SIMULATION OF PHOTOVOLTAIC SYSTEMS ELECTRICITY GENERATION USING HOMER SOFTWARE IN SPECIFIC LOCATIONS IN SERBIA

by

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In this paper basic information of Homer software for photovoltaic system electricity generation, NASA – Surface meteorology and solar energy database, RETScreen, PVGIS and HMIRS (Hydrometeorological Institute of Republic of Serbia) solar databases are given. The comparison of the monthly average values for daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, PVGIS, and HMIRS solar databases for three locations in Serbia (Belgrade, Negotin, and Zlatibor) is given. It was found that the annual average values of daily solar radiation taken from RETScreen solar database are the closest to the annual average values of daily solar radiation taken from HMIRS solar database for Belgrade, Negotin, and Zlatibor. Monthly and total for year values of electricity production of fixed on-grid photovoltaic system of 1 kW with optimal inclinated and south oriented solar modules, in Belgrade, Negotin, and Zlatibor using HOMER software simulation based on data for daily solar radiation taken from NASA, RETScreen, PVGIS, and HMIRS databases are calculated. The relative deviation of electricity production of fixed on-grid photovoltaic system of 1 kW using HOMER software simulation based on data for daily solar radiation taken from NASA, RETScreen, and PVGIS databases compared to electricity production of fixed on-grid photovoltaic system of 1 kW using HOMER software simulation based on data for daily solar radiation taken from HMIRS databases in Belgrade, Negotin, and Zlatibor are given.

Key words: *HOMER software, RETScreen, PVGIS, NASA – surface meteorology and solar energy database, on-grid photovoltaic systems*

Introduction

In the world market there is an apparent extent of solar database and software programs available for analyzing solar photovoltaic (PV) systems, either commercially available or not. Solar resource information is needed in all stages of the development of a PV project. Reliable solar radiation statistics is required for system siting, design, and for financing. In most cases, monthly averages, probability statistics of typical meteorological years (TMY) is sufficient. This information is sufficient also for the manufacturing industry and for policy makers defining support programmes. Some of solar database are: NASA – Surface meteorology and solar energy database, RETScreen solar database, PVGIS solar database, HelioClim-1, Metenorm, European solar radiation atlas, SoDa service, Solar and wind energy resource assessment (SWERA), *etc*.

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Solar PV software simulators on the market are designed with different goals in mind and have various limitations for solving certain problems. The desirable features of softwares for manufacturing simulation depend on the purpose of their use. Each software works in its specific area of application in solar PV systems. As more PV systems are installed there will be an increase in demand for software that can be used for design, analysis, and troubleshooting. There are 12 major types of softwares for simulating solar PV system: RETScreen, PV F-Chart, SolarDesign Tool, INSEL, TRNSYS, NREL Solar Advisor Model, ESP-r 11.5, PVSYST 4.33, SolarPro, PV DesignPro-G, PV*SOL Expert, HOMER, and many others available are DDS-CAD PV, Polysun, APOS PV StatLab, PV Designer, SolarNexus, Valentin Software, PV Cost Simulation Tool, PV Potential Estimation Utility, SolmetricIPV, Solmetric Suneye, Blue Oak Energy, and Solar Pro Magazine's Solar Select, Seneca Software & Solar, Inc., Sombrero, Horizon, Panorama master, METEONORM, GOSOL, Shadows, Shadow Analyser, SPYCE, ECOTECT, Tetti FV, Kerychip, PV Professional, Pvcad, Meteocontrol, *etc*. [1-3].

When designing PV system it is necessary to analyze data on sun radiation for given locations. Since data on sun radiation are different for each source – solar database and for each location, following questions are posed: which source of data is most reliable, which data predict highest generation of electrical energy, and which the lowest, what is the difference between them, *etc*.

The aim of this paper is to examine three different databases in order to identify the one with the most accurate data for three areas in Serbia, by comparing them with actual measurements of the Hydrometeorological Institute of the Republic of Serbia (HMIRS). The bias in various solar data sources can have significant effects on the prediction of PV performance, especially in the areas where there is no robust network of solar measurement devices such as Serbia.

