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SOLAR TECHNOLOGY: EMPOWERING SERBIA'S RENEWABLE ENERGY FUTURE

TEHNOLOGIJA IZKORIŠČANJA ENERGIJE SONCA: USPOSABLJANJE SRBIJE ZA OBNOVLJIVO ENERGIJSKO PRIHODNOST

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This study investigated the solar power potential and performance in Serbia, a country with favorable solar conditions but limited resource utilization. The principal objectives of the investigation were to analyze the performance ratio (PR) and assess the electricity production of simulated solar power plants in different distribution areas. The Photovoltaic System software (PVsyst 7.3) was employed to simulate five grid-connected solar power plants, each with a capacity of 10 MW, in five distribution areas of the Serbian Public Electric Utility Company. The study found that the PR values varied from 81.7 % to 84 %, indicating favorable conditions for harnessing the solar potential. The simulations projected an annual electricity delivery to the grid of 64.41 GWh. According to the study's estimates, installed solar power plants would be capable of meeting 0.22 % of the electricity needs in Serbia.

Keywords: solar energy, Serbia, performance ratio

V članku avtorji opisujejo študijo o raziskovanju potencialov in možnem izkoriščanju sončne energije v Srbiji. Srbija je dežela z velikim potencialom glede izkoriščanja energije sonca vendar z omejenimi finančnimi in drugimi sredstvi za njeno izkoriščanje. Glavna objekta njihove raziskave sta bila analiza oziroma določitev performančnega razmerja (PR, angl.: Performance Ratio) oziroma razmerja učinkovitosti in ocena proizvodnje elektrike na simulirani sončni (fotovoltaični) elektrarni na petih različnih geografskih delih ozemlja oziroma področjih (okrožjih) distribucije električne energije. Avtorji članka so uporabili računalniško programsko orodje Photovoltaic System software (PVsyst 7.3) za simulacijo petih v mrežo povezanih sončnih elektrarn s kapaciteto 10 MW na petih distribucijskih okrožjih srbskega elektrogospodarstva (Elektroprivreda Srbije). S pomočjo študije so ugotovili, da PR faktor varira med 81,7 % in 84 %, kar kaže na to, da so izbrana geografska (distribucijska) okrožja v Srbiji potencialno zelo ugodna za izkoriščanje sončne energije. Simulacije so pokazale, da je možna letna dobava električne energije v državno elektro omrežje enaka 64,41 GWh. V skladu s temi ocenami bi bile inštalirane sončne elektrarne sposobne pokriti 0,22 % vseh potreb po električni energiji Srbije.

Ključne besede: energija sonca, Srbija, razmerje učinkovitosti

1 INTRODUCTION

Faced with increasing challenges regarding energy sustainability and environmental protection, it is becoming increasingly clear that using renewable energy sources is vital for preserving our planet.[1–3] Conventional energy sources, such as fossil fuels, have significant negative environmental consequences, including the emission of harmful gases, degradation of water resources and destruction of biodiversity.[4–6] In this context, solar energy has become a key player in transitioning to a sustainable energy system. Harnessing solar potential offers numerous advantages, including reducing greenhouse gas (GHG) emissions, air and water pollution and independence from limited reserves of fossil fuels.[7–9]

According to the International Renewable Energy Agency (IRENA), the installed capacity of solar power plants worldwide exceeded 1.05 terawatts (TW) in 2022, marking a significant leap compared to previous years.[10] According to the data from the European Solar Industry Association (SolarPower Europe), the solar power capacity installed in the EU surpassed 200 GW in 2022. Furthermore, the organization forecasts that by 2030, the cumulative solar PV capacity in the EU will reach 920 GW.[11]

