SOLAR RADIATION ATLAS IN NORTHERN PART OF THE REPUBLIC OF SRPSKA

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Abstract
The paper presents an atlas of solar radiation for the northern part of the Republic of Srpska formed by PVGIS estimation utility. The atlas contains the results of calculating global solar radiation falling on the optimally placed surface in several cities located in the northern part of the Republic of Srpska (Bijeljina, Šamac, Derventa, Gradiška and Novi Grad) 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 the northern part of the Republic of Srpska is given by months. 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 the northern part of the Republic of Srpska, are also given. It was found that with the one-axis tracking solar power plant 27.97-29.36% more electricity can be generated, and with the dual-axis tracking solar power plant 30.80-32.32% more electricity can be generated as compared to the fixed solar power plant.

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

INTRODUCTION

In terms of solar potential, Bosnia and Herzegovina belong to more favorable locations in Europe, with the intensity of solar radiation falling on a horizontal surface of 1240 kWh/m^2 in the north, and up to 1600 kWh/m^2 in the south of the country [1]. Although southern part of it has higher values of solar radiation intensity, northern part of Bosnia and Herzegovina is also very convenient for solar systems installations.

PVGIS (Photovoltaic Geographical Information System–PVGIS © European Communities, 2001–2008, http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php) 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 [1-5].

NORTHERN PART OF THE REPUBLIC OF SRPSKA

The Republic of Srpska (RS) is located in the central part of the Balkan Peninsula, between 42°33’ and 45°16’ north latitude and 16°11’ and 19°37’ east longitude and occupies the northern and eastern parts of the geospatial area of Bosnia and Herzegovina. The Republic of Srpska has atypical form of state territory whose northern part is elongated west–east, and eastern in the north–south direction. This peculiar form is an aggravating circumstance of internal communication and economic integration of the interdependent western and southern parts of the Republic of Srpska. The Republic of Srpska covers an area of 25 053 km^2 or about 49% of the territory of Bosnia

and Herzegovina. RS according to the 2013 census has 1 170 342 inhabitants [1].

On the territory of the Republic of Srpska, there are three basic types of climate: moderate continental, mountain and mountain valley, and Mediterranean. Moderate continental climate occurs in the north, Mediterranean in the south, and the line dividing these two regions is the area of high mountains, plateaus, and ravines in which, depending on the altitude, the mountain climate dominates [1].

Moderate continental climate is present in the north of the Republic of Srpska. It includes Krajina, Posavina, and Semberija. In Semberija, Pannonian (steppe) climatic influence is felt due to the proximity of the Pannonian plain. The main features of this type of climate are warm summers and cold winters. Summer temperatures can rise above 40°C, and the absolute maximum was measured in 2007. In Bijeljina and Višegrad, it tops at 43°C. The average air temperature in the warmest part of the year (in July) ranges between 20°C and 23°C, while the average temperature in the coldest part of the year (January) is about zero degrees Celsius. Absolute minimum can reach up to −30°C. The average annual temperature is above 10°C. The amount of rainfall in the RS is affected by humid air masses coming from the west (from the Atlantic) and from the south (from the Adriatic). Precipitation is the most viable climate parameter in terms of space and time. In the area where temperate continental climate is present, the highest precipitation occurs in the warm part of the year and the maximum occurs in June. Precipitation amounts to around 750 l/m^2 per year in the north along the Sava River and 1500 l/m in the west of the Krajina. Moderate continental climate part is also present in the mountainous valley areas that are up to 1000 m above sea level [1].

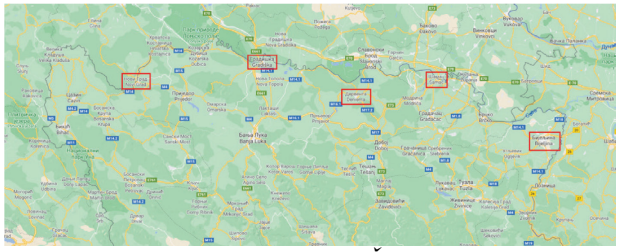

Fig. 1. *Location of Bijeljina, Šamac, Derventa, Gradiška and Novi Grad in the Republic of Srpska [6]*

Bijeljina is a city in the northeastern part of the Republic of Srpska. Bijeljina is located at 44°45'16" north latitude and at 19°12'59" east longitude, and at 90 m above sea level. In 2013, Bijeljina had 41121 inhabitants.

Šamac is a town in the Republic of Srpska. Šamac is located at 45° 03' 36" north latitude and at 18°28'08" east longitude. In 2013, Šamac had 5133 inhabitants.

Derventa is a city in the northwest part of the Republic of Srpska. Derventa is located at 44°58'40" north latitude and at 17°54'28" east longitude. In 2013, Derventa had 27404 inhabitants.

Gradiška is a town (city) in the Republic of Srpska. Gradiška is located at 45°08'46" north latitude and at 17°15'13" east longitude. In 2013, Gradiška had 13691 inhabitants.