This paper compares amount of electricity generated by on-grid fixed PV system of 1 kW with solar modules oriented southwards under optimal angle for three representative locations in Serbia (Belgrade-capital, Negotin-Eastern Serbia, and Zlatibor-Western Serbia). Calculations of electricity were performed by HOMER software. HOMER software defines parameters of on-grid PV system and input data for daily solar radiation per square meter received by the horizontal surface generated by four different solar databases: NASA – Surface meteorology and solar energy database, RETScreen database, PVGIS database, and HMIRS database. The end of the paper states relative deviation of the amount of electricity generated in the course of the year by simulation in HOMER software using values for daily solar radiation taken from NASA, RETScreen, and PVGIS databases in relation to the amount of electricity generated by measured (real) values for daily solar radiation from HMIRS solar database (reference database). Solar databases for daily solar radiation for the specific locations within the territory of Serbia are presented and analysed in order to achieve useful details and assessment for the potentials of solar PV utilization in three representative locations in Serbia. Some data and considerations given in this paper can be used by customers or companies keen to invest in the PV sector in Serbia.

HOMER software

Hybrid Optimization Model for Electric Renewables (HOMER) is a computer model developed in 1992 by the U. S. National Renewable Energy Laboratory (NREL) to assist in the design of micropower systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different design options based on their technical and economic merits.

Renewable power sources add further complexity because their power output may be intermittent, seasonal, and non-dispatchable, and the availability of renewable resources may be uncertain. HOMER was designed to overcome these challenges. HOMER simulates and optimises stand-alone and grid-connected power systems comprising any combination of PV arrays, wind turbines, run-of-river hydro power, biomass power, internal combustion engine generators, microturbines, fuel cells, batteries, and hydrogen storage, serving both electric and thermal loads (by individual or district-heating systems).

The simulation considers a one year time-period using a minimum time-step of 1 minute. It performs sensitivity analyses which can help the analyst to do what-if analyses and to investigate the effects of uncertainty or changes in input variables. The objective of the optimisation simulation is to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability [4-8].

Definition of PV system components in HOMER

Having in mind that all calculations in this paper use on-grid fixed PV system with optimally inclinated and south-oriented solar modules, it is necessary to clearly define all components and parameters needed for the simulation of on-grid PV system in HOMER software.

On-grid fixed PV system denotes a system using solar modules mounted on fixed metal supporters under optimal angle in relation to the horizontal surface to convert solar radiation into the electrical energy. PV system consists of solar modules, inverter converting DC into AC and switches and related connections giving the generated power into the grid net. On-grid PV systems represent one of the ways to decentralize the electric power network grid. The electrical energy is generated by these systems nearer to the locations in demand for the electricity and not only by thermo, nuclear or huge hydro power plants. Over time these systems will reduce the need to increase the capacity of the transmitting and distributive lines [5, 6, 8-11].

PV array model

Following values were needed to populate the model for the PV array: size [kW], output current (AC or DC), operational lifetime (year), derating factor [%], slope [degree], azimuth (degree W or S), ground reflectance [%], and type of tracking system used.

The model for the PV array in these simulations was a more generic model; that is, it was a model of a typical array rather than a specific array currently in production. This was relatively straightforward since HOMER calculates PV power production based on the rated capacity of the array. In other words values such as the relative efficiency were already rolled into the rated capacity figures. The PV derating factor is a scaling factor that HOMER applies to the PV array power output to account for reduced output in real-world operating conditions compared to the conditions under which the PV panel was rated. HOMER also uses a derating factor to reduce the actual output of the solar array relative to its rated capacity. This factor is designed to account for "soiling of the panels, wiring losses, shading, snow cover, aging, *etc.* [5, 6, 8, 12]. The lifetime of PV modules depends on the solar cell technology used as well. For monocrystalline and polycrystalline silicon solar cells most manufacturers give a warranty of 10/90 and 25/80 which means: a 10-year warranty that the module will operate at above 90% of nominal power and up to 25 years above 80%. The practical lifetime of the silicon-made PV modules is expected to be at least 30 years [9, 13]. The ground reflectance (also called albedo) is the fraction of solar radiation incident on the ground that is reflected. A typical value for grass-covered areas is 20%. Snow-covered areas may have a reflectance as high as 70%. This value is used in calculating the radiation incident on the tilted PV panels, but it has only a modest effect [5-6].

Each hour of the year, HOMER calculates the global solar radiation incident on the PV array using the Hay, Davies, Klucher, Reindl (HDKR) model, explained in Section 2.16 of Duffie and Beckmann [14]. This model takes into account the current value of the solar resource (the global solar radiation incident on a horizontal surface), the orientation of the PV array, the location on Earth's surface, the time of year, and the time of day. The orientation of the array may be fixed or may vary according to one of several tracking schemes. Based on data of daily solar radiation, HOMER automatically calculated average monthly values of clearness index and amount of electricity by the optimally inclinated PV modules.