In the Republic of Serbia, the situation regarding renewable energy sources is still challenging.[12,13] Most of the country's energy mix still relies on conventional sources such as coal and oil.[14,15] However, the awareness of the need for a transition to renewable energy sources, including solar energy, is steadily growing in Serbia.[16,17] The country has more sunlight hours compared to many European nations, ranging from 1500 to 2200 hours per year.[18] On an annual basis, the average radiation energy ranges from 1200 kWh/m^2/year in the northwest to 1550 kWh/m^2/year in the southeast. These favorable conditions make solar energy a promising avenue for further

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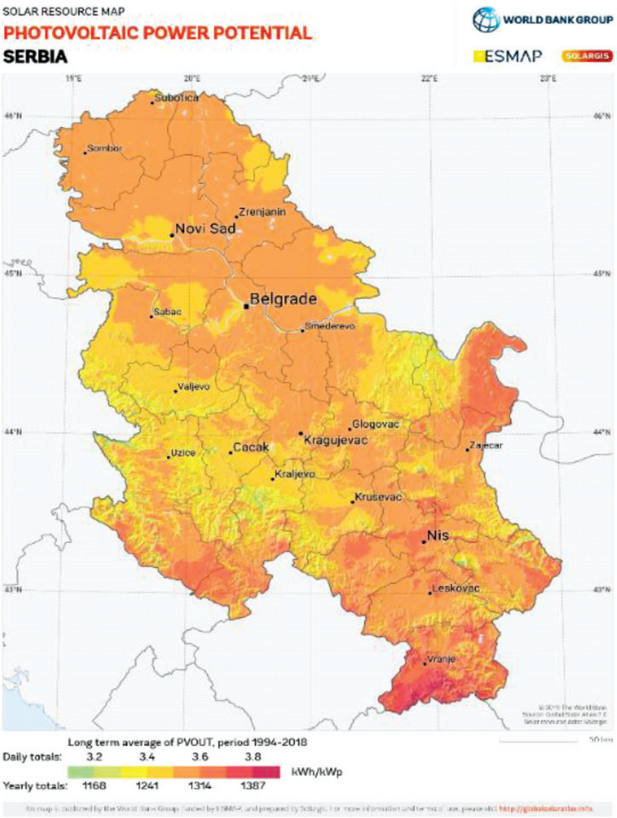

Figure 1: Serbia's PV power potential [kWh/kWp], © 2020 The World Bank, source: Global Solar Atlas 2.0, solar resource data: Solargis, (accessed on 01 July 2023)

development in Serbia.[19,20] **Figure 1** show Serbia's PV power potential from 1994–2018.[21]

According to reference[22], the Public Enterprise Electric Power Industry of Serbia had a total electricity generation capacity of 7391 MW in 2022. Out of the overall generation capacity, thermal power plants and combined heat and power plants accounted for 4376 MW or 59.20 %, while hydro power plants accounted for 3015 MW or 40.80 %. In terms of energy production, thermal power plants and combined heat and power plants contributed 22,166 GWh or 71.21 %, while hydro power plants contributed 8964 GWh or 27.89 %. The power delivered to customers through GreenEPS contracts in 2022 amounted to 1644.52 GWh, i.e., only 4.58 % of the total electricity consumption in Serbia. Solar power plants had a production capacity of 13 MW, generating 14,630 MWh of electricity. These numbers indicate that although the Republic of Serbia possesses significant solar potential, it has not effectively utilized this resource, leading to underutilization.

2 MATERIALS AND METHODS

The present study used the Photovoltaic System software (PVsyst 7.3) to simulate solar power plants. PVsyst 7.3 is an extensive software tool designed for the design, simulation and performance analysis of photovoltaic (PV) systems.[23–26] PVsyst provides detailed insights into a system performance, including energy generation and overall efficiency. The meteo data for the simulations were obtained from Metronome version 8.1. These data play a vital role in accurately assessing the potential of solar power plants and simulating their performance.

