ASSESSMENT AND POTENTIAL USE OF CONCENTRATING SOLAR POWER PLANTS IN SERBIA AND REPUBLIC OF SRPSKA

by

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Data assessment and potential use of concentrating solar power plants in Serbia and the Republic of Srpska, B&H, are given in the paper. Besides, concentrating solar power plants schematics and manner of their functioning are described. Then follows geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature, and 24 hours average of temperature for some locations in Europe where concentrating solar power plants are installed or are in construction, and in some cities in Serbia and the Republic of Srpska. The paper also gives comparative surveys of the solar irradiation on horizontal plane and ratio of diffuse to global solar irradiation on some locations in Europe with installed and concentrating solar power plants in construction, and in some cities in Serbia and the Republic of Srpska. Data for direct normal irradiance for locations in Europe with installed or concentrating solar power plants under construction, and for some other cities in Serbia and the Republic of Srpska are also given. Data for direct normal irradiance were obtained by means of SWERA. In the light of the obtained results it was concluded that Serbia and the Republic of Srpska have favorable climatic and geographical conditions for the installation of the experimental concentrating solar power plants, and the area of Trebinje in the Republic of Srpska has favorable conditions for commercial concentrating solar power plants installation.

Key words: *solar energy, solar concentrators, concentrating solar power plants, parabolic troughs, heliostats, solar towers, parabolic dishes, Fresnel reflectors*

Introduction

Demand for electricity in the world is constantly growing. In order to improve the quality of life mankind today uses electrical energy more than ever. Electrical energy has entered everyday life of each man but it is also indispensable for the social and economic progress

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of each country. Electrical energy is used in households for the appliances but also for other types of communications [1, 2].

Worldwide in 2005 a record in electrical energy production of 17450 TWh was achieved, out of which 40% coal fuelled, 20% gas fuelled, 16% nuclear fuelled, 16% hydro fuelled, 7% oil fuelled and only 2% renewable energy sources fuelled such as geothermal, solar, wind, combustible renewable, and waste. Solar power generation is essential for the sustainable energy supply in the future. In countries with high intensity of solar irradiation solar energy can substantially meet the demands for electrical energy [1, 2].

Concentrating solar power plants (CSP plants or solar thermal power plants) are plants that use concentrated solar irradiation to generate electrical energy. CSP plants are composed of solar concentrators, steam turbine and electrical energy generator. Solar concentrators can be parabolic troughs, heliostats, parabolic dishes, and Fresnel reflectors. From the outbreak of the oil crisis in 1973 more attention is devoted to the development of CSP plants. Having in mind that CSP plants generate electricity only during the day in the sunshine and to enable them to continuously operate one uses heat from the heat storage or gas as an additional source of energy. CSP plants do not emit greenhouse-gas and do not have adverse effect on the climate [3-6].

There are 30 active CSP plants out of which 21 parabolic trough power plants, 5 solar tower power plants, 1 parabolic dish power plant, and 3 power plants with Fresnel reflectors [7].

Most European countries very rarely use CSP plants as sources of electrical energy. Spain is the country with most prominent use of CSP plants but other countries worldwide have started developing them as well [8].

Areas with high direct normal irradiance (DNI) are most suitable for the installation of CSP plants. North America is envisaged to become the biggest producer and consumer of the electrical energy generated by CSP plants only to be followed by Africa, India, and the Middle East. In the next ten to twenty years CSP plants will become more competitive than the coal fuelled plants. It is expected that by 2050 CSP plants will provide around 10% of electrical energy in the world [1, 6].

Parabolic trough power plants

Parabolic trough power plants are composed of several linear connected parabolic troughs, steam turbine and electrical energy generator. Parabolic troughs are composed of cylindrical-parabolic reflectors whose focus contains vacuum glass tube. Within the vacuum glass tube there is an apsorption tube with the flowing working fluid. In order to maximally increase the absorption of the solar irradiation and to reduce heat losses the absorption tube is spectrally selective colored. Parabolic troughs are placed towards the south, vertically, or horizontally. Parabolic troughs can heat the working fluid from 300 °C to 400 °C. Efficiency of these thermal power plants is 24%. First parabolic trough power plant of 14 MW (SEGS I) was installed in 1984 by Luz International Co., in South California, but it was combined with gas so the plant could operate during reparation and at overcast weather [3, 9].