In the solar resource input window users specify, for each time step, the global solar radiation. That is the total amount of solar radiation striking the horizontal surface on the earth. But the power output of the PV array depends on the amount of solar radiation striking the surface of the PV array, which in general, is not horizontal. So in each time step HOMER automatically calculates the global solar radiation incident on the surface of the PV array, which is based on the analitic methods in the first two chapters of Duffie and Beckman [14] described in reference. Unfortunately, HOMER does not display numerical values of global solar radiation on optimally inclinated surface but automatically uses them to calculate the amount of the electricity of PV array [5, 6].

The input values we used were: 1 kW size, DC output current, 25 years operational lifetime, derating factor, Simulation dependent – 95, Slope – 34° for Belgrade, 32° for Negotin, and 36° for Zlatibor, Azimuth – 0°, 20% ground reflectance and no tracking system. Optimal module inclination for each city is taken from PVGIS and input in HOMER.

Inverter model

Inverter is a device that converts electric power from DC to AC in a process called inversion, and/or from AC to DC in a process called rectification. The inverter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of AC power that the device can produce by inverting DC power. The user specifies the rectifier capacity, which is the maximum amount of DC power that the device can produce by rectifying AC power, as a percentage of the inverter capacity. The rectifier capacity is therefore not a separate decision variable. The relevant values needed for this simulation are: size (kW), lifetime (year), inverter efficiency [%], and rectifier efficiency [%] [5, 6, 15].

The following (default) input values we used were: 1 kW size; 15 years lifetime; 95% inverter efficiency, and 95% rectifier efficiency.

Solar resources

Quantity of solar radiation incidence 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, surface inclination, *etc*. These data are very important because of their use in calculations of the cost effectiveness of equipment using solar radiation.

To model a system containing a PV array, the HOMER user must provide solar resource data for the location of interest. Solar resource data indicate the amount of global solar radiation (beam radiation coming directly from the sun, plus diffuse radiation coming from all parts of the sky) that strikes Earth's surface in a typical year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface, in kW/m^2, monthly average global solar radiation on the horizontal surface, in kWhm^{2}per day, or monthly average clearness index. The clearness index is the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere. A number between zero and one, the clearness index is a measure of the clearness of the atmosphere [5, 6, 16]. There are two ways to create solar baseline data: users can directly use HOMER to synthesize data from NASA – surface meteorology and solar energy database, or users can import hourly radiation data from a file. If the user chooses to provide monthly solar resource data, HOMER generates synthetic hourly global solar radiation data using an algorithm developed by Graham and Hollands [17].

In this paper data on daily solar radiation per square meter received by the horizontal surface needed for the simulation of on-grid fixed PV system of 1 kW by HOMER software were taken from four different solar databases: NASA – surface meteorology and solar energy database, RETScreen solar database, PVGIS solar database, and HMIRS – solar database.

NASA – Surface meteorology and solar energy database

NASA, through its Science Mission Directorate, has long supported satellite systems and research providing data important to the study of climate and climate processes. These data include long-term estimates of meteorological quantities and surface solar energy fluxes.

These satellite and modeled based products have been shown to be accurate enough to provide reliable solar and meteorological resource data over regions where surface measurements are sparse or non-existent, and offer two unique features – the data are global and, in general, contiguous in time. These two important characteristics, however, tend to generate very large data archives which can be intimidating for commercial users, particularly new users with little experience or resources to explore these large data sets. To foster the commercial use of the global solar and meteorological data, NASA supported, and continues to support, the development of the Surface meteorology and Solar Energy (SSE) dataset that has been formulated specifically for the PV and renewable energy system design needs. The SSE data set is formulated from NASA satellite and re-analysis-derived insolation and meteorological data for the 22-year period, July 1983 through June 2005. Results are provided for 1° latitude by 1° longitude grid cells over the globe. Average daily and monthly measurements for 1195 World Radiation Data Centre ground sites are also available. The SSE parameters are available via user-friendly web-based applications founded on user needs. NASA's SSE dataset provides monthly average solar radiation data for everywhere on earth. The data are directly linked to design tools such as HOMER and RETscreen [16, 18, 20].

RETScreen (Renewable Energy Technology Screen) software and solar database

The RETScreen clean energy project analysis software is a decision support tool developed with the contribution from government, industry, and academia. It was originally developed in 1996 by Natural Resources Canada (NRCan) CANMET Energy Technology Centre for renewable energy technologies analysis. The software, provided free-of-charge from [http://www.nrel.gov/] and [http://www.retscreen.net/], can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of renewable energy and energy efficient technologies. The RETScreen software is available in multiple languages and also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook. Also, the RETScreen software provides users' access to climatic data from ground monitoring stations, or as an alternative, to the NASA Space Environments and Effects (SEE) satellite-derived data sets.

