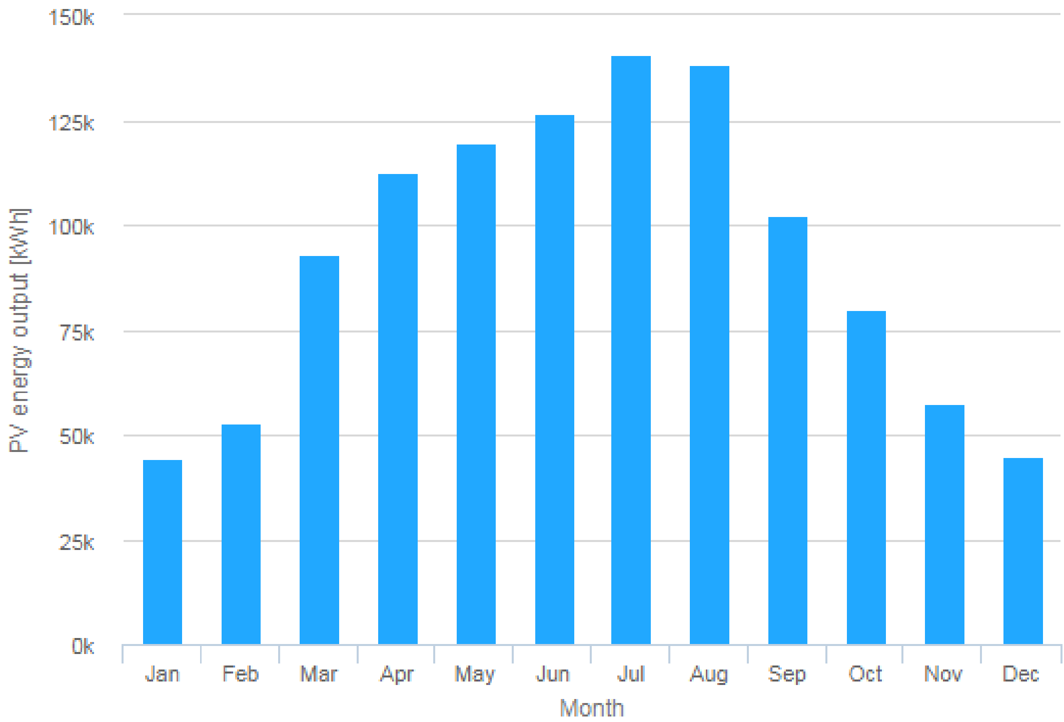

Figure 17. PVGIS data for monthly electricity production by a fixed solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka

One-axis tracking PV solar power plant

PVGIS characteristics of the one-axis tracking PV solar power plant power of 1 MWp that would be installed in Banja Luka are given in Table 3.

PVGIS data for monthly electricity production by the one-axis tracking PV solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka are shown in Figure 18.

Table 3. PVGIS characteristics of the one-axis tracking PV solar power plant power of 1 MWp that would be installed in Banja Luka

Location	Banja Luka
Power of photovoltaic solar power plant (MWp)	1
Power plant losses (%)	14
Tilt angle (º)	36
Annual electricity production (kWh)	1448040.88

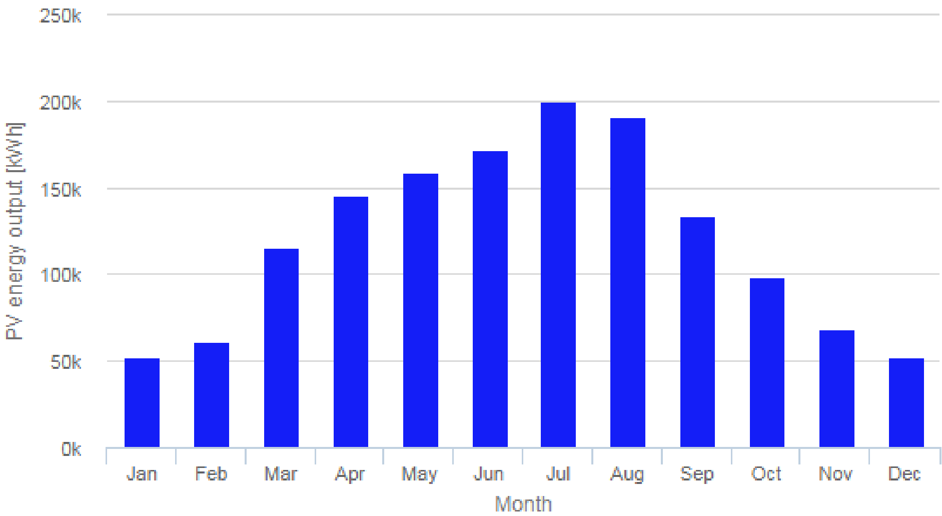

Figure 18. PVGIS data for monthly electricity production by the one-axis tracking PV solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka

Dual - axis tracking PV solar power plant

PVGIS characteristics of the dual - axis tracking PV solar power plant power of 1 MWp that would be installed in Banja Luka are given in Table 4.

PVGIS data for monthly electricity production by the dual-axis tracking PV solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka are shown in Figure 19 [11].