Solar tower power plants

Solar tower power plants are composed of several heliostats, a tower on whose top there is a receiver with working fluid and electricity generator. Heliostats are composed of several flat mirrors that focus concentrated solar irradiation onto the receiver. Each heliostat has its own sun tracking system along two axes. Receivers are made of ceramics or high temperature resistant metals. As a working fluid one uses water, molten salt, liquid sodium or air. Water steam or the molten salt steam in the electricity generator turns mechanical work into the electrical energy that is then given to the network grid. Solar tower power plants obtain temperatures up to 1200 °C. Efficiency of these thermal power plants is 22% [3, 4, 9].

Parabolic dish power plants

Parabolic dish power plants are composed of parabolic reflectors in the form of a dish whose focus houses Stirling engine and electricity generator. During the day solar dishes are automatically directed towards the Sun and reflect solar irradiation towards the Stirling engine. By means of parabolic dishes with factor of concentration ratio of around 2000, a temperature of 700 °C and the working fluid pressure of 200 bars in the focus are reached. In Stirling engine the heat of the concentrated solar irradiation is converted into a mechanical work. Electricity generator is connected to the Stirling engine. Parabolic dish power plants with Stirling engines perform the conversion of the solar irradiation into the electrical energy with the efficiency of 30% [1, 4, 9-11].

Power plants with Fresnel reflectors

Power plants with Fresnel reflectors are composed of flat or slightly curved Fresnel reflectors, receiver of the concentrated solar irradiation with the cylindrical-parabolic concentrator, steam turbine and electricity generator. During the day Fresnel reflectors are automatically directed towards the Sun and reflect solar irradiation towards the cylindrical-parabolic reflector whose focus contains receiver in the form of long tubes having water running through. Under the influence of the solar irradiation that is reflected from the cylindrical-parabolic reflector water in receiving tubes evaporates and under pressure goes into the steam turbine that stirs electricity generator. Fresnel reflectors are composed of a large number of flat mirrors that are cheaper than the parabolic mirrors. On the same surface larger number of Fresnel reflectors than the parabolic mirrors can be located. Fresnel reflectors can be used in small and large scale CSP plants [1, 4, 7, 9].

Solar concentrator reflectors materials

Solar concentrators market offers variety of materials for the manufacture of solar concentrator reflectors [12]. For the manufacturing of solar concentrators one uses glass with silver layer, aluminum, and plastic materials. Mirrors that are used in solar concentrators should have high mirror reflection, long shelf life in aggressive atmosphere (such as in deserts, or in a big city), and affordable cost. Due to a long exposure to the influence of the atmosphere a reflection coefficient of the solar concentrator is reduced [13].

Glass mirrors. Silver plated glass mirrors have high reflection coefficient 0.9-0.94, are adverse atmosphere conditions resistant, and are easy to clean. Nevertheless, they are rarely used in solar concentrators because of the high price, brittleness and the need for strong supporting structure [12-14].

Aluminum mirrors. In solar concentrators aluminum mirrors with good mechanical properties, reflection coefficient between 0.9 and 0.99, and easy recycling are used. Aluminum mirrors are resistant to the influence of the atmosphere since on the surface of the aluminum, quite naturally, a transparent layer of the aluminum oxide is formed, and it protects the aluminum from the corrosion, and affects slightly the reflection from its surface. To better protect the aluminum one uses anode oxidation to coat a transparent oxide layer (Al_2O_3) which contributes to the stability of the optical characteristics of aluminum mirrors [14, 15].

Plastic mirrors. To produce mirrors one increasingly uses plastic materials to coat reflecting metal layers by vacuum vaporing or chemically. The cheapest reflecting material with high reflection coefficient is metal plated plastic foil. A foil of aluminum plated nylone (mylar) is of high quality and shows good mechanical resistance. As a mirror with high reflection coefficient (0.9) one also uses silver plated mylar with protective acrylic plastic. Flat mirrors with plastic reflectors are formed by stretching plastic foils over the firm frame [14].

Aluminum foil mirrors. For the manufacture of parabolic solar concentrators aluminum foil is mostly used due to its lightness, high reflection coefficient and adhesive easily fixed to the supporting structure [12].

Stainless steel. Solar concentrators are formed of stainless steel and have high reflection coefficient [12].

Parabolic troughs

In parabolic trough power plants one mostly uses Luz, Euro Trough and Solargenix concentrators [16].

Luz concentrators are products of Israeli-American company BrightSource Energy (former Luz International Ltd.) and represent the standard to which all other concentrators are compared. A reflector of the Luz concentrator is made of glass, thickness of 4 mm with low iron content, is silver plated and protected with five additional layers of copper and varnish. By heating in moulds and special furnaces glass assumes parabolic form. Receiving tube of the Luz concentrator is spectrally coloured stainless steel. Receiving tube is located in vacuumised glass tube with low iron content (0.015%). In order to increase transmission of solar irradiation glass tube contains antireflection layer. The receiver has glass-to-metal seals and metal bellows to accommodate for differing thermal expansions between the steel tubing and the glass envelope. Selective layer in LS-1 and LS-2 concentrators is black chrome, while LS-3 concentrator uses new ceramic-metal layer thickness of 0.3 μm [5, 16].

