Original scientific papers UDK 502.131.1:351.778.3(497.11)(497.6RS)
DOI 10.7251/COMEN2102151P

RENEWABLE ENERGY AND CLIMATE CHANGE IN SERBIA AND THE REPUBLIC OF SRPSKA

Tomislav M. Pavlović[1], Dragoljub Lj. Mirjanić[2], Ivana S. Radonjić[1], Darko Divnić[2], Galina I. Sazhko[3]*

[1] University of Niš, Faculty of Sciences and Mathematics, Department of Physics, Višegradska 33, 18000 Niš, Serbia
[2] Academy of Sciences and Arts of the Republic of Srpska, Bana Lazarevića 1, 78000 Banja Luka, Republic of Srpska
[3] Ukrainian engineering pedagogics academy, str.Universitetskaya 16, Kharkiv, 61003 Ukraine

Abstract: This paper focuses on the use of renewable energy sources in Serbia and the Republic of Srpska and their impact on the environment and climate change. Renewable energy sources used in Serbia are hydropower, solar energy, wind energy, biomass, and biogas. Renewable energy sources used in the Republic of Srpska are hydropower, solar energy, biomass, and biogas. When using hydropower, the formed reservoirs often impact the microclimate of the environment in which they are located. Photothermal and photovoltaic solar radiation conversion installations are mostly stationary, do not emit harmful substances into the environment, and have no impact on climate change. The use of wind turbines has a certain influence on the flow of ambient air. When using biomass and biogas, combustion gases are released into the atmosphere, which has slightly negative impact on climate change. The paper concludes that the use of renewable energy sources in Serbia and the Republic of Srpska has a negligible negative impact on the environment and climate change.

Keywords: renewable energy, hydropower, solar energy, wind energy, biomass, biogas, climate change.

1. INTRODUCTION

To replace non-renewable energy sources, protect the environment and mitigate the effects of climate change in Serbia and the Republic of Srpska, renewable energy sources have been increasingly used to generate heat and electricity.

Renewable energy sources include hydropower, solar energy, wind energy, biomass and biogas, geothermal energy, sea and ocean energy, etc.

Serbia utilizes the following renewable energy sources generating electricity: hydropower, solar energy, wind energy, biomass, and biogas. Solar energy, biomass, and biogas are used to obtain thermal energy.

The Republic of Srpska utilizes the following renewable energy sources generating electricity: hydropower, solar energy, biomass, and biogas. Solar energy, biomass, and biogas are used to obtain thermal energy.

Following the relevant European directives, efforts are being made in Serbia and the Republic of Srpska to use renewable energy sources as much as possible instead of fossil fuels (wood and coal), oil, and nuclear energy.

The paper gives a brief overview of the use of renewable energy sources in Serbia and the Republic of Srpska and their impact on the environment and climate change.

2. HYDROPOWER

A hydropower plant is an energy plant for the production of electricity derived from the kinetic energy of water. The accumulation hydropower plant consists of a dam and a machine hall containing turbines and an electricity generator. Water from the reservoir is brought to the machine hall by a tunnel or a pipeline. The water drives the turbines, which are connected to electricity generators producing three-phase alternating current.

Hydropower plants are built in places with sufficient running water and the difference in height

* Corresponding author: pavlovic@pmf.ni.ac.rs

between the upper and lower water levels. The power of a hydroelectric power plant is directly proportional to the amount of water and the height difference. Watercourses with a large flow of water or mountain rivers with a smaller flow but large falls are chosen for the construction of hydroelectric power plants.

Large hydropower plants are those with a capacity of more than 10 MW, mini hydropower plants have the capacity of 100 kW-10 MW, and micropower plants up to 100 kW [1].

2.1. Hydropower plants in Serbia

In Serbia, in Electro Power Industry (EPS – Elektroprivreda Srbije), there are 16 large and 10 small-scale hydropower plants and a large number of small, private-owned hydropower plants. Hydropower plants are the most important electricity resource in Serbia generated from renewable energy sources. In terms of their importance in the electric power industry of Serbia, solar power plants, wind power plants, and biomass and biogas power plants lag far behind hydropower plants.

Small-scale hydropower plants

The first small hydropower plant (SHP) in Serbia with polyphase current, named "*Pod gradom*" and located on the river Đetinja, near Užice, was put into operation in 1900.

SHPs Pod Gradom and Vučje are shown in figures 1 and 2 respectively.

SHPs owned by the Public Company Electric Power Industry of Serbia (PE EPS) are given in Table 1.

Figure 1. SHP Pod Gradom, Užice, 1900.

Figure 2. SHP Vučjen ear Leskovac, 1903.