Simulations of five grid-connected solar power plants, each with a capacity of 10 MW, were conducted

Figure 2: Locations of simulated power plants and distribution areas

Table 1: Locations and characteristics of the simulated solar power plants

	DA Novi Sad	DA Belgrade	DA Kraljevo	DA Kragujevac	DA Niš
	Zrenjanin	Beograd	Tutin	Kragujevac	Vranje
Latitude	45.36 N	44.86 N	42.98 N	43.98 N	42.50 N
Longitude	20.44 E	20.23 E	20.33 E	20.86 E	21.92 E
Altitude [m]	79	84	907	234	446
Tilt – optimized	36	36	36	36	38
Azimuth – optimized	–2	–1	–1	–1	–1
No. of modules	25,002				
Pnom total	10 MWp				
Module area [m^2]	51,819				

in five distribution areas (DA) of the Serbian Public Electric Utility Company (EPS). The EPS is divided into five distribution areas established according to the territorial principle: DA Novi Sad (DA 1), DA Belgrade (DA 2), DA Kraljevo (DA 3), DA Kragujevac (DA 4) and DA Niš (DA 5). The data on the locations and characteristics of the simulated solar power plants are shown **in Table 1**.

The locations for these simulations were carefully selected based on the solar radiation map, focusing on areas with the highest irradiation levels. This approach ensures that the analysis is grounded in real-world conditions and the solar energy potential at these locations. The locations of the simulated power plants and distribution areas are shown in **Figure 2**.

The simulations used a monocrystalline/N-type (Cello technology) PV module. To achieve the desired power output of a single solar power plant, a total of 25,002 units of this PV module were used. The power plant design incorporated a total of 22 inverters. Detailed technical descriptions of the PV modules and inverters can be found in **Table 2**.

Table 2: Technical descriptions of the PV modules and inverters

PV module	
Model	LG 400 N2W-A5
Cell type	Monocrystalline / N-type
Dimensions (L × W × H)	2024 × 1024 × 40 mm
Maximum power (Pmax)*	400
MPP voltage (Vmpp)*	40.6
MPP current (Impp)*	9.86
Open circuit voltage (Voc)*	49.3
Short circuit current (Isc)*	10.47
Module efficiency*	19.3
*STC (standard test condition): irradiance of 1000 W/m^2, ambient temperature of 25 °C, AM 1.5	
Inverter	
Model	SUN2000-100KTL-M1-400Vac
Nom. power	100 kWac
Operating voltage	200–1000 V
Pnom ratio	1.3

The PR is a significant parameter within the PVsyst software, providing crucial insights into the modeled system. It is a metric used to assess the efficiency and overall performance of a PV system or solar power plant. The PR allows an overall assessment of a PV array's performance. The PR is obtained with Equation (1).[27,28]

$$PR = \frac{Y_{\mathrm{A}}}{Y_{\mathrm{R}}} \cdot 100\ (\%) \tag{1}$$

The array yield (Y_A) allows evaluating and comparing the performance of PV modules by measuring their energy output relative to their rated power. It represents the time, measured in hours per day, during which a PV array needs to operate at its nominal power to generate the total energy produced. Y_A is calculated with Equation (2).[29]

$$Y_{\mathrm{A}} = \frac{E_{\mathrm{PV}}}{P_{\mathrm{nom}}}\ (\mathrm{h}) \tag{2}$$

The reference yield (Y_R) is defined as the ratio of the insolation (H) to the irradiance under standard test conditions, specifically for an irradiance level of 1000 W/m^2. It provides a standardized measure of the energy production potential under ideal conditions. Y_R calculation is given in Equation (3).[30]