Ground-based meteorological data includes averages of ground-based observations for over 6,500 sites around the world, compiled from over 50 different sources for the period 1982 to 2006.

NASA's satellite-derived meteorological data for any location on earth is provided for use with the RETScreen software via the NASA prediction of worldwide energy resource (POWER) project. The current NASA data set is formulated from data gathered for a 20-year period starting in July 1983, using a 1-degree cell. At mid-latitudes (45°), the cell size is approximately 80·110 km. Solar irradiance values are inferred using satellite observations of the atmosphere and Earth's surface. The other meteorological parameters (*e. g*. temperature, humidity, *etc*.) are adapted from the NASA's Global Modeling and Analysis Office (GMAO), Goddard Earth observing system (GEOS v. 4.0.3) meteorological analysis [8, 16, 21].

PVGIS solar database

Photovoltaic Geographical Information System (PVGIS©) European Communities, 2001-2008 is a part of the SOLAREC action aimed at contributing to the implementation of renewable energy in the EU. SOLAREC is an internally funded project on PV solar energy for the 7th framework programme. PVGIS has been developed at the Joint Research Centre (JRC) of the European Commission within its Renewable Energies Unit since 2001 as a research Geographical Information Systems (GIS) oriented tool for the performance assessment of solar PV systems in European geographical regions. From the very start of its functioning PVGIS was envisaged to be locally used, however access to the PVGIS database and estimations were drawn as open system access for professionals and the general european public as well by means of the web-based interactive applications. PVGIS provides data for the analysis of the technical, environmental, and socio-economic factors of solar PV electricity generation in Europe and supports systems for EU countries solar energy decision-makings.

There are various databases and PV estimation tools offering solar radiation and other climatic data useful for an assessment of the PV potential for specific location worldwide: European Solar Radiation Atlas (ESRA), Saolar Radiation Data (SoD), NASA SSE, Meteonorm, *etc*. PVGIS as a solar radiation database has advantages over other similar databases as an open data and software PV estimation tool with an excellent geographical grid resolution (1 km × 1 km) and map based user-friendly interface, providing easy-understandable information for PV geographical assessments. The estimated accuracy of PVGIS calculations is proven to be within several percents. Detailed geographical, climatic and other data make PVGIS on-line calculator ideally suited, not only for non-professionals and initial PV system estimations, but also even for serious PV systems design as part of the integrated management of distributed energy generation, for specifically selected locations in Europe. The methods used by PVGIS to estimate PV system output have been described in a number of papers. The basis for the European part of PVGIS is a dataset with 10 years of data from 566 ground stations in Europe measuring global horizontal radiation and in some cases diffuse radiation. The station data were collected and processed as a part of the ESRA and published as monthly averages of daily irradiation sums [9, 13, 16, 19, 22-24]. The construction of high spatial resolution data sets for solar radiation has been previously reported [25, 26]. The computational approach is based on a solar radiation model (r.sun model), and the spline interpolation techniques (s.surf.rst and s.vol.rst) that are implemented within the open-source GIS software GRASS. The r.sun model algorithm uses the equations published in the ESRA. This is certainly a powerful tool that can be used for the development of new solar power plants that will obviate climate change and promote sustainable development through poverty alleviation [19, 27, 28]. More details of the r.sun model and the spline interpolation techniques (s.surf.rst and s.vol.rst) can be found in some key references [29-32]. Other details of the PVGIS methodology and development can be found in some key reference papers [33, 34].

In this paper PVGIS-3 is used. The PVGIS-3 data set is based on measurements made on the ground in the period 1981-1990 which are then interpolated between points to get radiation values at any point. A new version PVGIS-CMSAF has been recently introduced which uses the new databases for the solar radiation data provided by the Climate Monitoring Satellite Application Facility (CMSAF) from the period 1998-2010. Due to the possible wrong terrestrial measurements and to the fact that the amount of solar radiation has increased over Europe in the last 30 years, calculations with new PVGIS-CMSAF give higher values than with the older PVGIS-3. For the territory of Serbia PVGIS-CMSAF gives up to 5% higher values for the solar irradiation data [13, 22].

HMIRS

Organized measurements of the solar radiation started on the territory of the former Yugoslavia in 1957, with the network of 13 measuring stations which were equipped with pyranometers for the registering of global solar radiation [35]. By the decision of the World Meteorological Organization Yugoslavia took part in the program of the world monitoring and has regularly sent data to the World center for data on irradiation in St. Petersburg, where these data are stored in data base nowadays available through the internet. By the shutdown of the Yugoslav National Center for Solar Radiation in 1988 network of stations has gradually been shutdown so that in 1991 it stopped completely measurements of solar radiation. HMIRS began to reestablish solar radiation measurements only at the end of 2009 [35-37].