Table 1. SHP owned by EPS[1]

Location	Watercourse	Small-scale hydropower plants (SHP)		Power (MW)	Year of installation
Užice	Djetinja	Pod gradom		0.300	1899
Leskovac	Vučjanka	Vučje		1.135	1903
Zaječar	Crni Timok	Gamzigrad		0.320	1908
Niška banja	Nišava	Sveta Petka		0.735	1908
Ivanjica	Moravica	Moravica		0.600	1911
Bajina Bašta	Vrelo	Vrelo		0.060	1927
Surdulica	Jelašnica	Jelašnica		0.396	1928
Užice	Đetinja	Turica		0.345	1929
Niška banja	Nišava	Sićevo		1.550	1931
Pirot	Temštica	Temac		0.860	1940
Zaječar	VelikiTimok	Sokolovica		4.100	1948
Novi Pazar	Raška	Raška		4.450	1953
Prijepolje	Seljašnica	Seljašnica		0.900	1953
Čačak	Zapadna Morava	Međuvršje		4.500	1954
Čačak	Zapadna Morava	Ovčar banja		7.000	1957

Location	Watercourse	Small-scale hydropower plants (SHP)		Power (MW)	Year of installation
Mali Zvornik	Veliki Radalj	Radaljska banja		0.250	1989
Priboj	Krakovska reka	Krakovska reka		0.762	1989
		Total:		28.263	

Large hydropower plants

EPS Serbia comprises 16 large hydropower plants whose basic characteristics are given in Table 2.

Figure 3. Hydropower plant Đerdap I, 1970.

2.2. Hydropower plants in the Republic of Srpska

Small-scale hydropower plants

The Republic of Srpska (RS) has 29 small-scale hydropower plants with the status of privileged electricity producer [1-3]. Their characteristics are given in Table 3.

HPPs Đerdap I and Đerdap II are shown in figures 3 and 4 respectively.

HPPs Trebinje 2 and Mesići are shown in figures 5 and 6 respectively.

Figure 4. Hydropower plant Đerdap II, Kusjak, Negotin, 1985.

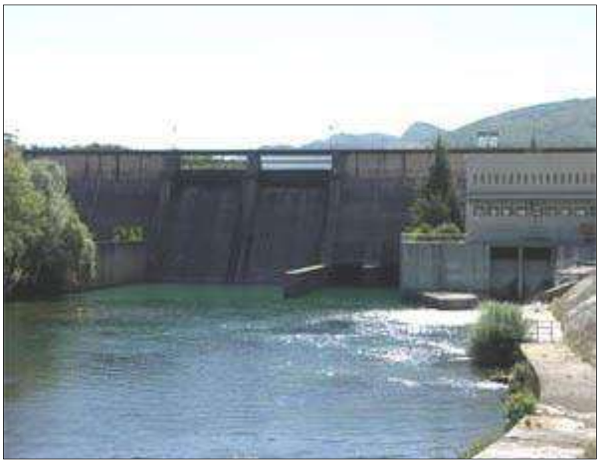

Figure 5. Hydropower plant Trebinje 2, on the river Trebišnjica, 1981.

Figure 6. Small-scale hydropower plant Mesići, 1950.

Table 2. Basic characteristics of large hydropower plants in Serbia [1-3]

TYPE AND POWER OF HYDROPOWER PLANTS IN SERBIA						
TITLE	Type	No. of generators	Power of generators (MW)	Total power (MW)	Annual production (GWh)	Reservoir volume 10^6 m^3
DUNAV						
Đerdap I	Dam	4 2	176 205	1115	6000	2800
Đerdap II	Run-of-river	10	27	270	1500	716.5
DRINA						
Zvornik	Dam toe powerhouse run-of-river	4	24	96	550	89
Bajina Bašta	Pre-dam	4	105	420	1800	340
RH Bajina Bašta	Reversible	2	307	614	800-1000	170
LIM						
Uvac	Diversion	1	36	36	76	213
Kokin Brod	Dam toe powerhouse	2	11.75	23.5	45	250
Bistrica	Reservoir	2	54	108	220	7.6
Potpeć	Pre-dam	3	17	51	100	27.5
ZAPADNA MORAVA						
Ovčar banja	Run-of-river	1 1	3.4 5.3	8.7	29	1.5
Međuvršje	Run-of-river	1 1	3.4 5.6	9	29	13
VISOČICA						
Pirot	Reservoir	2	40	80	87	180
VLASINA						
Vrla 1	Reservoir	2	11.2	52.8	95	165
		2	14.2			
Vrla 2	Reservoir	1	10.7	24	51	0.1
		1	13.3			
Vrla 3	Reservoir	1	12.8	29.4	73	-
		1	16.6			
Vrla 4	Reservoir	1	11.2	25.4	63	0.1
		1	14.2			

Table 3. Characteristics of some small-scale hydropower plants in RS [2]

Location	Title	Power (kW)	Planned annual production (kWh)	Year of installation
RekaVrbanja	Divič	2283	4429000	2012
Kalinovik	Bistrica B-5a	3930	6998278	2012
Reka Sućeska	Sućeska R-S-1 and R-S-2	3029	5634768	2012
Reka Ugar	Novakovići	5770	18500000	2013
Rogatica	Ustiprača	6900	34948896	2015
Kneževo	Zapeće	3877	14900000	2016
Rogatica	Mesići Nova	4900	23900000	2016
Berkovići	Do	2000	8987400	2016
Foča	Govza B-G-1-Jeleč	4980	22448978	2017
Rogatica	Dub	9400	43658932	2018
Kneževo	Ilomska	4950	15950000	2015