$$Y_{\mathrm{R}} = \frac{H}{G_{\mathrm{STC}}}\ (\mathrm{h}) \tag{3}$$

Table 3: Values of the PR, GHI, GI and ambient temperature average

	Zrenjanin	Belgrade	Tutin	Kragujevac	Vranje
GHI [kWh/m^2]	1276.2	1285.5	1386.0	1318.6	1448.7
GI [kWh/m^2]	1463.6	1466.3	1577.5	1509.8	1680.7
Ambient temperature average [°C]	12.51	12.85	7.89	11.78	11.71
Month	Performance ratio				
January	0.873	0.888	0.903	0.898	0.911
February	0.869	0.884	0.896	0.884	0.884
March	0.845	0.854	0.863	0.854	0.851
April	0.822	0.835	0.847	0.837	0.843
May	0.805	0.816	0.835	0.815	0.826
June	0.792	0.804	0.819	0.808	0.816
July	0.784	0.797	0.811	0.797	0.802
August	0.790	0.796	0.814	0.803	0.804
September	0.808	0.820	0.831	0.824	0.816
October	0.835	0.841	0.856	0.844	0.857
November	0.848	0.862	0.875	0.878	0.876
December	0.877	0.886	0.902	0.894	0.897
Average	0.817	0.828	0.845	0.833	0.840

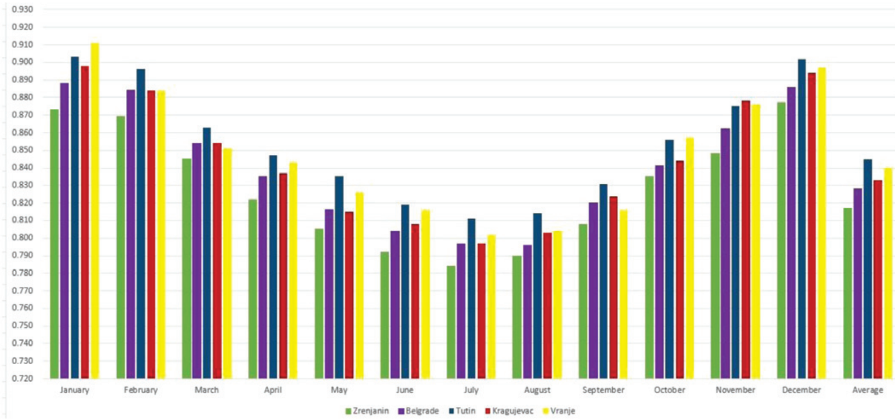

Figure 3: Obtained PR values

Table 4: Data on DA electricity consumption[31] and the value of electricity supplied to the grid from the solar power plants [GWh]

Month	DA 1 consumtion	Zrenjanin	DA 2 consumtion	Belgrade	DA 3 consumtion	Tutin	DA 4 consumtion	Kragujevac	DA 5 consumtion	Vranje
I	800.5	0.535	905.8	0.51	722.2	0.75	212.2	0.62	496.8	0.79
II	690.3	0.67	741.4	0.73	619.2	0.9	180.5	0.83	422.9	0.99
III	761.5	1.07	805.5	1.1	675.8	1.23	197.7	1.13	464.1	1.27
IV	643.1	1.2	629.1	1.2	556.1	1.21	165	1.18	371.6	1.25
V	576.4	1.33	527.5	1.33	496.7	1.37	143.3	1.3	325	1.41
VI	593.8	1.36	539.9	1.37	489.3	1.44	139.6	1.38	316.9	1.46
VII	625.3	1.46	558.5	1.47	529.8	1.47	149.9	1.42	336.7	1.48
VIII	606.9	1.38	541.9	1.4	515.5	1.48	148.7	1.4	332.9	1.48
IX	567.8	1.07	509.3	1.11	499.7	1.23	139.1	1.15	322.9	1.27
X	620.1	0.95	567.8	0.91	553.2	1.12	155.6	0.98	361.8	1.14
XI	685.9	0.57	682.1	0.59	599.8	0.78	170.3	0.67	385.9	0.83
XII	759.1	0.33	815.1	0.37	670.9	0.59	196	0.48	439.2	0.71
Σ	7930.9	11.96	7821.1	12.14	6928.3	13.62	1998.2	12.58	4577	14.11

3 RESULTS

The simulations provided valuable insights into the plants' performance, represented by the calculated PR values. These PR values are graphically depicted in **Figure 3**. Additionally, **Table 3** presents the numerical values of the PR, global horizontal irradiation (GHI), global irradiation in the collector plane (GI), and ambient temperature average.