European consortium, EuroTrough deals with the development of parabolic troughs. First version of these concentrators is an ET-100 concentrator made of 8 modules total length of 100 m and aperture area around 545 m^2. Second version of EuroTrough concentrators is an ET-150 concentrator with 12 modules, length of 150 m and aperture of 820 m^2. SKAL-ET concentrators are the third generation of EuroTrough concentrators. German company Flabeg manufactures reflectors for EuroTrough concentrators [5, 16].

Aiming at the increase of efficiency and reduction of costs American company Solargenix Energy has developed two generations of parabolic troughs-SGX1 and SGX2. SGX1 concentrator modeled on LS-2 concentrator, is two times longer. SGX1 concentrator has a light structural frame made of aluminum, is corrosion proof, simple for transport and installing [5].

Spanish company Abengoa Solar manufactures PT-1 and PT-2 concentrators. PT-1 concentrator has a metal sheet reflector and non-evacuated receiving tube. PT-2 concentrator's reflector is made of polished or silver plated aluminum, and the receiving tube is evacuated [5, 17].

Parabolic trough power plants use mainly glass mirror Flabeg company concentrators. These concentrators have reflecting layer on the back side of the glass. The glass is 4 millimeter thick, special low iron or white glass with high transmittance. The mirrors have a solar-weighted specular reflectivity of about 0.935. Silver on the back side of the mirror is protected with special multilayer colour. Each mirror panel has surface of around 2 m^2. Flabeg company is internationally recognised in manufacturing mirrors with curved annealed glass. If an edge or the corner of annealed solar mirror breaks, rest of the mirror surface remains functional until replaced. On the contrary, mirror made of tempered glass breaks into lots of pieces, which is dangerous in strong wind. Usually, rim situated mirrors break. It is possible to completely eliminate glass breaking if instead of mirrors thickness of 4 mm one installs mirrors thickness of 5 mm along the rim of the plant [16, 18].

Up to now there were several futile attempts to manufacture concentrators with polymer film reflector [13].

Parabolic trough power plants use synthetic oil and molten nitrate salts as heat exchanger fluids. Synthetic oil is toxic and stabile up to 400 °C. Molten nitrate salts are non-flammable, cheaper than synthetic oil and environmental friendly. Drawbacks of molten salts are the requirement of expensive anti-freezing systems and of stainless steel materials because of salts high solidification temperature, about 250 °C, and corrosion characteristics [2].

Solar towers

Solar tower power plants use mainly heliostats of Abengoa Solar, eSolar (USA) and Sener (Spain) companies. Abengoa Solar company has manufactured heliostats Sanlucar 90 and Sanlucar 120.

German company Schlaich Bergermann und Partner (SBP) has developed a prototype (ASM 150) metal-membrane heliostat, diameter of 14 m using stainless steel membranes, thickness of 0.4 mm. The concentrator is made of a ”drum” that in turn consists of a pressure ring and tautened metal membranes on the front and back sides. On the front membrane there are thin-glass mirrors with high reflection coefficient. Within the drum, by fans a negative pressure of just several milibars is created [19].

As heat exchanging fluids in solar towers one mostly uses water/steam, molten nitrate salts, and air. Water/steam offers the benefit that it can be directly used in a steam-turbine cycle without further heat exchange. Steam has good heat exchanging characteristics and is suitable to use in systems with high concentration of sun radiation. There is no simple solution to store large amounts of high temperature/high pressure steam, in order to operate the plant during non-sunshine hours. Molten nitrate salts are cheaper, have good heat exchanging characteristics, and can be used as high temperature energy storage fluids. When using molten nitrate salts one has to be careful not to induce their freezing, which could cause a halt in CSP plant. Air can be used as heat exchange fluid in all temperatures, is non-toxic and is available for free. However, due to low density and low heat conducting air does not belong to good heat exchanging materials [20].

Working temperature of solar towers is higher than in parabolic troughs and Fresnel reflectors, but it is lower than in parabolic dishes [21].

Parabolic dishes

Depending on the engine they use, parabolic dishes can have various dimensions. In parabolic dishes diameter of 5-10 m surface that reflects solar irradiation ranges from 40-120 m^2. At a nominal maximum direct solar irradiation of 1000 W/m^2, a 25 kW solar dish Stirling system’s concentrator has a diameter of approximately 10 m. Reflectors of these concentrators are mostly made of aluminum or silver on glass or plastic. Stirling engines usually use hydrogen or helium as heating fluid [13].