Novi Grad is a town (city) in the Republic of Srpska. Novi Grad is located at 45°02'51" north latitude and at 16°22'50" east longitude, and at 216 m above sea level. In 2013, Novi Grad had 11063 inhabitants.

GLOBAL SOLAR RADIATION

The energy of global solar radiation falling on a surface set at an optimal angle in Bijeljina (34°), Šamac (34°), Derventa (33°), Gradiška (33°) and Novi Grad (33°) is given in Figures 2-6.

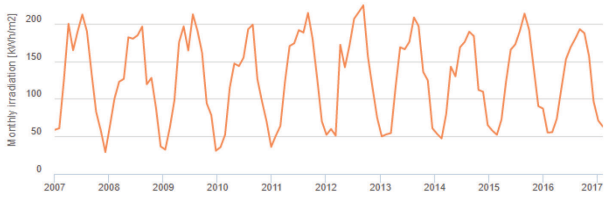

Fig. 2. *The energy of global solar radiation falling on a surface set at an optimal angle of 34° in Bijeljina [7]*

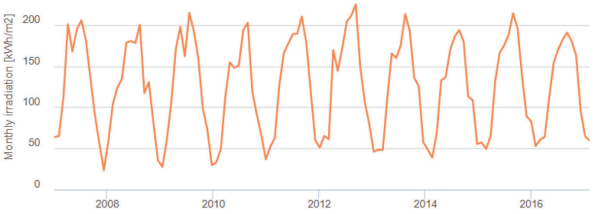

Fig. 3. *The energy of global solar radiation falling on a surface set at an optimal angle of 34° in Šamac [7]*

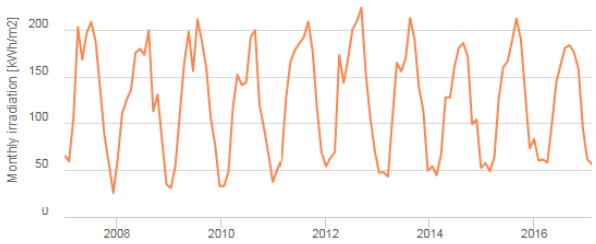

Fig. 4. *The energy of global solar radiation falling on a surface set at an optimal angle of 33º in Derventa [7]*

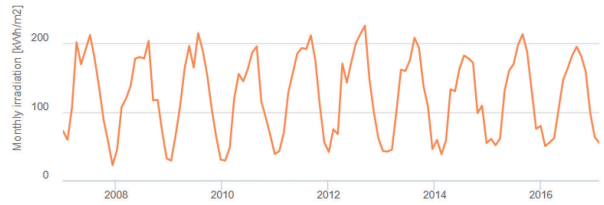

Fig. 5. *The energy of global solar radiation falling on a surface set at an optimal angle of 33º in Gradiška [7]*

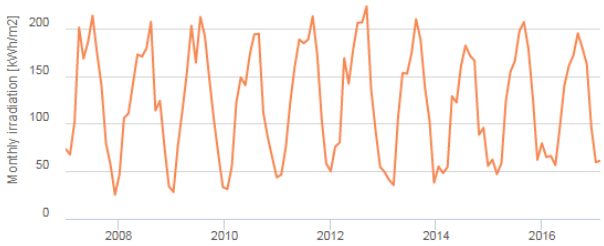

Fig. 6. *The energy of global solar radiation falling on a surface set at an optimal angle of 33º in Novi Grad [7]*

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 solar radiation falling on the optimally placed surface in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad.

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 Bijeljina, Šamac, Derventa, Gradiška and Novi Grad is shown in Tables 1-3.

Tab. 1. *The intensity of global solar radiation that falls on the optimally placed surface by months in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Town	Daily irradiance (W/m^2)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bijeljina	297	400	600	706	717	777	824	852	661	548	410	275
Šamac	292	375	590	721	727	769	835	849	664	543	394	256
Derventa	316	380	582	708	708	751	805	822	661	530	394	288
Gradiška	281	377	597	734	725	792	819	851	669	518	363	255
Novi Grad	289	396	569	687	699	763	823	841	641	491	357	285

Tab. 2. *The intensity of direct solar radiation that falls on the optimally placed surface by months in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Town	Daily irradiance (W/m^2)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bijeljina	147	210	362	436	456	517	588	620	438	350	238	139
Šamac	146	187	352	448	470	503	595	617	442	352	227	123
Derventa	165	195	349	429	443	493	567	583	434	337	228	150
Gradiška	138	193	364	466	460	537	592	620	459	324	197	125
Novi Grad	142	211	346	425	429	496	589	611	434	297	196	148