The measured values for daily solar radiation collected by Yugoslav National Center for Solar Radiation during the period 1964-1991 are used here. Measured values and data obtained for intensity of global, diffuse, and reflected solar radiation were measured by pyranometers Moll-Gorczynski, class II [35]. Direct solar radiation was measured by pyrheliometers Linke Feussner, class II. Duration of solar radiation was measured by Campbell-Stokes heliograf. These solar data were measured in the measuring stations of Serbia in Belgrade-Zeleno Brdo, Negotin, and Zlatibor. Analysis of the solar data is performed on the basis of the recommendation of the World Meteorological Organization (WMO).

Results and discussion

In many scientific works and papers of international importance various solar databases and HOMER and other PV softwares for assessments and perspectives of PV solar power engineering in the world, such as [8, 9, 11-13, 19, 24, 27, 28, 33-38, *etc*., were used. This section gives the results obtained upon the study of the daily solar radiation per square meter received by the horizontal surface taken from different databases and electricity generated by on-grid fixed PV system of 1 kW with optimally inclined and south-oriented solar modules, in three representative cities of Serbia: Belgrade-capital (44°48' north latitude and 20°27' east longitude), Negotin-eastern Serbia (44°13' north latitude and 22°31' east longitude) and Zlatibor-Western Serbia (43°43' north latitude and 19°41' east longitude), processed by the HOMER software simulation.

Solar radiation

The SSE data set which is formulated from NASA satellite- and reanalysis-derived insolation and meteorological data for the 22-year period July 1983 through June 2005; RETScreen solar database which includes averages of ground-based observations for over

Table 1. Monthly and annual average values for clearness index and daily solar radiation at the horizontal surface for Belgrade, Negotin, and Zlatibor

Location	Month	Average values for daily solar radiation at the horizontal surface [$kWh^{-1}m^{-2}d^{-1}$]				Clearness index			
		NASA database	RETScreen database	PVGIS database	HMIRS database	NASA database	RETScreend database	PVGIS database	HMIRS database
Belgrade 44°48' north latitude and 20°27' east longitude	Jan	1.42	1.39	1.25	1.49	0.415	0.407	0.366	0.436
	Feb	2.27	2.15	2.00	2.24	0.467	0.442	0.412	0.461
	Mar	3.34	3.38	3.17	3.47	0.478	0.484	0454	0.497
	Apr	4.25	4.50	4.36	4.72	0.460	0.487	0.472	0.511
	May	5.30	5.59	5.53	5.80	0.487	0.513	0.508	0.533
	Jun	5.81	6.12	5.98	6.19	0.501	0.528	0.516	0.534
	Jul	5.97	6.29	6.30	6.27	0.532	0.561	0.561	0.559
	Aug	5.38	5.53	5.55	5.59	0.547	0.562	0.564	0.569
	Sep	3.87	4.19	4.14	4.26	0.500	0.541	0.535	0.550
	Oct	2.61	2.88	2.71	2.92	0.476	0.526	0.495	0.533
	Nov	1.50	1.54	1.50	1.74	0.402	0.412	0.402	0.466
	Dec	1.17	1.10	1.06	1,06	0.391	0.391	0.367	0.354
	Annual	3.58	3.73	3.64	3.82	0.488	0.509	0.496	0.520
Negotin 44°13' north latitude and 22°31' east longitude	Jan	1.44	1.35	1.26	1.45	0.409	0.384	0.358	0.412
	Feb	2.24	2.00	1.90	2.11	0.452	0.404	0.383	0.426
	Mar	3.28	3.25	2.94	3.65	0.464	0.460	0.416	0.516
	Apr	4.09	4.55	4.30	4.86	0.440	0.490	0.463	0.523
	May	5.14	5.66	5.39	6.47	0.471	0.519	0.494	0.593
	Jun	5.79	6.38	6.09	6.83	0.499	0.550	0.525	0.589
	Jul	6.06	6.62	6.18	7.07	0.540	0.589	0.550	0.629
	Aug	5.36	5.66	5.53	6.11	0.543	0.573	0.560	0.619
	Sep	3.85	4.38	4.16	4.74	0.493	0.561	0.533	0.607
	Oct	2.49	2.74	2.56	3.23	0.447	0.492	0.460	0.580
	Nov	1.50	1.48	1.45	1.60	0.391	3.860	0.378	0.417
	Dec	1.15	1.12	0.994	1.24	0.372	0.362	0.321	0.401
	Annual	3.54	3.78	3.57	4.13	0.478	0.510	0.482	0.557
Zlatibor 43°43' north latitude and 19°41'east longitude	Jan	1.64	1.68	1.66	1.53	0.455	0.466	0.461	0.425
	Feb	2.43	2.48	2.38	2.35	0.482	0.492	0.473	0.467
	Mar	3.43	3.49	3.50	3.36	0.481	0.489	0.491	0.471
	Apr	4.12	4.40	4.64	4.37	0.442	0.472	0.497	0.468
	May	4.94	5.29	5.50	5.31	0.452	0.484	0.503	0.486
	Jun	5.67	5.79	6.04	5.58	0.489	0.499	0.521	0.481
	Jul	5.97	6.00	6.52	5.80	0.531	0.534	0.580	0.516
	Aug	5.28	5.42	5.68	5.34	0.533	0.547	0.574	0.539
	Sep	3.90	4.22	4.31	4.08	0.496	0.536	0.548	0.518
	Oct	2.62	3.04	2.97	2.98	0.464	0.538	0.526	0.528
	Nov	1.58	1.88	1.74	1.98	0.403	0.480	0.444	0.505
	Dec	1.33	1.39	1.35	1.34	0.418	0.418	0.425	0.422
	Annual	3.58	3.76	3.87	3.68	0.480	0.504	0.518	0.493