Parabolic dish power plants use dishes of the American company stirling energy systems (SES)-SunCatcherTM. SunCatcherTM parabolic dish od 25 kW consists of curved glass mirror facets that reflect and concentrate sunlight. The concentrated energy drives a Stirling engine in the power conversion unit (PCU), which spins a generator producing emission free, grid-quality electricity [11].

The SBP company has developed and tested several prototypes of parabolic dishes power of 10-50 kW. In Schlaich Bergermann und Partner's 10 kW Dish-Stirling systems, the concentrator has a diameter of 8.5 m and is manufactured in a sandwich construction of easily transportable segments made of fiberglass-reinforced epoxy resin. Thin-glass mirrors with a long-term high reflectivity of 94% are fixed onto the high-precision surface [19].

Thin glass mirrors of the international company AGC Glass Europe (former Glaverbel), with headquarters in Brussels, are successfully used for the manufacture of solar dishes and heliostats [15].

Unlike the other CSP technologies, parabolic dish technology does not easily lend itself to thermal storage, so these systems are designed to provide electricity only when the sun is shining [21].

Fresnel reflectors

Power plants with Fresnel reflectors use mainly Fresnel reflectors of the French company Areva Solar (former Ausra company) and Novatec Solar company with headquarters in Germany (concentrator Nova-1).

CSP plants in the world

CSP is a proven technology. First CSP plants were installed in California in the period from 1984 to 1991 and were subsidized by federal and state tax levies and contracts on compulsory long term purchase of electrical energy. Decrease in the prices of fossil fuels urged federal and state governments to abandon the policy framework that envisaged advancement of CSP system. In 2006, the market reemerged in Spain and the United States, again in response to government measures such as feed-in tariffs (Spain) and policies obliging utilities to obtain some share of power from renewables – and from large solar in particular. At the beginning of 2010 power of CSP plants worldwide was around 1 GW. It is expected from the developing or ongoing projects in more than ten countries (including China, India, Marocco, Spain, and USA) to generate total of 15 GW. Parabolic troughs account for the largest share of the current CSP market, but competing technologies are emerging [6].

Table 1. Types of installed and CSP plants in construction in the world [7]

CSP plants	Active	In construction
With parabolic troughs	21	25
With solar tower	5	3
With parabolic dishes	1	1
With Fresnel reflectors	3	2
Total	30	31

Nowadays, in the world there are 30 CSP plants while 31 plants are being constructed (tab. 1). Power of parabolic trough power plants ranges from 0.25-354 MW, in solar tower power plants it ranges from 1.5-20 MW, in parabolic dish power plants it is 1.5 MW and in power plants with Fresnel reflectors it ranges from 1.4-5 MW [7].

CSP system requires high DNI for cost-effective operation. Sites with excellent solar radiation can offer more attractive levelled electricity prices, and this single factor normally has the most significant impact on solar system costs. It is generally assumed that CSP systems are economical only for locations with DNI above 1800 kWh/m^2 per year (around 5 kWh/m^2 per day). To generate 1 MWh of solar electricity per year with CSP plant, a land area of only 4-12 m^2 is required [10, 22, 23].

PVGIS

PVGIS (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 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 [24].

In practice PVGIS on-line calculator is used for the estimation of solar irradiation that falls on the horizontal plane or a plane tilted with some angle in relation to the horizontal plane, ratio of diffuse to global solar irradiation, optimal tilting angle of PV module and reflector of solar irradiation and temperature for any given location in Europe and North Africa. These data are very important when doing calculations of the profitability of PV solar plants and CSP plants equipment [24].

Table 2 shows characteristics of the locations in Europe with some active CSP plants and some CSP plants that are still being constructed. On locations of Sanlucar la Mayor, Puertollano, Alvarado, and Priolo Gargallo there are commercial CSP plants, and on locations of Ghisonaccia, Targassonne, and Julich there are experimental and demonstration CSP plants which are active or under construction.

The Sun does not shine as often in Julich as in southern Europe or in North Africa, but for the experimental power plant in which the technology is to be further developed having good connections to the research institutes is more important than continuous operation. The CSP plant in Julich thus serves as a reference for future commercial power plants in southern Europe and North Africa. The technology and the knowledge obtained by the researchers in Julich will be used in sunny regions of the world, where CSP plants have the greatest potential [25].

Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature and 24 hours average of temperature for some locations in Europe where CSP plants are installed or are still being constructed are given in tab. 2 [26].

Mean value of the annual average solar irradiation on the horizontal plane for given locations where CSP plants are installed or are still being constructed in Europe is 4281.4 Wh/m^2 per year. Mean value of the annual average of the ratio of diffuse to global solar irradiation for given locations where CSP plants are installed or are still being constructed in Europe is 0.41.

Table 2. Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature, and 24 hours average of temperature for some locations in Europe where CSP plants are installed or are still being constructed [26]

Location	Sanlucar la Mayor, Spain	Puertollano, Spain	Alvarado, Spain	Priolo Gargallo, Italy	Ghisonaccia, Corsica, France	Targassonne, France	Julich, Germany
Geographical position	37°23'09" North latitude and 6°12'07" West longitude	38o41'10" North latitude and 4°06'44" West longitude	38°48'33" North latitude and 6°47'26" West longitude	37°09'24" North latitude and 15°11'17" East longitude	42°01'01" North latitude and 9°24'14" East longitude	42°29'56" North latitude and 1°59'47" East longitude	50°55'16" North latitude and 6°21'40" East longitude
Solar irradiation on horizontal plane [$Whm^{-2}year^{-1}$]	4750	4680	4660	4800	4140	4310	2630
Solar irradiation on vertical plane [$Whm^{-2}year^{-1}$]	3400	3430	3390	3370	3100	3610	2040
Solar irradiation on optimally inclined plane [$Whm^{-2}year^{-1}$]	5400	5360	5320	5430	4760	5190	2960
Optimal inclination [deg.]	33	34	34	33	34	39	34
Linke turbidity	2.7	3.2	2.7	3.9	3.7	3.3	4.0
Ratio of diffuse to global solar rradiation	0.36	0.37	0.37	0.36	0.40	0.40	0.59
Average daytime temperature [°C]	20.4	17.7	19.1	19.5	17.8	11.8	11.8
24 hour average of temperature [°C]	18.6	16.2	17.4	18.5	16.2	10.7	10.9

SWERA

The SWERA (solar and wind energy resource assessment) initiative brings together solar and wind energy resource data sets and analysis tools from a number of international organizations in a dynamic user-oriented environment. The information and data provided on the site are freely available to the public and are intended to support the work of policy markers, project planners, research analysts and investors. SWERA solar products provide information on the solar resource at a specific location that is available for use by solar technologies. These products include maps and data of available solar resource, as well as documentation on the methodology employed to generate these solar resource estimates. SWERA solar products are classified by the radiation components they describe. The DNI products are relevant for concentrating solar applications. They describe the solar resource available to CSP systems that track the sun throughout the day. The SWERA archive contains maps and data of DNI resources [27].

Table 3 shows DNI values of the locations in Europe with some active CSP plants and some CSP plants that are still being constructed [27].

Table 3. DNI values of the locations in Europe with some active CSP plants and some CSP plants that are still being constructed [27]

Location	DNI [$kWhm^{-2}day^{-1}$]	DNI [$kWhm^{-2}year^{-1}$]
Sanlucar la Mayor, Spain	6.19	2259.35
Puertollano, Spain	6.07	2215.55
Alvarado, Spain	5.99	2186.35
Priolo Gargallo, Italy	5.18	1890.70
Ghisonaccia, Corsica, France	5.36	1956.40
Targassonne, France	4.84	1766.60
Julich, Germany	2.57	938.05

Mean value of DNI for given locations on which CSP plants are installed or are under construction in Europe is 5.17 kWh/m^2 per day, *i. e.* 1887.57 kWh/m^2 per year

Serbia

Serbia is located between 41°46′40″ and 46°11′25″ of the north latitude and 18°06′ and 23°01′ east longitude [9]. Climate of Serbia is moderate-continental with more or less prominent local characteristics. Area distribution of the climate parameters is conditioned by the geographic position, relief, and local influence as a result of the combination of the relief, distribution of large scale air pressure, exposition of the terrain, existence of water systems, vegetation, urbanization, *etc*. Geographic parameters characterizing synoptic situations significant for the weather and climate of Serbia are the Alps, Mediterranean sea and Genoa bay, Pannonia lowlands and valley of Morava, the Carpathians, the Rhodopes, and mountain part with the valleys and highlands. Prominent meridian position of the river valleys and flat planes on the north of the country enable deep penetration of the polar air masses towards the south. In Serbia the sunshine duration ranges from 1500-2200 hours annually [28].

Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature and 24 hours average of temperature for some cities in Serbia are given in tab. 4 [26].

