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Evaluation of Geographical Conditions for the Usage of the Hydropower Energy – Case Study River Uvac Basin (Republic of Serbia)

Abstract: Hydropower, as a form of renewable energy resource, has an important role in the modern economic, energetics and technological development of the Republic of Serbia. Estimated value of hydropower potential for Serbia is 31 000 GWh (of that 55% is technically exploitable). Future perspectives of energy development require the maintenance of existing hydropower plants and construction and usage of small hydropower plants (capacity up to 10 MW) for the purpose of electricity production planned for the local consumers. As a potential area for their construction, smaller river basins and streams in mountainous parts of Serbia have been isolated, due to convenient natural conditions for their construction and use. One of these areas includes river Uvac basin, which is located in South-western Serbia, and it basin has surface of 1.334 km^2. The biggest part of basin (around 70%) is located at high altitudes (between 1000 and 1500 meters), which together with high average river and basin falls and the beneficial water discharges, is the main factor for usage of water in hydroelectric purposes. The aim of the following work is the analysis and evaluation of topographic and hydrological conditions of land in the Uvac River basin for hydropower usage. The analysis includes the determination of total and available resources, evaluation of current usage, as well as the analysis of the positive and the negative effects of such type of energy. Complementary influence of river regime and water usage will be particularly highlighted. Programme of the Republic of Serbia for energy development have established suitable location for building hydropower plants on the Uvac River and its tributaries.

Key words: hydropower energy, River Uvac basin, river flow, electricity

Introduction

Modern technological and economic development can't be imagined without the usage of renewable energy resources. In the second half of the 20th century and at the beginning of the 21st century, there is a great demand for new types of energy resources in the world. The same period is characterized by global problems related to irrational use of natural resources and environmental protection. Within the group of renewable energy sources, hydro energy occupies a significant place. The rapid development of hydropower in the 20th century is most often associated with the construction of large dams and reservoirs. Hundreds of mass barriers from concrete, stone and soil have been laid across river valleys around the world to create large artificial reservoirs. These procedures resulted in a large amount of electricity, irrigation water, and created conditions for more effective flood

protection. At the same time, microclimate conditions and lost areas under fertile soil have been altered (Bahtiyar & Gokcol, 2011).

Water is becoming scarcer planetarium resource. At the same time, energy needs are increasing, while non-renewable energy resources are gradually exhausted. That's why renewable resources are gaining importance, with hydropower playing a very important role. The role of hydropower, along with other renewable energy sources, is expected to become increasingly important in future. Hydropower is still the most efficient way to generate electricity. Modern hydro turbines can convert as much as 90% of the available energy into electricity, while the efficiency of the best fossil fuel plant is only about 50% (Jaber, 2012). Additionally, hydropower is an outstanding source to generate electricity in all over the world, and will seemingly keep on growing especially in the developing countries.

Republic of Serbia is an energy medium-dependent country, as the annual consumption of all types of energy is greater than the domestic production, with a total dependence of around 40%. In 2007, Serbia ratified the Kyoto Protocol, taking over the responsibility to increase the portion of energy produced from renewable energy sources up to 20% until 2012 (Karakosta, et al, 2011).

The utilization of renewable resources for energy production is a very topical issue in Serbia, both among experts and among the public. Having in mind that hydropower potential is considered the most important renewable resource (31.000 GWh per year) which is only partially exploited (10.000 GWh per year), accent is laid on the possibilities for its complete utilization through construction of new hydropower plants. The total technical hydropower potential of Republic of Serbia is about 17.000 GWh, out of which about 60% is currently utilized. The unused potential is situated mainly in the catchments of Drina and Morava rivers and it can be utilized for large as well as for small hydropower plants. According to the electricity utility company „Elektroprivreda Srbije“, this potential may be used in 52 large hydropower plants that would have average capacity of around 25 MW (Karakosta, et al, 2011). Almost all hydro energy produced in Serbia is from plants with installed capacity above 10 MW (Golusin, 2010).

Currently, large hydropower plants produce around 10.3 TWh/year (32% of Serbia’s total annual electricity production). A smaller part of hydropower potential is exploited using small hydropower plants with installed capacity of up to 10 MW (Ardizzon, 2014). With 39 small plants currently operating in Serbia (with a total installed capacity of up to 49 MW), the potential remains largely untapped. Previous analysis has showed that overall territory of Drina hydropower system can be provided significant amount of electrical energy (Langović, et al, 2016). Future perspectives indicate that one part of the energy should be produced in new hydropower plants. They also indicate that it should increase the production of energy on already built plants (Milovanović, et al, 2004).