6.500 sites around the world, compiled from over 50 different sources for the period 1982 to 2006; the PVGIS-3 data set which is based on measurements made on the ground in the period 1981-1990 and the measured values for daily solar radiation collected by the Yugoslav National Center for Solar Radiation during the period 1964-1991 are used here.

Monthly and annual average values for clearness index and daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, PVGIS, and HMIRS solar databases for Belgrade, Negotin, and Zlatibor used for simulation of on-grid PV system of 1 kW by HOMER software are given in tab. 1.

The relative deviation of daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, and PVGIS solar databases compared to daily solar radiation per square meter received by the horizontal surface taken from HMIRS solar database for Belgrade, Negotin, and Zlatibor are given in tab. 2.

Comparison of electricity production of fixed on-grid PV system of 1 kW

Monthly average and total for year values of electricity production of fixed on-grid PV system of 1 kW with optimally inclinated and south oriented solar modules in Belgrade, Negotin, and Zlatibor using HOMER software simulation based on data for daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, PVGIS, and HMIRS solar databases are shown in tab. 3.

Comparison of total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated and south-oriented solar modules using HOMER software simulation based on data for daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, PVGIS, and HMIRS solar databases in Belgrade, Negotin, and Zlatibor is given fig. 1.

The relative diference of electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules using HOMER software simulation based on data for daily solar radiation taken from NASA, RETScreen, and PVGIS databases compared to electric-

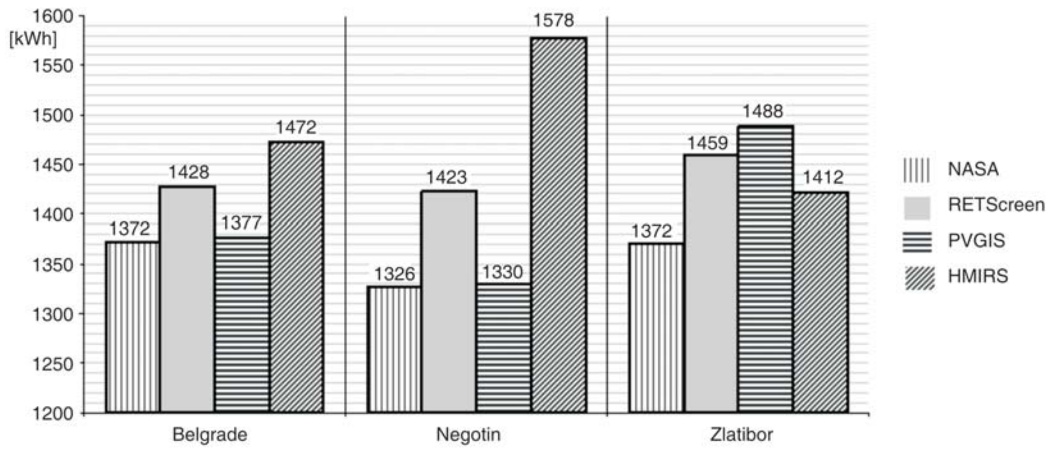

Figure 1. Comparison of total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated and south-oriented solar modules using HOMER software simulation based on data for daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, PVGIS, and HMIRS solar databases in Belgrade, Negotin, and Zlatibor

Table 2. The relative deviation of daily solar radiation at the horizontal surface taken from diferent sources compared with HMIRS solar database for Belgrade, Negotin, and Zlatibor