Table 4. Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature, and 24 hours average of temperature for some cities in Serbia [26]

Location	Subotica	Belgrade	Kragujevac	Niš	Novi Pazar
Geographical position	46°6'1" North latitude and 19°39'56" East longitude	44°48'8" North latitude and 20°27'56" East longitude	44°0'45" North latitude and 20°55'36" East longitude	43°19'9" North latitude and 21°53'46" East longitude	43°8'34" North latitude and 20°31'1" East longitude
Solar irradiation on horizontal plane [$Whm^{-2}year^{-1}$]	3430	3620	3710	3690	3900
Solar irradiation on vertical plane [$Whm^{-2}year^{-1}$]	2620	2750	2780	2680	2960
Solar irradiation on optimally inclined plane [$Whm^{-2}year^{-1}$]	3910	4130	4210	4130	4470
Optimal inclination [deg.]	35	35	34	33	34
Linke turbidity	3.7	2.8	2.7	2.5	2.6
Ratio of diffuse to global solar irradiation	0.49	0.47	0.47	0.48	0.45
Average daytime temperature [°C]	12.7	13.3	13.0	13.2	11.9
24 hour average of temperature [°C]	11.3	12.0	11.7	11.9	10.7

Mean value of the annual average of solar irradiation on horizontal plane for given cities in Serbia is 3670 Wh/m^2 per year. Mean value of the annual average of the ratio of diffuse to global solar irradiation for given cities in Serbia is 0.472.

Solar irradiation on horizontal plane on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia is shown in fig. 1. Ratio of diffuse to global solar irradiation on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia is shown in fig. 2.

Mean value of the annual average of solar irradiation on horizontal plane for given cities in Serbia is by 14.28% lower than the mean value of the annual average of solar irradiation on horizontal plane for given locations with installed and CSP plants that are still being constructed in Europe.

Mean value of the annual average of the ratio of diffuse to global solar irradiation for given cities in Serbia is by 15.12% higher than the mean value of the annual average of the ratio of diffuse to global solar irradiation for given locations with installed CSP plants and CSP plants that are still being constructed in Europe.

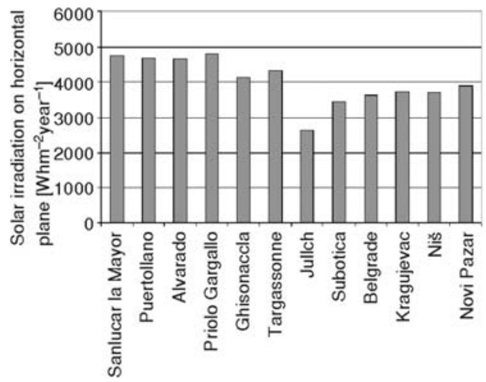

Figure 1. Solar irradiation on horizontal plane on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia

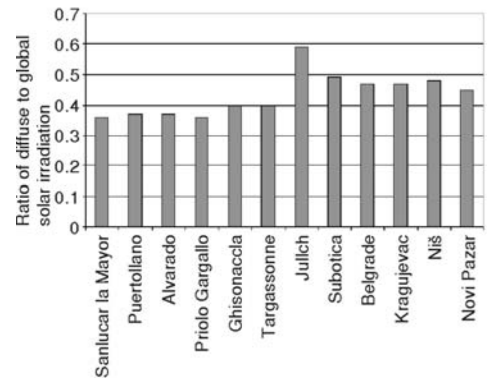

Figure 2. Ratio of diffuse to global solar irradiation on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia

On the basis of the obtained results shown in tab. 2 and tab. 4 it can be concluded that solar irradiation on horizontal plane in Subotica, Belgrade, Kragujevac, Niš, and Novi Pazar is higher than in Julich and lower than on the mentioned locations in Spain, Italy, and France. Ratio of diffuse to global solar irradiation in Subotica, Belgrade, Kragujevac, Niš, and Novi Pazar is lower than in Julich but higher than on the mentioned locations in Spain, Italy, and France.

Table 5 shows DNI values for some cities in Serbia [27].

DNI on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia is shown in fig. 3.

Mean value of DNI for given locations in Serbia is 3.894 kWh/m^2 per day, *i. e.* 1421.31 kWh/m^2 per year. Mean value of DNI for given locations in Serbia is by 24.70% smaller than the mean value for DNI for given locations in Europe where CSP plants are installed or are under construction.

On the basis of the results shown in tab. 3 and tab. 5 one can conclude that the values for DNI for given cities in Serbia are higher than the values for DNI for Julich, and that they are smaller than the values for all other locations given in tab. 3.