Location	Title	Power (kW)	Planned annual production (kWh)	Year of installation
Foča	Jeleč	4800	17950000	2018
Kneževo	Medna	4900	20990000	2018
Mrkonjić Grad	Bočac 2	10000	41203000	2019
Trnovo	Bogetići Nova	9960	29189976	2019
Reka Žiraja	Žiraja	410	1747	2013
Grabovička reka	Grabovička reka	785	1840	2014
Reka Velika Jasenica	VelikaJasenica	650	1500000	2014
Reka Oteša	Oteša B-O-2	992	4509000	2014
Teslić	Žeželja	300	1295000	2015
Šipovo	Otoke 1	32	147000	2016
Foča	BK2	250	1350000	2017
Milići	Jovana	944	3340000	2017
Paklenica Donja	Paklenica	245	995700	2017
Gacko	Čemerno	200	849000	2018
Teslić	Žiraja II	890	2395000	2018
Milići	Štedrić	850	3520000	2018
Teslić	Crkvina	249	965300	2018
Zvornik	Ispod Kušlata	990	6500000	2018

Large hydropower plants

The following large hydropower plants are located in the Republic of Srpska:

- On the river Trebišnjica: HPP *Trebinje 1*, HPP *Dubrovnik*,
- On the river Drina: HPP *Višegrad*,
- On the river Vrbas: HPP *Bočac*.

The system of hydropower plants on the river Trebišnjica was built in phases, as follows [1,3]:

Phase 1 – In 1968, the *Dubrovnik* HPP, the Gorica-Plat supply tunnel, the Gorica dam, the Grančarevo dam, and two generators in HPP *Trebinje* 1 were built and put into operation. The third generator in HPP *Trebinje 1* was put into operation in 1975. The distribution of produced electricity was performed between the electric power companies of B&H and Croatia in the ratio of 78:22% in favor of the electric power industry of B&H. Since November 1, 1994, one generator of HPP Dubrovnik (unit G1) has been connected to the Croatian Power System, and the other (G2) to the Power System in RS. The current distribution of electricity from this system is the subject of a dispute that needs to be resolved,

Phase 2 – RHPP *Čapljina*, supply channels for RHPP *Čapljina* and HPP *Trebinje 2* were built. RHPP *Čapljina* is managed by EP HZHB, and HPP Trebinje 2 supply channel and accompanying facilities are managed by ERS (i.e., HET). The distribution of electricity in the second phase of the system has not been resolved. During the past few years, production at RHPP Čapljina has been carried out under interim agreements based on discharged waters in the Gorica dam.

HPPs Trebinje 1 and Dubrovnik are shown in figures 7 and 8 respectively.

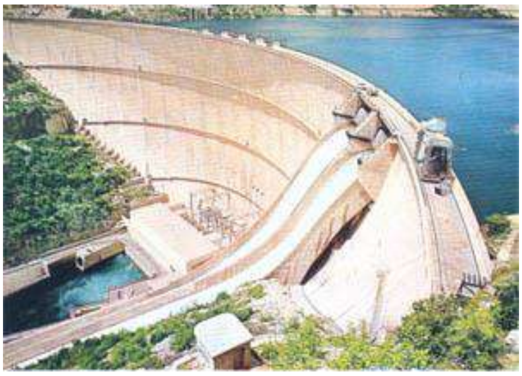

Figure 7. Hydropower plant Trebinje 1 on the river Trebišnjica, 1968.

Figure 8. Hydropower plant Dubrovnik on the river Trebišnjica, 1965.

2.3. The impact of hydropower plants on climate change

Hydropower plants have a longer period of operational life than thermal power plants. There are hydropower plants that have been in operation for more than 50 years. Reservoirs formed upstream of the dam have the greatest impact on the environment. Hydropower plants have a positive impact on the ability to control flood waves, irrigation, water supply, fishing, tourism development, and water sports.

When the reservoir is on a plain river, the flow slows down upstream and the groundwater level rises (the case of HPP Đerdap). The Great Lake causes a change in the microclimate in certain areas by increasing the humidity. Therefore, the advocates of the protection of cultural values do not allow the creation of reservoirs near buildings with sensitive frescoes. In addition, dams interrupt the migration routes of fish species that spawn upstream if there are no separate fishways on the dam. An example of this is the sturgeon in the Danube, which has not appeared since the Đerdap Dam was built. Mountain rivers with canyons and gorges are suitable for creating reservoirs with a large head and hydropower production potential but at the cost of complete flooding and changes in ecosystems. In addition, a lot of river sediment accumulates in the reservoirs creating organic material which over time decomposes, leading to the appearance of methane.

Regarding the impact of small hydropower plants on the environment in Serbia, opinions are divided among experts and the general public. One part of the professional and general public is in favor of the construction of SHPPs, and the other part advocates the ban on the construction thereof. In Serbia, there is no cadaster registration of completed SHPPs, systematized insight into their power, annual electricity production, or studies on their environmental impact. Having all this in mind, the Serbian Academy of Sciences and Arts (SASA) organized on June 6, 2012, a symposium named „Environmental impact of small hydropower plants". At the end of the symposium, the Organizing Committee made conclusions that can be found in the references [1,3].