Location	Month	Solar database for three locations in Serbia [%]		
		NASA database	RETScreen database	PVGIS database
Belgrade	Jan	–4.7	–6.7	–16.1
	Feb	+1.3	–4	–10.7
	Mar	–3.8	–2.6	–8.7
	Apr	–10	–4.7	–7.6
	May	–8.6	–3.6	–4.7
	Jun	–6.1	–1.1	–3.4
	Jul	–4.8	+0.3	+0.5
	Aug	–3.8	–1.1	–0.7
	Sep	–9–2	–1.6	–2.8
	Oct	–10.6	–1.4	–7.2
	Nov	–13.8	–11.5	–13.8
	Dec	10.4	+3,8	0
	Annual average	–5.3	–2.85	–4.7
Negotin	Jan	–0.7	–6.9	–13.1
	Feb	+6.2	–1.9	–10
	Mar	–10.1	–11	–19,5
	Apr	–15.8	–6.4	–11.5
	May	–20.6	–12.5	–16.7
	Jun	–15.2	–6.6	–10.8
	Jul	–14.3	–6.4	–12.6
	Aug	–12.3	–7.4	–9.5
	Sep	–18.8	–7.6	–12.2
	Oct	–22.9	–15.2	–20.7
	Nov	–6.3	–7.5	–9.4
	Dec	–7.3	–9.7	–19.8
	Annual average	–14.3	–8.5	–13.6
Zlatibor	Jan	+7.2	+9.8	+8.5
	Feb	+3.4	+5.5	+1.3
	Mar	+2.1	+3.9	+4.2
	Apr	–5.7	+0.7	+6.2
	May	–7	–0.4	+3.6
	Jun	+1.6	+3.8	+8.2
	Jul	+2.9	+3.5	+12.4
	Aug	–1.1	+1.5	+6.4
	Sep	–4.4	+3.4	+5.6
	Oct	–12.1	+2	–0.3
	Nov	–20.2	–5.1	–12.1
	Dec	–0.8	+3.7	+0.8
	Annual average	–2.7	+2.2	+5.2

Table 3. Monthly average and total year values of electricity production obtained using HOMER software for Belgrade, Negotin, and Zlatibor, based on data taken from NASA, RETScreen, PVGIS, and HMIRS databases

Location	Month	Solar database for three locations in Serbia [%]			
		NASA database	RETScreen database	PVGIS database	HMIRS database
Belgrade	Jan	72	70	61	77
	Feb	89	83	75	87
	Mar	121	122	113	126
	Apr	124	132	127	139
	May	145	154	152	160
	Jun	148	156	153	158
	Jul	160	169	169	168
	Aug	157	162	163	164
	Sep	127	139	137	141
	Oct	101	115	106	117
	Nov	68	70	68	82
	Dec	60	55	52	52
	Total for year	1372	1428	1377	1472
Negotin	Jan	59	65	59	72
	Feb	70	74	69	79
	Mar	101	115	102	132
	Apr	124	133	125	144
	May	148	157	149	180
	Jun	156	164	156	175
	Jul	166	179	167	192
	Aug	162	166	162	180
	Sep	136	145	136	158
	Oct	96	105	96	131
	Nov	64	66	64	72
	Dec	44	54	45	63
	Total for year	1326	1423	1330	1578
Zlatibor	Jan	82	86	85	75
	Feb	94	95	93	89
	Mar	122	124	126	119
	Apr	119	128	135	127
	May	135	145	148	146
	Jun	145	148	151	143
	Jul	160	161	172	156
	Aug	154	158	165	156
	Sep	126	138	142	133
	Oct	98	119	118	117
	Nov	69	85	81	91
	Dec	68	72	72	69
	Total for year	1372	1459	1488	1421

Table 4. The relative diference of electricity production obtained by fixed on-grid PV system of 1 kW with optimally inclinated solar modules using HOMER software simulation based on data from NASA, RETScreen, and PVGIS databases compared to electricity production obtained based on data taken from HMIRS databases in Belgrade, Negotin, and Zlatibor