Table 5. DNI values for some cities in Serbia [27]

Location	DNI [kWhm^{-2}day^{-1}]	DNI [kWhm^{-2}day^{-1}]
Subotica	3.53	1288.45
Belgrade	4.03	1470.95
Kragujevac	3.94	1438.10
Niš	4.03	1470.95
Novi Pazar	3.94	1438.10

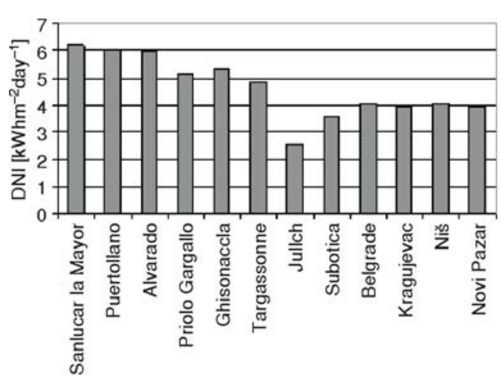

Figure 3. DNI on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in Serbia

Republic of Srpska

Territory of the Republic of Srpska lies between 42°33' and 45°16' of the north geographical latitude and 16°11' and 19°37' of the east longitude. Republic of Srpska is situated in the north moderate belt and there are three prominent climatic areas:

– mediterranean, with the variant of classical and changed Mediterranean climate,
– mountain, characterized with the abundance of snow in winters and pleasant and chilly summers, and
– continental, with the variants of moderate-continental and continental climate [29].

Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature, and 24 hours average of temperature for some cities in the Republic of Srpska are given in tab. 6 [26].

Table 6. Geographical position and the results of PVGIS calculation of the yearly average values of the solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination, linke turbidity, ratio of diffuse to global solar irradiation, average daytime temperature, and 24 hours average of temperature for some cities in the Republic of Srpska [26]

Location	Novi Grad	Banja Luka	Sarajevo	Višegrad	Trebinje
Geographical position	45°2'43" North latitude and 16°23'4" East longitude	44°46'0" North latitude and 17°10'59" East longitude	43°50'51" North latitude and 18°21'23" East longitude	43°47'7" North latitude and 19°17'35" East longitude	42°42'40" North latitude and 18°20'33" East longitude
Solar irradiation on horizontal plane [$Whm^{-2}year^{-1}$]	3500	3540	3800	3740	4220
Solar irradiation on vertical plane [$Whm^{-2}year^{-1}$]	2620	2660	2930	2820	3240
Solar irradiation on optimally inclined plane [$Whm^{-2}year^{-1}$]	3960	4010	4380	4270	4890
Optimal inclination [deg.]	34	34	35	34	35
Linke turbidity	3.8	3.7	3.5	3.3	3.4
Ratio of diffuse to global solar irradiation	0.50	0.50	0.45	0.46	0.41
Average daytime temperature [°C]	13.4	13.1	12.2	12.4	14.1
24 hour average of temperature [°C]	12.0	11.8	11.1	11.3	12.9

Mean value of the annual average of the solar irradiation on the horizontal plane for given cities in the Republic of Srpska is 3760 Wh/m^2 per year. Mean value of the annual average of the ratio of diffuse to global solar irradiation for given cities in the Republic of Srpska is 0.464.

Solar irradiation on the horizontal plane on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska is shown in fig. 4. Ratio of diffuse to global solar irradiation on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska is shown in fig. 5.

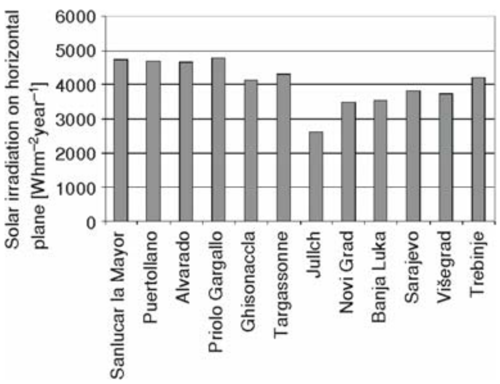

Figure 4. Solar irradiation on the horizontal plane on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska

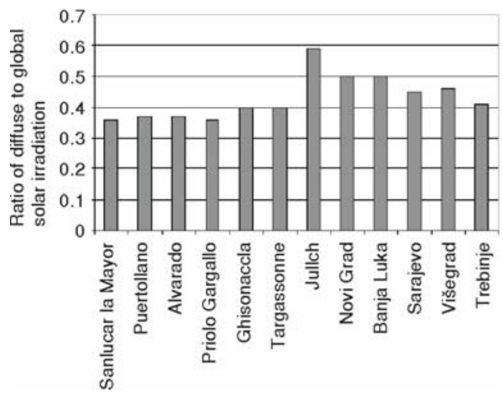

Figure 5. Ratio of diffuse to global solar irradiation on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska

Mean value of the annual average of the solar irradiation on the horizontal plane for given cities in the Republic of Srpska is by 12.18% lower than the mean value of the annual average of the solar irradiation on the horizontal plane for given locations with installed and CSP plants that are still being constructed in Europe.