3. SOLAR ENERGY

Solar energy is a modern field of energy in which the energy of solar radiation is converted into heat and electricity using certain devices. Heat collectors with and without solar radiation concentrators are used to convert solar radiation into thermal energy. Flat collectors with water and air are used for low-temperature conversion of solar radiation (up to 100ºC). Collectors with solar radiation concentrators are used for medium temperature conversion of solar radiation (100-400ºC). Heliostats and parabolic concentrators of solar radiation are used for high-temperature conversion of solar radiation (400-4000ºC).

To convert solar radiation into electricity, photovoltaic systems which consist of solar cells, batteries, a converter from direct current to alternating voltage, etc. are used. Nowadays, solar cells are mostly made of monocrystalline and polycrystalline silicon and, to a lesser extent, amorphous silicon, CdTe, GaAs, and other materials. Photovoltaic systems are increasingly used to generate electricity in private households and solar power plants worldwide.

Hybrid collectors are used to simultaneously convert solar radiation into heat and electricity.

Residential and other buildings constructed by the principles of solar architecture are used for passive capture of solar radiation [4–6].

3.1. Solar energy use in Serbia

Photothermal conversion of solar radiation

A large number of solar systems with flat collectors for water heating have been installed in Serbia: in the General Hospital in Požarevac (210 collectors), Stamnica near Petrovac on the river Mlava (80 collectors), the Youth Center in Kragujevac (20 collectors), etc.

Solar collectors in the hospital and the Residence Hall „Angelina Kojić-Gina" in Zrenjanin are shown in figures 9 and 10.

Figure 9. Solar collectors in „Dr Đorđe Jovanović Hospital" in Zrenjanin

Figure 10. Solar collectors on the roof of the Residence Hall „Angelina Kojić-Gina" in Zrenjanin

In Serbia, vacuum collectors are used in several places to heat water.

The first project of high-temperature conversion of solar radiation in Serbia was implemented in Badnjevac, near Kragujevac. The project was completed according to the conceptual design of Full Professor Vladan Petrović, and it solves two main problems in solar energy; namely, the efficient conversion of solar radiation into thermal energy, and the storage of thermal energy for a longer period (Figure 11).

Figure 11. Badnjevac solar power plant prototype

The measured value of the temperature in the focus was t_f = 1650°C, which shows that the system deviates very little from the theoretical temperature. Due to the high temperatures in the construction of the absorber, materials resistant to high temperatures were used [3].

Photovoltaic conversion of solar radiation

In Serbia, research and applications of solar cells began in 1963. The first monocrystalline silicon solar cell with an efficiency of 8% was constructed at the Institute of Chemistry, Technology, and Metallurgy (IHTM) in Belgrade in 1963. At the same time, solar cells used on the satellites had an efficiency of 10%. In the period 1978-1981, in *EI – Radio-Tubes Co.* in Niš, monocrystalline silicon solar cells with low efficiency were experimentally made.

Solar cells and solar modules are not produced in Serbia but are imported.

In Serbia, there are two fixed solar power plants with an individual capacity of 2 MWp, namely: the Matarova Solar Power Plant in the village of Matarova near Merdar, the municipality of Kursumlija, and the Velesnica Solar Power Plant in the village of Velesnica near Kladovo (Figure 12 and 13).

Figure 12. PV solar power plant Matarova power of 2 MWp, 2013.

Figure 13. PV solar parkin the village Velesnica near Kladovo, 2013.

In Serbia, there are a large number of smaller solar power plants on the ground and on the roofs of residential and other buildings that transmit electricity to the electricity distribution system of Serbia at a discounted price [1,4–6].

Some examples of small PV solar plants are given in figures 14 and 15.

Figure 14. PV solar power plant on the roof of Energoprojekt in Belgrade, 115.62 kWp, 2013.

Figure 15. PV solar power plant Anitex, 40.32 kW, 2013, Bosilegrad (Plan-net-solar, Slovenia)

3.2. Solar energy use in the Republic of Srpska

Solar cells and solar modules are not produced in the Republic of Srpska.

There are several companies in the Republic of Srpska involved in the design and installation of solar systems, namely: *Etmax Ltd.* (Banja Luka), *Bemind* (Banja Luka), *Koming* (Gradiška), *Klenik* (Gradiška), *Topling* (Prnjavor), *Pavlović Mont* (Banja Luka), etc. Solar cells and solar modules are not manufactured in the Republic of Srpska, while solar modules, charge controllers, accumulators, and inverters are marketed by several private companies.

There are 49 producers of electricity in the Republic of Srpska with the status of privileged and temporarily privileged producers of electricity using PV systems with power of up to 250 kW [1–2,5–6].

Some examples of small PV solar plants in the Republic of Srpska are given in figures 16-19.

Figure 16. 20 kWp PV solar power plant BLC 1 (2012) and 10 kWp PV solar power plant BLC 2, (2014) Banja Luka

Figure 17. 249 kWp PV solar power plant Novaković-besjeda in Vijačani village, Prnjavor, 2014.

Figure 18. PV solar power plant MI Trivas Ltd. of 50 kWp, Prnjavor, 2014/15.

Figure 19. 48 kWp PV solar power plant of the company Verano Motors from Banja Luka, 2013.