Geographical characteristics of Uvac River basin

The Uvac River basin extends in the southwestern part of Serbia between the Lim River basin in the south, the Golijska Moravica River basin in the northeast, the Ibar and Raška River basins in the southeast and the Drina River basin in the northwest (Fig. 1). Uvac is formed of several cold springs on the slopes of mount Ozren, flows through the Sjenica basin and the Uvac canyon and flows into the Lim River at the altitude of 440 meters. It represents the right tributary of the Lim River. The Uvac River basin extends mostly on the

territory of Serbia and has a small extent on the territory of Bosnia and Herzegovina. The Uvac River basin covers 1 334 km^2, and the direction it occupies is the southeast - northwest. The length of the river is 119 km. The basin is asymmetrical - the largest number of tributaries is flown to Uvac on the right side (Vapa, Kladnica, Tisnica, Marića potok, etc.), and the smaller number on the left side (Veljušnica, Zlošnica) (Gavrilović & Dukić, 2014). The most western point of the basin is located not far from the confluence between Uvac and Lim River, near the village of Štrpci (43^{o}37'53'' N and 19^{o}29'14'' E) at the altitude of 445 m. The northest point is located on the mountain Murtenica, near the village of Dobroselica (43^{o}38'25'' N and 19^{o}41'28'' E) at the altitude of 1275 m. The most eastern point represents exaltation of Kula (1674 m), while the southest point of the basin is difficult to determine because of the karst relief in the area of Pešter (a large number of tributaries presents the subterranean rivers). The entire terriitory is confined with the markant mountain peaks (the basin border): in the southwest, the Zlatar mountain (Golo brdo, 1627 m), bare and scattered Jadovnik mountain (Katunić, 1734 m), which is connected with Ozren (1693 m) and Suhara mountain (1326 m); the northeast border is made by Golija (Jankov kamen 1833 m), Javor (1468 m), Giljeva (1617 m) , Mučanj (1534 m) and Zlatibor mountain (1496 m).

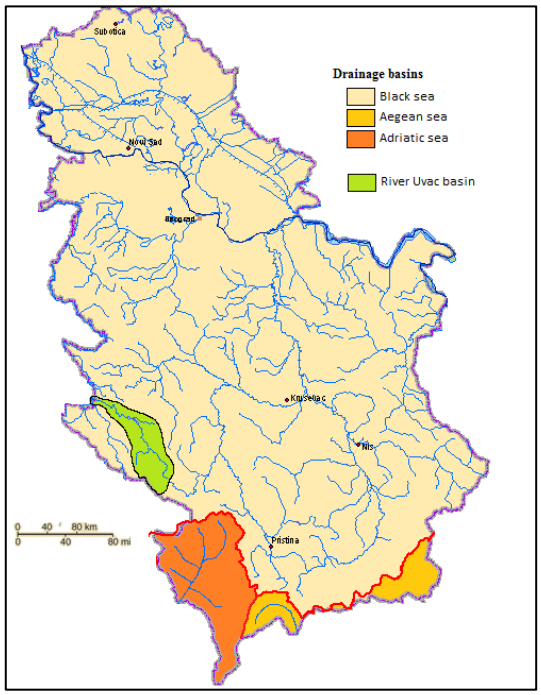

Fig. 1 – Geographical position of Uvac River basin in the Republic of Serbia (Source: Authors)

The Uvac River basin is predominantly built of sedimentary rocks, but there are also magmatic and metamorphic rocks. The oldest rock masses in the basin area are from upper Paleozoic age and they construct small areas north of the Zlatar Lake. In the area of Mučanj, they are presented by metasandstones, argiophylitte, phyllite and conglomerates of the middle carbon age. Quartz conglomerates of permoteric lie transgressively over them. The sediments of the Triassic are the most dominant rock mass in which canyon valley of the river Uvac has been carved. The older sediments of the lower Triassic were presented with two types. The first type is represented by marl, limestone and clay (Prostorni plan područja posebne namene SRP Uvac, 2014). Occurrences of this type built the southern slopes of the Kamena Glava, the zone around the confluence spots of Veljušnica and Kladnica rivers. The

second type is presented along the periphery of the Zlatar Lake and downstream from the dam (around the Kokin brod) with gray limestone.