Table 4 presents comparative data on the electricity consumption per month in distribution areas, along with

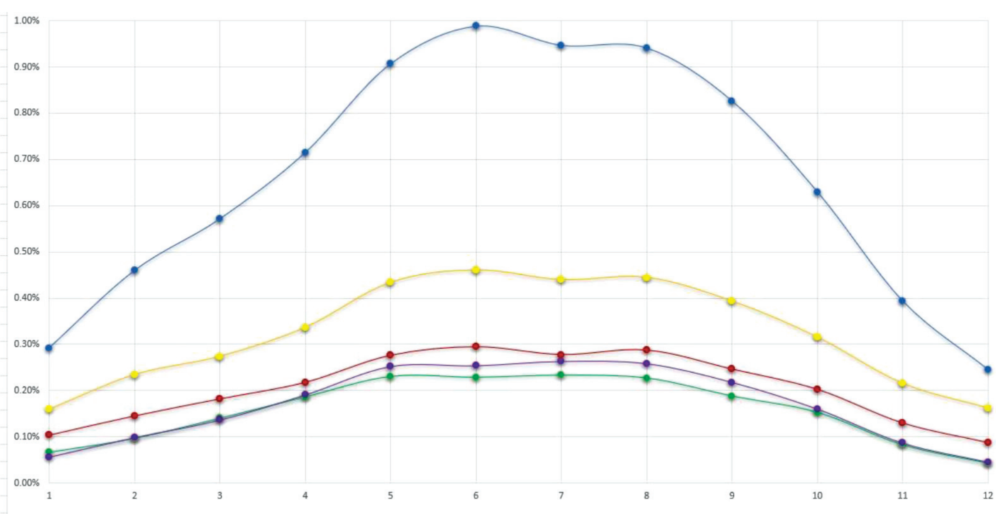

Figure 4: Graphical representation of the electricity demand satisfaction in DAs

the data, obtained through simulations of the solar power plants, on the amount of electricity delivered to the grid.

Table 5 presents data on the percentage of electricity demand fulfillment in the distribution areas using the electricity generated from the solar power plants, displayed on a monthly basis. Additionally, **Figure 4** shows a graphical representation of the obtained values depicting the percentage of electricity demand satisfaction.

Table 5: Percentage of electricity demand satisfaction in DAs

Month	DA 1	DA 2	DA 3	DA 4	DA 5
I	0.07 %	0.06 %	0.10 %	0.29 %	0.16 %
II	0.10 %	0.10 %	0.15 %	0.46 %	0.23 %
III	0.14 %	0.14 %	0.18 %	0.57 %	0.27 %
IV	0.19 %	0.19 %	0.22 %	0.72 %	0.34 %
V	0.23 %	0.25 %	0.28 %	0.91 %	0.43 %
VI	0.23 %	0.25 %	0.29 %	0.99 %	0.46 %
VII	0.23 %	0.26 %	0.28 %	0.95 %	0.44 %
VIII	0.23 %	0.26 %	0.29 %	0.94 %	0.44 %
IX	0.19 %	0.22 %	0.25 %	0.83 %	0.39 %
X	0.15 %	0.16 %	0.20 %	0.63 %	0.32 %
XI	0.08 %	0.09 %	0.13 %	0.39 %	0.22 %
XII	0.04 %	0.05 %	0.09 %	0.24 %	0.16 %
Average	0.15 %	0.16 %	0.20 %	0.63 %	0.31 %

4 DISCUSSION

As presented in **Figure 3** and **Table 3**, the PR values obtained from the simulations demonstrate favorable conditions for installing solar power plants. The lowest PR value was observed for DA 1 in July, amounting to 78.4 %, while the highest value was recorded for DA 5 in January, reaching 91.1 %. The PR values across all simulations were higher during the winter than the summer period, indicating the dependence of solar panel efficiency on the temperature, where an increased temperature leads to a decreased efficiency.[32,33] The highest average PR value was observed for DA 3, amounting to 84.5 %, while the lowest value of 81.7 % was recorded for DA 1.