3.3. The impact of solar energy use on climate change

In the low-temperature conversion of solar radiation, aluminum, copper, glass, rubber, polyurethane, etc., are used to make flat collectors with water and air, and clean technologies. During the operation, flat collectors with water and air do not pollute the environment and do not have a negative impact on climate change.

The medium-temperature conversion of solar radiation uses Winston's parabolic collector, cylindrical-parabolic collector, tubular-vacuum collector, spiral-focusing collector, trapezoidal-focusing collector, and solar ovens for the production of which iron, aluminum, glass, etc., are used. These solar radiation collectors do not pollute the environment during operation and do not have a negative impact on climate change.

Spherical and parabolic concentrators of solar radiation, heliostats, solar furnaces, and solar thermal power plants are used for high-temperature conversion of solar radiation. Concentrators for high-temperature conversion of solar radiation are made of materials that do not pollute the environment and do not have a negative impact on climate change.

Globally, photovoltaic systems today mainly use solar cells made of monocrystalline and polycrystalline silicon obtained using clean technologies. GaAs and CdTe solar cells are used to a lesser extent due to their possible toxic effects on the environment. Recently, great efforts have been made in the world to find efficient, long-lasting, and environmentally-friendly organic and perovskite solar cells.

Solar cells have no moving parts, operate silently, and do not emit harmful substances into the environment.

After a service life of 25-30 years, solar cells are recycled, thus decreasing the negative impact on the environment.

In the case of independent photovoltaic systems, the most sensitive part are batteries, which are removed from operation and recycled after the end of their service life. Lead, NiCd, and similar batteries contain toxic substances with a possible negative impact on the environment during their operation and recycling. Recently, Li-ion batteries, which have a longer service life and less adverse impact on the environment, have been increasingly used in photovoltaic systems.

Copper, aluminum, glass, rubber, polyurethane, and solar cells from various materials are used to make hybrid solar radiation collectors. These materials and technologies for the production of solar cells are not harmful to the environment and do not have a negative impact on climate change. The hybrid collector is a stationary photoconversion system that does not emit harmful substances into the environment during operation and does not have a negative impact on climate change.

Materials that do not pollute the environment (stone, brick, concrete) are used for the construction of residential and other buildings for passive capture of solar radiation using canopies, windows, thermal curtains, wall and furniture paint, thrombus wall, phase-changing, and floor heat storage and glass verandas, iron, aluminum, glass, etc.). These materials and systems do not harm the environment and do not have a negative impact on climate change [1,3–6].

4. WIND ENERGY

Uneven distribution of solar energy per unit area at different latitudes (uneven heating) allows heat transfer through the atmosphere and changes in temperature and pressure, which, together with the rotation of the Earth around its axis, results in the movement of air masses in the atmosphere. In that manner, the wind is an airflow that occurs as a consequence of different heating of the atmosphere and the Earth's surface due to the thermal action of solar radiation and the difference in air density in certain zones. Wind can be used to generate electricity, perform mechanical work, etc.

A wind generator is a device that converts the kinetic energy of the wind into electricity. The wind generator consists of a wind turbine, reducer, generator, block transformer, control and management system, auxiliary system (crane, cooling systems, lighting, etc.), aerodynamic braking control system, housing rotation system, monitoring and communication, determination device for wind speed and direction, housing and support column, etc. [3].

4.1. Wind energy use in Serbia

There are nine wind parks for the production of electricity in Serbia. The first wind park was built on Pešter plateau in the municipality of Tutin, in 2011. The largest, 158-MWp wind park „Čibuk I” is located in Mramorak near Kovin. The total power of all wind parks in Serbia is 430 MW.

The location of wind parks in Serbia is given in Figure 20.

Basic information on wind parks in Serbia is given in Table 4.

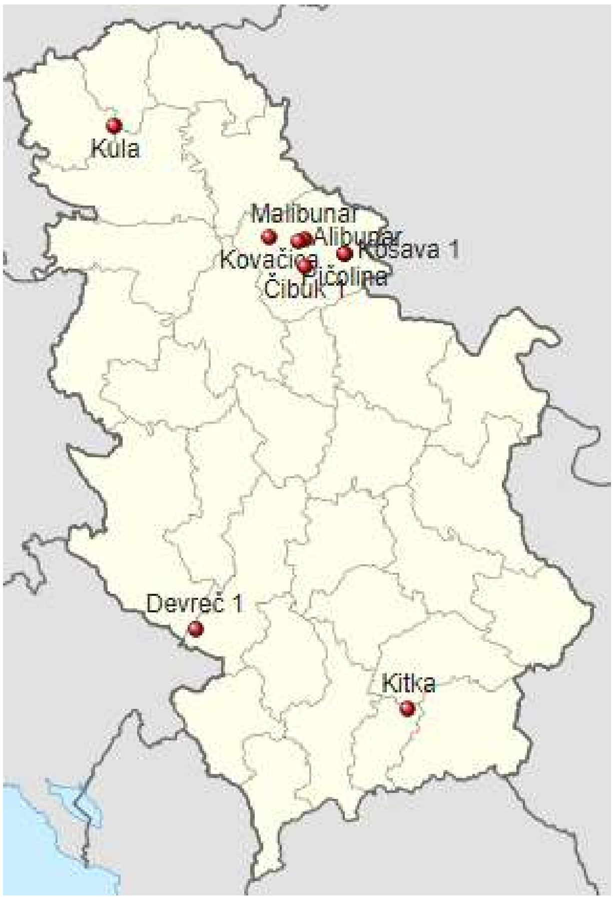

Figure 20. Locations of wind parks in Serbia [1]