The largest part of the river Uvac basin is covered by sediments of the middle Triassic. Solid limestone have been developed and mainly lie above the sediments of the lower Triassic (Ćiric, et al, 1979). They are remarkably carved and contain a large number of underground forms of relief, mainly caves (Ušački cave system - the longest cave system in Serbia) (Dragović, 2004). Volcanogenic - sedimentary structures of Jurassic also have a large distribution. They are presented with diabase - chert formation and they built the area around the Zlatar Lake. Its composition consists of sandstone, alevrolite, gray, limestone, and gabrow, diabase and rare serpentines are included. The Neogene basins of Rutoši and Radoinja are presented by conglomerates over which lie gray marl and sandy clay. Quaternary sediments are presented by alluvial sediments (gravel, sand and clay) and are related with the confluence area of Vapa and Uvac rivers in the Sjenica basin (Fig. 2).

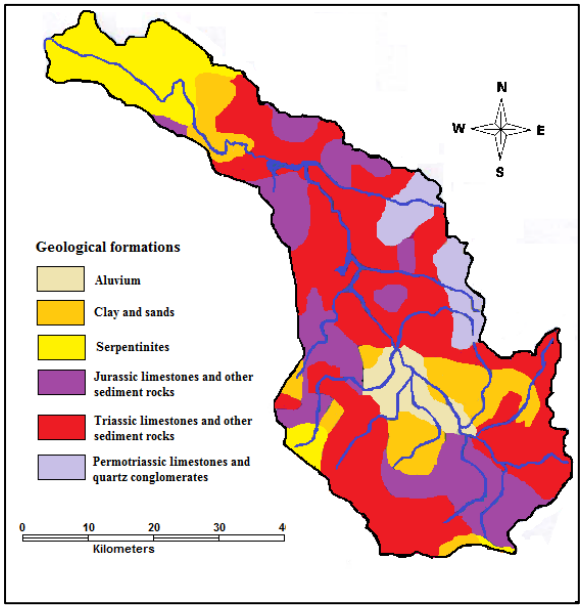

Fig 2. Geological map of River Uvac basin (Source: Authors)

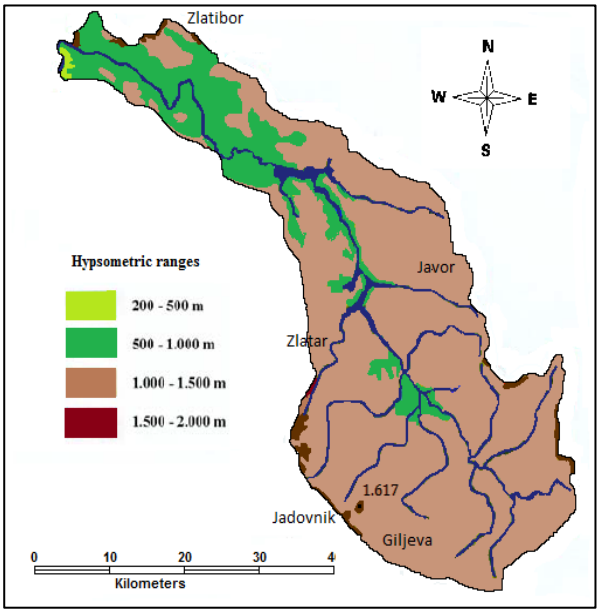

Fig 3. Hypsometric map of River Uvac basin (Source: Authors)

Although the whole area of the basin is tectonic predisposed, the erosive forms are represented by the spacious surfaces and the canyon valleys of the mountain rivers prevalent in the relief. The river Uvac springs at the altitude of 1460 m in Caričina village, on the northern slopes of the Ozren, spends its valley across the Pešter plateau, sinks in the limestone magnificent canyon of an epigenetic character with trapped meanders. There are nine meanders and they are tectonic predisposed (Dragović, 2004). Analyzing terrain hypsometry and altitude zones, it is concluded that the largest part of the basin occupies a high altitude belt (between 1000 and 1500 m) - almost 70% of total surface. The highest zone (over 1500 m) occupies the minimum area around the highest peaks of Javor, Golija Giljeva, Ozren and Zlatar. The 500 - 1000 m belt is surrounded by a narrow underflow of the river Uvac, while the only "*real*" lowland area appears at the confluence of the river Uvac (Fig. 3).