According to the solar radiation map, the GHI values align with the expected values. The lowest GHI value of 1276.2 kWh/m^2 was observed in the northernmost DA 1, while the highest value of 1448.7 kWh/m^2 was recorded in the southernmost DA 5. The GHI values are inversely proportional to the PR, meaning that during the summer months, the GHI is higher, while during the winter period, it is lower (up to 7 times lower). The average ambient temperature also significantly influences the efficiency of solar power plants, as lower temperatures result in higher PR values.

The selected locations and the obtained results highlight the significance of the temperature impact on the efficiency of solar panels. Furthermore, this study underscores the interconnectedness between the location and altitude in determining the performance of solar power plants. Higher altitudes, as exemplified by the geographic context of Serbia within a continental climate, are characterized by low average temperatures that are conducive to enhanced solar panel efficiency. The results of this research substantiate this correlation as the location with the highest altitude (DA 3) exhibits the highest performance ratio (PR). In contrast, the site with the lowest altitude (DA 1) records the lowest PR. This observation reinforces the idea that elevated locations with reduced average temperatures offer a favorable environment for solar energy production. These findings have practical implications for an optimal placement and operation of solar power facilities in regions with varying altitudes and climate conditions.

From **Table 4**, it can be observed that the lowest quantity of electricity delivered to the grid was recorded in December in DA 1, amounting to 0.33 GWh. Additionally, DA 1 achieved the lowest electricity production among all the simulated solar power plants, with an annual quantity of electricity delivered to the grid of 11.96 GWh. The highest value was observed in DA 3 in August, with a quantity of 1.48 GWh. Similar values were achieved in DA 5 in July and August, albeit slightly lower. The highest quantity of electricity delivered to the grid was achieved in DA 5, with a quantity of 14.11 GWh.

The percentage of electricity demand fulfillment shown in **Table 5** and **Figure 4** greatly depends on a DA's population density. Similar fulfillments of electricity demand are visible in DA 1, DA 2 and DA 3. This is mainly due to similar numbers of consumers and similar electricity consumptions in these areas. A slightly higher fulfillment of electricity demand is observed in DA 5, while DA 4 exhibits values that are, on average, three times higher. A common characteristic of all the distribution areas is the fact that during the summer period, the fulfillment of electricity demand is significantly higher. This is primarily due to a lower electricity consumption during the summer months and an increased electricity production during that period.

5 CONCLUSIONS

Several key conclusions can be drawn based on the analysis of the provided data. The PVsyst software simulations revealed favorable conditions for installing solar power plants in Serbia. The performance ratio values indicated an efficient operation. The global horizontal irradiation values were consistent with the expectations. Lower ambient temperatures positively impacted the PR values, indicating an improved performance in cooler conditions.

The electricity production analysis indicated variations among different distribution areas. DA 1 exhibited the lowest electricity amount delivered to the grid, while DA 3 had the highest value. The percentage of electricity demand fulfillment varied based on the population density of each distribution area. DA 1, DA 2 and DA 3 exhibited similar levels of fulfillment due to comparable consumer numbers and electricity consumptions, while DA 4 displayed the highest average values. Installed solar power plants would meet 0.22 % of the electricity needs in the Republic of Serbia.

This study provides researchers with crucial insights and is a valuable resource for future solar power plant investments in Serbia. The projected installation of a solar power capacity of 300 MW by the end of 2025[34] emphasizes the importance of such research. Investors can utilize the findings to make informed decisions regarding the site selection, efficiency optimization, and meeting future electricity demands. The study's comprehensive analysis contributes to the knowledge base of renewable energy sources and supports the transition towards a more sustainable energy landscape in Serbia.

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