Table 4. Basic information on wind parks in Serbia [7]

Name	Location	Municipality	Capacity (kW)	No. of generators	Installation year	Status
Devreč I	Devreč	Tutin	600	1	2011	Active
Kula	Kula	Kula	9,900	3	2016	Active
La Pičolina	Zagajica	Vršac	6,600	2	2016	Active
Malibunar	Alibunar	Alibunar	8,000	4	2017	Active
Alibunar	Alibunar	Alibunar	42,000	21	2018	Active
Kitka	Polička	Kosovska Kamenica	32,500	9	2018	Active
Kovačica	Debeljača	Kovačica	104,500	38	2019	Active
Košava I	Izbište	Vršac	69,000	20	2019	Active
Čibuk I	Mramorak	Kovin	158,000	57	2019	Active
Plandište I	Plandište	Plandište	102,000	34	2021	Under construction
Krivača	Krivača	Golubac	104,000	38		Under construction
Kostolac	Kostolac	Požarevac	66,000	20		Under construction
Bajgora	Bajgora	Kosovska Mitrovica	105,000	27		Under construction

4.2. Wind energy in the Republic of Srpska

The Republic of Srpska does not have wind power plants [2].

4.3. The impact of wind energy use on climate change

The use of wind energy has a little negative impact on the environment compared to the conventional energy sources that directly affect climate change and disturb the natural balance. Wind energy does not create harmful emissions or hazardous waste, does not deplete natural resources, is not a cause of environmental damage due to the use of resources, transport, or waste management. The impact of wind turbines on the environment in relation to the impact of fossil fuels is relatively small. Compared to other sources of electricity, wind turbines have the least impact on global warming per unit of electricity produced.

The impact of wind power plants on the natural habitats of birds, bats, and other flora and fauna depends on the specifics of the location. Great efforts are being made worldwide to avoid setting up wind power plants in the areas of migratory routes of birds or bats. To avoid potential disturbance of the surrounding population from noise, wind power plants are placed at an appropriate distance from the settlement. In wind power plants, the noise comes from the rotation of the propellers (aerodynamic noise) and the mechanical elements in the wind turbine (mechanical noise). The aerodynamic noise depends on the design of the propeller, the speed of their rotation, the wind speed, and the turbulence of the incoming air. Mechanical noise from wind power plants is tonal in nature. Advances in technology and design have led to a reduction in the noise that occurs during the operation of wind power plants. In addition, wind power plants emit electromagnetic radiation that can lead to interference in radio and other telecommunications signals.

When choosing a location for the construction of wind power plants, their visual impact on the environment should be taken into account. Based on the above, the visual effect, noise, interference of radio telecommunications and the impact on flora and fauna, negative impacts of wind turbines on the environment, and climate changes are relatively small and can be adequately reduced or avoided [1,3].

5. BIOMASS

Biomass is an organic matter of plant or animal origin that can be converted into usable energy by various processes.

Biomass includes:

– agricultural waste: straw, leaves, parts of fruit trees, etc.,

– agricultural cereals, different types of sugar beet, sugar cane, corn, etc.,

– forest waste: unused wood, log and stump residues, industrial waste (the organic waste in the beverage industry, food industry, etc.),

– municipal waste: paper, cardboard, etc. [1,3].

Generally, biomass consists of combustible (carbon, hydrogen, sulfur, etc.) and non-combustible parts (ash and water). The elements of biomass that participate in the combustion process are carbon, hydrogen, sulfur, oxygen, and nitrogen. The combustion of biomass produces ash, CO_2, water vapor, and a certain amount of thermal energy.

5.1. Biomass power plant in Serbia

In Serbia, there is only one power plant to produce electricity from biomass. The 2.4 MW plant, in operation since mid-2021, is located within a pellet production site in Boljevac. The production of electricity uses wood waste from the pellet production. The construction of the pellet production facility and the power plant began in 2017, and cost 12 million euros. The production facility and power plant are owned by Point Group (Figure 21).

Figure 21. Pellet and biomass power production plant, Boljevac, 2021. [8]

5.2. Biomass power plants in the Republic of Srpska

In the Republic of Srpska, there is only one privileged producer of biomass electricity, the characteristics of which are given in Table 5.

Table 5. Privileged producer of biomass electricity in the Republic of Srpska [2]

Location	Name	Power (kW)	Planned annual production (kWh)	Installed in
Prijedor	Toplana 2	250	1 960 000	2016

In the Republic of Srpska, the 6.52 MW Pale Heating Plant uses coal and 18000 – 24000 m^3 of wood per year for heating. In the Republic of Srpska, there are three plants for the production of pellets (in Novi Grad, Zvornik, and Srbac). About 54% of urban households in the Republic of Srpska use wood for heating, while in rural areas this percentage is higher (85%). According to the results obtained from surveys, 4.64 PJ of wood biomass is used for heating in urban areas [1].