On a general climatic characteristics of the Uvac River basin, great significance have equal distance of the Pannonia plain on one side and the Adriatic Sea on the other. The canyon valleys of Uvac, Vapa and their tributaries direct the movement of lower air masses, which

affect the air temperatures, precipitation, relative humidity and cloudiness (Ljević, et al, 2004). According to Kopen's climate classification, most of the territory of Serbia is classified as C type. The same author gives the area of western and southwestern Serbia the mark Cfwbx,[1]. The mentioned author in this area distinguishes one more climate mark with Dfwbx (Pešter and Zlatibor). The letter D in the code indicates a cold climate. There is only one active meteorological station on the territory of the Uvac River basin - Sjenica. On January 26, 2006 in Sjenica the temperature minimum for Serbia was registered, which was -39^{o}C.

Precipitation is one of the most important element, which conditions usage of hydropower energy. Average annual rainfall rises from southeast to northwest. Maximum precipitation occurs at the end of spring and early summer, while the minimum is typical for winter months. Total annual precipitation in the Sjenica (1974 -2014) is 706.6 mm. Maximum precipitation is in June (79.9 mm) and May (73.7 mm), and the minimum in March (40.7 mm), February (41.2 mm) and January (43.1 mm). Considering that the maximum precipitation is in summer and the minimum in January, the Sjenica region belongs to the continental pluviometric regime. The relatively small annual rainfall in the Sjenica is explained by the microposition of the meteorological station. Because of that, this climate has a sharp and relatively dry mountainous climate characteristic. The mountains, in this area, have over 800 mm of precipitation per year.

After formation of Uvac River, the first large tributary is Duboki potok, which flows at the 1212 m into Uvac, from the right side. In the upper course, the most important, and at the same time, the biggest tributary of Uvac is Vapa River. It drains the northern part of the Pešter's plateau and the Sjenica field. The Vapa River basin has a surface of 519 km^2, and therefore accounts for almost 40% of the total Uvac catchment. Confluence of these two rivers is flooded with Sjenica Lake. The average flow rate of Vapa is 7.2 m^3/s. The flow of the Uvac River has been rebuilt with dams formed by three artificial lakes that fill the greater part of the gorge and canyons: Zlatar, Sjenica and Radoinja lakes (Tab. 1).

Tab 1. Characteristics of artificial lakes on Uvac River

	Year of formation	Altitude (m)	Surface (km^2)	Length (km)	Depth (m)	HP plants
Zlatar Lake	1962	888	7.25	24	75	Kokin Brod (22.5 MW)
Sjenica Lake	1978	985	5.7	25	108	Uvac (36 MW)
Radoinja Lake	1981	810	0.55	11	30	Bistrica (108 MW)

(Statistical Office of the Republic of Serbia)

Two most important factors that are needed for qualitative usage of hydropower energy are total and average falls of river course and existence of uniform river flow. The total fall on the entire course of the river Uvac is 1020 meters, average 8.5 ‰, and in different sectors ranges from 2.3 to 9.1 ‰. The most pronounced average drop of the current is in the canyon area and it has value of 9.1 ‰, or 91 meters per 10 km of river flow. The tributaries of Uvac River also represent the true mountain rivers of large falls and high hydroelectric potential.

Depending on the activity of various geomorphological and climatological factors, the Uvac river regime shows certain fluctuations. Monthly and annual fluctuations are the result of

[1] f - an even distribution of precipitation during the year; w - the warmer half of the year is still richer with precipitation; b - the average monthly temperature of the hottest month does not exceed 22^{o}C; x - in the pluviometric regime, the primary and the secondary maximum of precipitation are distinguished.

unequal quantities and distribution of precipitation, evaporation, geological background and vegetation. In the Uvac River Basin, there is only one active hydrological station where water flows are measured. It is located on the Vapa River. On the course of the river Uvac we set two maximum and two minimum annual water levels (Dragović, 2004).
Flow is the most important element of the river regime (Langović, et al, 2017). All tributaries of Lim River are characterized by seasonal fluctuations in flows. The annual flow of Uvac at the confluence in Lim is 18 m^3/s, but part of its water is stopped and diverted for hydroenergy exploitation. The average annual flow of water in the upper Uvac River is 5 m^3/s, while in Kokin Brod 12,45 m^3/s (Stanković, 2005). The mean annual flow for the period 1977 - 2015 was 4.06 m^3/s. The maximum mean annual flow rate was 6.7 m^3/s (2014), while the minimum recorded in 1990 was 1.8 m^3/s. Analyzing the researched period, it is observed that the value of the medium-term flow rate varies (significantly above the average were 1990, 1993 and 1994, while the highest water quality was recorded in 1984, 2014, 2015).