Location	Month	Solar database for three locations in Serbia [%]		
		NASA database	RETScreen database	PVGIS database
Belgrade	Jan	–6.5	–9.1	–20.3
	Feb	+2.3	–4.6	–13.8
	Mar	–4.0	–3.2	–10.3
	Apr	–10.8	–5	–8.6
	May	–9.4	–3.8	–5
	Jun	–6.3	–1.3	–3.2
	Jul	–4.8	+0.6	+0.6
	Aug	–4.3	–1.2	–0.6
	Sep	–9.9	–1.4	–2.8
	Oct	–13.7	–1.7	–9.4
	Nov	–17.1	–14.6	–17.1
	Dec	+15.4	+5.8	0
	Annual average	–6.8	–3	–6.5
Negotin	Jan	–18.1	–9.7	–18.1
	Feb	–11.4	–6.3	–12.7
	Mar	–23.5	–12.9	–22.7
	Apr	–13.9	–7.6	–13.2
	May	–17.7	–12.8	–17.2
	Jun	–10.9	–6.3	–10.9
	Jul	–13.5	–6.8	–13.0
	Aug	–10	–7.8	–10
	Sep	–13.9	–8.2	–13.9
	Oct	–26.7	–19.9	–26.7
	Nov	–11.1	–8.3	–11.1
	Dec	–30.2	–14.3	–28.6
	Annual average	–16	–9.8	–15.7
Zlatibor	Jan	+9.3	+14.7	+13.3
	Feb	+5.6	+6.7	+4.5
	Mar	+2.5	+4.2	+5.9
	Apr	–6.3	+0.8	+6.3
	May	–7.5	–0.7	+1.4
	Jun	+1.4	+3.5	+5.6
	Jul	+2.6	+3.2	+10.3
	Aug	–1.3	+1.3	+5.8
	Sep	–5.3	+3.8	+6.8
	Oct	–16.2	+1.7	+0.9
	Nov	–24.2	–6.6	–11
	Dec	–1.5	+4.4	+4.3
	Annual average	–3.5	+2.7	+4.7

ity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules using HOMER software simulation based on data for daily solar radiation taken from HMIRS databases in Belgrade, Negotin, and Zlatibor is given in tab. 4.

Conclusions

Solar resource information is needed in all stages of the development of a PV project and design PV systems. Identification of differences in measured insolation from various data sources for specific locations can be an important contribution as the bias in various data sources can have significant effects on the prediction of PV performance, especially in areas where there is no robust network of solar measurement devices such as Serbia.

In Serbia still irregular solar radiation measurements are performed on small number of locations. Therefore for the investors for PV systems in Serbia it is of vital importance to know which solar database is accessible through the internet, and which gives the closest solar radiation data that are obtained by the local measurements. On the basic of the results obtained in this paper it can be concluded that.

- In Belgrade annual average values of daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, and PVGIS solar databases are 5.3%, 2.85%, and 4.7% lower, respectively, than the annual average values of daily solar radiation per square meter received by the horizontal surface taken from HMIRS solar database.
- In Negotin annual average values of daily solar radiation per square meter received by the horizontal surface taken from NASA, RETScreen, and PVGIS solar databases are 14.3%, 8.5%, and 13.6% lower, respectively, than the annual average values of daily solar radiation per square meter received by the horizontal surface taken from HMIRS solar database.
- In Zlatibor annual average values of daily solar radiation per square meter received by the horizontal surface taken from NASA solar database are 2.7% lower than the annual average values of daily solar radiation per square meter received by the horizontal surface taken from HMIRS solar database and annual average values of daily solar radiation per square meter received by the horizontal surface taken from RETScreen and PVGIS solar databases are 2.2% and 5.2%, respectively, higher, than the annual average values of daily solar radiation per square meter received by the horizontal surface taken from HMIRS solar database.
- The annual average values of daily solar radiation taken from RETScreen solar database are the closest to the annual average values of daily solar radiation taken from HMIRS solar database for Belgrade, Negotin, and Zlatibor. This probably comes from the fact that there is the best similarity in the length of the measurement of the values of solar radiation between HMIRS (27 years) and RETScreen (24 years) solar databases.
- In Belgrade total for year electricity productions of fixed on-grid PV system of 1 kW with optimally inclinated solar modules, using HOMER software simulation, based on NASA, RETScreen, and PVGIS solar databases are by 6.8%, 3%, and 6.5%, respectively, lower, than the total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules based on HMIRS solar database.
- In Negotin total for year electricity productions of fixed on-grid PV system of 1 kW with optimally inclinated solar modules, using HOMER software simulation, based on NASA, RETScreen, and PVGIS solar databases are by 16%, 9.8%, and 15.7%, respectively, lower, than the total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules based on HMIRS solar database.
- In Zlatibor total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules, using HOMER software simulation, based on NASA solar database is 3.5% lower than the total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules based on HMIRS solar database and total for

year electricity productions of fixed on-grid PV system of 1 kW with optimally inclinated solar modules based on RETScreen and PVGIS solar databases are by 2.7% and 4.7% higher than the total for year electricity production of fixed on-grid PV system of 1 kW with optimally inclinated solar modules based on HMIRS solar database.

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