5.3. The impact of biomass power plants on the environment and climate change

The content of volatile or combustible volatile organic substances in biomass, such as methyl ethyl ketone, vinyl acetate, acetone, ethanol, methanol, ethyl acetate, carbon disulfide, etc., is quite high. The volatile content ranges from 70-80%. The significant share of combustible volatile substances represents the most significant part of the energy potential of biomass.

Ash is a mixture of minerals that remain after completion of biomass combustion process. The ash content in biomass is relatively small and ranges from 1-8%.

The combustion of biomass pollutes the environment to some extent due to the emission into the air of CO_2, volatile substances, and ash that remain after its combustion.

6. BIOGAS

Biogas is formed by the anaerobic fermentation of organic matter. Anaerobic fermentation is a process of decomposition (decay) of organic matter without the presence of oxygen. As a result of this fermentation, gaseous fuel (biogas) and high-quality organic fertilizer and/or protein-rich fodder are obtained.

Biogas is a mixture of combustible and non-combustible gases, where methane accounts for about 70% of combustible gases (CH_4), and 30% are non-combustible gases (carbon dioxide, carbon monoxide, ammonia, water vapor, oxygen, and nitrogen).

Biogas is produced in anaerobic digesters by fermentation of organic matter (biomass-manure). The production of biogas in digesters takes place until all the necessary conditions for the process of fermentation of the substrate are met, maintaining a constant temperature being the most important one. At an optimum temperature of 32 – 35ºC, the separation of biogas lasts from 18 – 22 days.

In practice, different types of digesters are used (differing in construction, size, the way the processes take place in them, the material from which they are made, the installation of heaters, pumps, etc.). [1, 3].

6.1. Biogas power plants in Serbia

Today, there are 28 biogas power plants in Serbia with a total capacity of 27.8 MWp. The characteristics of some biogas power plants in Serbia are given in Table 6.

6.2. Biogas cogeneration installations in the Republic of Srpska

Novo Selo

In the Republic of Srpska, there is only one preferential producer of biogas electricity, in Novo Selo, municipality of Šamac (Table 7).

In this plant, the following are used as a raw material for obtaining biogas:

– liquid/solid swine and cattle manure
– maize fodder and other plant and herb residues,
– biomass residues in field production and
– other organic residues.

Table 6. Characteristics of some biogas power plants in Serbia [9]

Location	Power (kW)	Installation date
Čurug	1270	27 Nov 2018
Vrbas	1410	16 Jan 2014
Blace	999	12 Mar 2012
Bač	650 650 650	02 Mar 2018 03 Nov 2016 03 Nov 2016
Potoš	600	12 May 2016
Senta	1738	11 May 2011
Zrenjanin (Lukićevo)	2126	11 Aug 2020
Alibunar	3570	12 Sep 2016
Sečanj	999	27 Sep 2019

Location	Power (kW)	Installation date
Bačka Palanka	999	27 May 2019
Svetoza rMiletić	999	20 Feb 2019
Stara Pazova	600	26 Dec 2017
Čoka	530	16 Jul 2010
Kanjiža	800 800	11 Dec 2018 11 Dec 2018
Novo Miloševo	1200	26 Jan 2021.

Table 7. Preferential producer of biogas electricity in the Republic of Srpska [2]

Location	Name	Power (kW)	Planned annual production (kWh)	Installation year
Novo Selo (Šamac)	Buffalo Energy – Gold MG	999	8 345 800	2016

Agricultural cooperative Livač

In 2011, a 37-kW cogeneration plant on biogas was put into operation in the agricultural cooperative *Livač* in Aleksandrovac, the municipality of Laktaši. The agricultural cooperative *Livač* is a dairy farm. The produced heat and electricity are used in the farm, where cheese production plant is also located. In 2014, the agricultural cooperative *Livač* applied for the status of a privileged power producer in RS.

Prijedor

In Prijedor, a cogeneration plant was put into operation in 2016. The facility comprises a wood chip heating plant and a 250-kW biogas power plant, where the biogas is obtained by pyrolysis of wood chips. The obtained thermal energy is used for communal heating, and electricity is delivered to the 20-kV MV network. The operation of the power plant is intensive in the summer when the heating plant is not in operation [1].

6.3. The impact of biogas power plants on the environment and climate change

Biogas technology treats organic waste as a raw material for the production of electricity and organic fertilizers with a significant reduction in pollution of soil, water, air, and the ozone layer. Achieved production of electricity, heat, biofertilizers, and a significant reduction in greenhouse gas emissions that affect climate change derives considerable financial benefits and produces significant reduction in imports of gas, oil, electricity, compost, etc.

Heat generation is one of the basic roles of the use of biogas in raising the quality of the environment in rural areas. Thermal energy is mostly generated by burning solid biomass (wood). Such thermal energy production reduces fuel utilization and a certain amount of ash and soot is produced, which are also disposed of uncontrollably, thus posing an environmental hazard. Biogas combustion products are environmentally friendly, producing no ash or soot. The use of biogas to generate thermal energy eliminates the use of solid biomass from this process, and the quality of the environment largely depends on the quality of ecosystems, i.e., flora and fauna. Biogas production by anaerobic digestion gives high-quality fertilizer. By using this fertilizer, which is biogas production by-product, produces better effects than fertilization by unprocessed manure. Electrification of rural areas is also a common problem. The most common problem here is with the distribution of electricity to remote areas. The described cogeneration process can produce a certain amount of electricity, which significantly reduces transport costs. The construction of transmission lines and transformer stations also affects the quality of the environment [1,3].