Tab. 3. *The intensity of diffuse solar radiation that falls on the optimally placed surface by months in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Town	Daily irradiance (W/m^2)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bijeljina	146	184	230	262	263	255	240	220	222	191	168	134
Šamac	142	183	230	269	269	254	227	219	214	189	162	130
Derventa	148	180	225	267	260	256	224	226	217	188	162	135
Gradiška	140	180	225	258	261	251	216	222	214	190	161	129
Novi Grad	144	180	216	253	261	255	222	222	210	189	156	134

Tables 1-3 show the following:

- the intensity of global solar radiation in the northern part of the Republic of Srpska has the lowest values in December (minimum value of 255 W/m^2 in Gradiška), and the highest values in August (maximum value of 852 W/m^2 in Bijeljina);
- the intensity of direct solar radiation in the northern part of the Republic of Srpska has the lowest values in December (minimum value of 123 W/m^2 in Šamac), except for Novi Grad where the lowest value of 142 W/m^2 was recorded in January;
- the intensity of direct solar radiation in the northern part of the Republic of Srpska has the highest values in August (maximum value of 620 W/m^2 in Bijeljina and Gradiška);
- the intensity of diffuse solar radiation in the northern part of the Republic of Srpska has the lowest values in December (minimum value of 129 W/m^2 in Gradiška), and the highest values in May (maximum value of 269 W/m^2 in Šamac), except for Derventa where the highest value of 267 W/m^2 was recorded in April.

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 Bijeljina, Šamac, Derventa, Gradiška and Novi Grad, 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 Bijeljina, Šamac, Derventa, Gradiška and Novi Grad are given in Table 4.

Tab. 4. *PVGIS characteristics of a fixed solar power plant power of 1 MWp that would be installed in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Location	Bijeljina	Šamac	Derventa	Gradiška	Novi Grad
Power of photovoltaic solar power plant (MWp)	1	1	1	1	1
Power plant losses (%)	14	14	14	14	14
Tilt angle (°)	34	34	33	33	33
Azimuth angle (°)	0	0	0	0	0
Annual electricity production (kWh)	1180536.78	1161638.61	1156601.46	1151430.06	1144201.19

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 Bijeljina, Šamac, Derventa, Gradiška and Novi Grad are given in Table 5.

Tab. 5. *PVGIS characteristics of the one-axis tracking PV solar power plant power of 1 MWp that would be installed in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Location	Bijeljina	Šamac	Derventa	Gradiška	Novi Grad
Power of photovoltaic solar power plant (MWp)	1	1	1	1	1
Power plant losses (%)	14	14	14	14	14
Tilt angle (°)	36	36	36	36	36
Annual electricity production (kWh)	1527103.13	1501207.36	1484124.7	1482526.26	1464234.26

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 Bijeljina, Šamac, Derventa, Gradiška and Novi Grad are given in Table 6.

Tab. 6. *PVGIS characteristics of the dual-axis tracking PV solar power plant power of 1 MWp that would be installed in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad [7]*

Location	Bijeljina	Šamac	Derventa	Gradiška	Novi Grad
Power of photovoltaic solar power plant (MWp)	1	1	1	1	1
Power plant losses (%)	14	14	14	14	14
Annual electricity production (kWh)	1562084.74	1534268.32	1517303.42	1514494.95	1496661.83

Based on the data shown in Tables 4 and 5, it can be seen that the one-axis tracking solar power plant generates 29.36%, 29.23%, 28.32%, 28.75%, and 27.97% more electricity in relation to a fixed solar power plant in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad, respectively. The dual-axis tracking PV solar power plant generates 32.32%, 32.08%, 31.19%, 31.53%, and 30.80% more electricity as compared to a fixed solar power plant in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad, respectively.

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 solar radiation that falls on a optimally placed surface in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad;
- the intensity of global solar radiation in the northern part of the Republic of Srpska has the lowest values in December (minimum value of 255 W/m^2 in Gradiška), and the highest values in August (maximum value of 852 W/m^2 in Bijeljina);
- the intensity of direct solar radiation in the northern part of the Republic of Srpska in most cities has the lowest values in December (minimum value of 123 W/m^2 in Šamac) and the highest values in August (maximum value of 620 W/m^2 in Bijeljina and Gradiška);
- the intensity of diffuse solar radiation in the northern part of the Republic of Srpska has the lowest values in December (minimum value of 129 W/m^2 in Gradiška), and the highest values for the most cities in May (maximum value of 269 W/m^2 in Šamac);
- the one-axis tracking solar power plant generates 29.36%, 29.23%, 28.32%, 28.75%, and 27.97% more electricity as compared to a fixed solar power plant in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad, respectively;

- the dual-axis tracking PV solar power plant generates 32.32%, 32.08%, 31.19%, 31.53%, and 30.80% more electricity as compared to a fixed solar power plant in Bijeljina, Šamac, Derventa, Gradiška and Novi Grad, respectively.

ACKNOWLEDGEMENT

This paper was done with the financial support of the project 19.032/961-100/19 approved by the Ministry of scientific and technological development, higher education and information society of the Republic of Srpska.

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