Based on the data shown in Table 4, it can be seen that the one-axis tracking solar power plant generates 28.36% more electricity in relation to a fixed solar power plant. The dual-axis tracking PV solar power plant generates 30.18% more electricity as compared to a fixed solar power plant. The result for dual-axis tracking PV solar power plant is in good agreement with experimentally obtained results for energy efficiency of dual-axis tracking PV solar power plant in Athens (34.8%), Stuttgart (28.7%) and Aberdeen (30.4%) [12].

Table 4. PVGIS characteristics of the dual - axis tracking PV solar power plant power of 1 MWp that would be installed in Banja Luka

Location	Banja Luka
Power of photovoltaic solar power plant (MWp)	1
Power plant losses (%)	14
Annual electricity production (kWh)	1483486.84

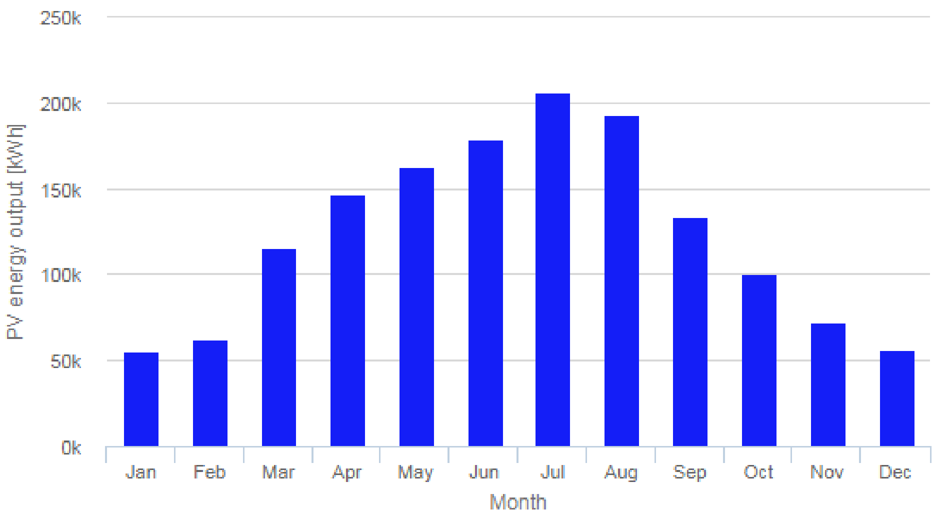

Figure 19. PVGIS data for monthly electricity production by the dual-axis tracking PV solar power plant with monocrystalline silicon solar modules total power of 1 MWp in Banja Luka

6. CONCLUSION

In the light of all said, it can be concluded that:

– in the period 2007-2016 there is no significant deviation of the energy of global and direct solar radiation respectively that falls on a horizontal and optimally placed surface;

– the intensity of global solar radiation increases from 320 W/m^2 in January to 800 W/m^2 in August and it decreases from August to December when it is 320 W/m^2;

– the intensity of direct solar radiation increases from 180 W/m^2 in January to 580 W/m^2 in August and it decreases from August to December when it is 190 W/m^2;

– the intensity of diffuse solar radiation increases from 170 W/m^2 in January to 220 W/m^2 in August and it decreases from August to December when it is 130 W/m^2;

– the values of the intensity of direct and diffuse solar radiation are almost the same in January, February, November and December;

– in the period from March to November, the curves of direct and diffuse radiation intensity do not coincide, whereby the intensity of direct radiation is always higher than the intensity of diffuse radiation;

– 13.89% less energy of solar radiation falls on the horizontally placed surface, and 47.31% less on the vertical placed surface in relation to the optimally placed surface;

– the one-axis tracking solar power plant generates 30.18% more electricity and the dual-axis tracking PV solar power plant generates 33.37% more electricity as compared to a fixed solar power plant.

7. ACKNOWLEDGEMENT

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АТЛАС СУНЧЕВОГ ЗРАЧЕЊА У БАЊОЈ ЛУЦИ У РЕПУБЛИЦИ СРПСКОЈ

Сажетак: У раду је представљен атлас Сунчевог зрачења за Бања Луку у Републици Српској, добијен коришћењем PVGIS програма. У атласу су дати резултати израчунавања глобалног и директног Сунчевог зрачења које пада на хоризонталну површину и глобалног Сунчевог зрачења које пада на оптимално постављену површину у Бањој Луци, у периоду од 2007. до 2016. године. Поред овога, дат је интензитет глобалног, директног и дифузног Сунчевог зрачења које пада на оптимално постављену површину у Бањој Луци по мјесецима. Утврђено је да у поређењу са Сунчевим зрачењем које пада на оптимално постављену површину, 13,89% мање Сунчевог зрачења пада на хоризонталну површину и 47,31% мање на вертикалну површину. У раду су такође дате и основне карактеристике фиксне, једноосно и двоосно ротационе PV соларне електране снаге 1 MWp, као и количина електричне енергије која се помоћу њих може добити у Бањој Луци. Утврђено је да се у поређењу са фиксном, помоћу једноосно ротационе PV соларне електране може добити 30,18% више електричне енергије, а помоћу двоосно ротационе PV соларне електране 33,37% више електричне енергије.

Кључне ријечи: PVGIS програм, Сунчево зрачење, соларна енергија, PV соларне електране.

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