7. CONCLUSION

In the light of the above mentioned, the following can be concluded:

Serbia

– hydropower, solar energy, wind energy, biomass, and biogas from renewable energy sources are utilized in Serbia;

– there are several publicly and privately owned small hydropower plants and 16 large hydropower plants;

– there are two solar power plants, 2 MWp each (Matarova and Velesnica) and a large number of small solar power plants mounted on the ground, and the roofs of public and private buildings;

– there are nine wind power plants in Serbia with a total generation capacity of 430 MW;

– there is one 2.4 MW biomass power plant in Serbia;

– there are 28 biogas power plants in Serbia with a total capacity of 28.7 MW.

Republic of Srpska

– hydropower, solar energy, biomass, and biogas from renewable energy sources are utilized in the Republic of Srpska;

– there are 29 small, privately-owned hydropower plants and four large state-owned hydropower plants (Trebinje 1, Dubrovnik, Višegrad and Bočac);

– there are 49 solar power plants on the ground and the roofs of residential and other buildings;

– there are no wind power plants in the Republic of Srpska;

– the Republic of Srpska has one biomass power plant with a total power of 250 kW;

– the Republic of Srpska has three biogas power plants with a total power of 1.286 MW.

Impact on the climate and environment

– in hydropower, reservoirs have some influence on the microclimate of the environment in which they are located;

– the use of solar energy and wind generators has minimal impact on climate change;

– during the combustion of biomass and biogas, certain gases and particles are released into the atmosphere and have a low impact on the environment and climate change;

– in Serbia and the Republic of Srpska, using renewable energy sources compared with conventional electric energy sources has a negative impact on the environment and climate change.

8. REFERENCES

[1] T. M. Pavlović, D. Lj. Mirjanić, D. D. Milosavljević, *Electric power industry in Serbia and the Republic of Srpska*, Academy of Sciences and Arts of the Republic of Srpska, Banja Luka, 2018 (in Serbian).

[2] https://reers.ba/ [Accessed: 6 August 2021].

[3] T. M. Pavlović, D. D. Milosavljević, D. Lj. Mirjanić, *Renewable energy sources*, Academy of Sciences and Arts of the Republic of Srpska, 364, Banja Luka 2013 (in Serbian).

[4] T. Pavlović, B. Čabrić, *Physics and techniques of solar energy*, Gradjevinska knjiga, Belgrade, 2007 (in Serbian).

[5] T. Pavlović ed, *The Sun and Photovoltaic Technologies*, Springer Verlag, 2020.

[6] T. M. Pavlović, Y. Tripanagnostopoulos, D. Lj. Mirjanić, D. D. Milosavljević, *Solar Energy in Serbia, Greece and the Republic of Srpska*, Academy of sciences and arts of the Republic of Srpska, Banja Luka, 2015.

[7] https://sr.wikipedia.org/sr-ec/Списак_ветропаркова_у_Србији [Accessed: 6 August 2021].

[8] https://www.ekapija.com/news/2688592/prva-elektrana-na-biomasu-radi-u-boljevcu-drakulic-zadovoljni-smo-poslovanjem [Accessed: 6 August 2021].

[9] https://biogas.org.rs/biogas-sektor/biogas-elektrane-u-srbiji/
[Accessed: 6 August 2021].

ꙮ

ОБНОВЉИВИ ИЗВОРИ ЕНЕРГИЈЕ И КЛИМАТСКЕ ПРОМЕНЕ
У СРБИЈИ И РЕПУБЛИЦИ СРПСКОЈ

Сажетак: У раду је пажња посвећена коришћењу обновљивих извора енергије у Србији и Републици Српској и њиховом утицају на животну средину и климатске промене. У Србији се од обновљивих извора енергије користе хидроенергија, соларна енергија, енергија ветра, биомаса и биогас. У Републици Српској се од обновљивих извора енергије користе хидроенергија, соларна енергија, биомаса и биогас. Приликом коришћења хидроенергије често се формирају језера која имају утицај на микроклиму средине у којој се налазе. Уређаји за фототермалну и фотонапонску конверзију Сунчевог зрачења углавном су стационарни, не емитују штетне материје у околину и немају утицај на климатске промене. Коришћење ветрогенератора има одређени утицај на струјање околног ваздуха. Приликом коришћења биомасе и биогаса долази до испуштања у атмосферу гасова сагоревања који имају одређени утицај на климатске промене. У закључку рада је истакнуто да коришћење обновљивих извора енергије у

Србији и Републици Српској има мали негативан утицај на животну средину и климатске промене.

Кључне речи: обновљиви извори енергије, хидроенергија, соларна енергија, енергија ветра, биомаса, биогас, климатске промене.

Paper received: 20 August 2021
Paper accepted: 15 September 2021