Mean value of the annual average of the ratio of diffuse to global solar irradiation for given cities in the Republic of Srpska is by 13.17% higher than the mean value of the annual average of the ratio of diffuse to global solar irradiation for given locations with installed and CSP plants that are still being constructed in Europe.

On the basis of the obtained results shown in tab. 2 and tab. 6 it can be concluded that in Novi Grad, Banja Luka, Sarajevo, Višegrad, and Trebinje the intensity of solar irradiation on the horizontal plane is higher than in Julich, and that solar irradiation on horizontal plane in Trebinje is higher than in Ghisonaccia. Ratio of diffuse to global solar irradiation in Novi Grad, Banja Luka, Sarajevo, Višegrad, and Trebinje is lower than in Julich, and is higher than on the mentioned locations in Spain, Italy, and France.

Table 7 shows DNI values for some cities in the Republic of Srpska [27].

Table 7. DNI values for some cities in the Republic of Srpska [27]

Location	DNI [$kWhm^{-2}day^{-1}$]	DNI [$kWhm^{-2}year^{-1}$]
Novi Grad	4.07	1485.55
Banja Luka	3.64	1328.60
Sarajevo	4.24	1547.60
Višegrad	3.98	1452.70
Trebinje	5.25	1916.25

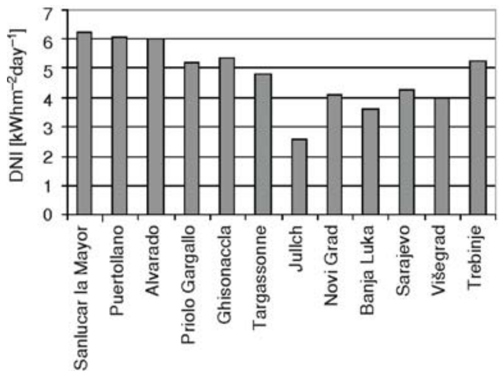

Figure 6. DNI on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska

DNI on some locations in Europe with installed and CSP plants that are still being constructed and in some cities in the Republic of Srpska is shown in fig. 6.

Mean value of DNI for given cities in the Republic of Srpska is 4.236 kWh/m^2 per day, *i. e.* 1546.14 kWh/m^2 per year. Mean value of DNI for given cities in the Republic of Srpska is by 18.09% smaller than the mean value for DNI for given locations in Europe where CSP plants are installed or are under construction.

On the basis of the results shown in tab. 3 and tab. 7 one can conclude that the values for DNI for Trebinje are higher than the corresponding values for Julich, Targassonne, and Priolo Gargallo, but they are smaller than the values for DNI for all other locations given in tab. 3. Values for DNI for Novi Grad, Banja Luka, Sarajevo, and Višegrad are higher than the values for DNI for Julich but they are smaller than the corresponding values for all other locations given in tab. 3.

Conclusions

CSP plants are composed of solar concentrators, steam turbine, and electricity generator. Depending on the type of solar concentrator, CSP plants can be divided into: parabolic trough power plants, solar tower power plants, parabolic dish power plants, and power plants with Fresnel reflectors. Worldwide there are currently 30 active CSP plants and 31 are still being constructed. In Europe there are currently 18 active CSP plants and 26 are still being constructed.

In the light of the previously mentioned facts it can be concluded that Serbia and the Republic of Srpska have favorable climatic and geographical conditions for the installation of the experimental and demonstration CSP plants. Experimental CSP plants in Serbia and the Republic of Srpska would enable obtaining new knowledge and technologies from this area which does not call for their continuous operation throughout the year. New knowledge would be used for designing and installation of the commercial CSP plants on locations where DNI is higher than 1800 kWh/m^2 per year. Installation of the experimental CSP plants in Serbia and the Republic of Srpska would enable the engagement of experts and qualifying of new experts for research in that area.

Having in mind that CSP systems are economic only if installed on locations with DNI values higher than 1800 kWh/m^2 per year (around 5 kWh/m^2 per day) in Serbia and the Republic of Srpska, only the location of Trebinje meets the requirmements for the installation of CSP plants.

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