State and perspectives for usage of hydropower energy

The main geographical factors that have influence on usage of hydropower energy are physical – geographic (total and average fall of watercourse and mean and annual river flows) and social (number of inhabitant, future consumers, economic situation, etc). From previous analysis, we can conclude that this basin has good physical – geographic conditions for usage of hydropower energy. Future perspectives suggest some new locations for construction of small hydropower plants in the Uvac River basin. It is been pointed out 16 new location for new SHPP (Fig. 4). Most of them would be constructed on tributaries of the Uvac river, because of their big course falls and also because of relieving the course of main river.

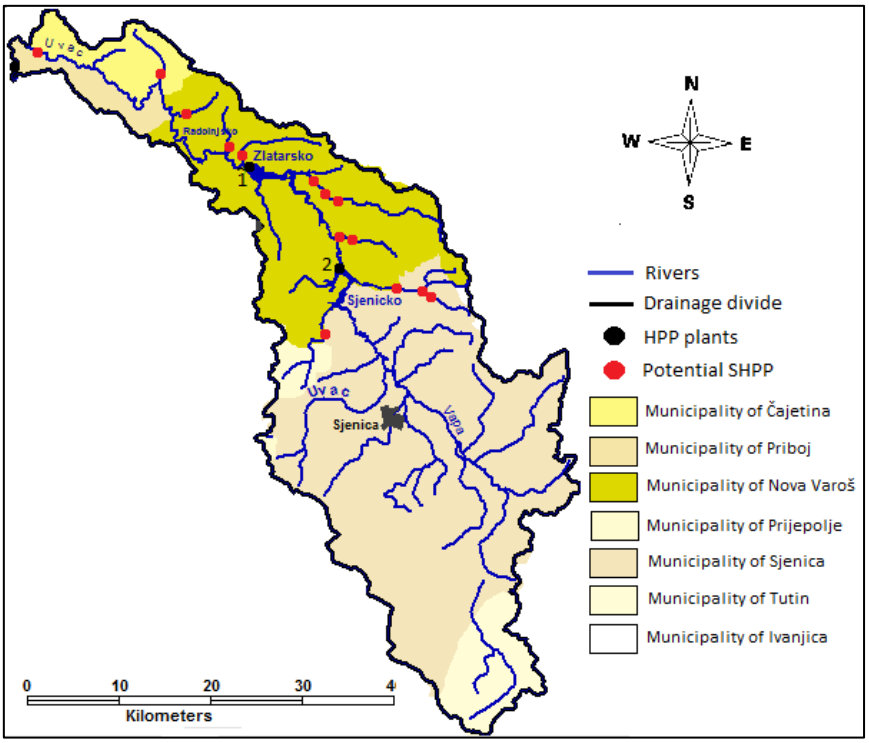

Fig 4. State and perspectives of hydropower plants in River Uvac basin (Source: Author)

In the Uvac River basin, there are 103 settlements, in which, according to Population Census in 2011, live 51 443 inhabitants. These settlements belong to the municipalities of: Sjenica, Nova Varoš, Ivanjica, Prijepolje, Tutin, Čajetina and Novi Pazar. The populationally largest town settlements in this area are: Sjenica and Nova Varoš, and among the villages: Banja and Rača on territory of Priboj municipality.

Population is mainly concentrated in urban settlements. The major processes, which are characteristic for this region, are depopulation and deagrarization (Ristić & Deđanski, 2016). Because of these processes, there are big number of small settlements (up to 50 inhabitants), about 20%. The smallest settlement is Skradnik, which, according to Population Census 2011, has only one permanent resident. Depopulation process began in the 80s of the 20th century, while the processes of industrialization and urbanization began earlier.

Based on the employment data of the population, we analyzed the sector of employment, which belongs to the supply and the production of electricity (Republic Bureau of Statistics, 2011). In these settlements, there are 13 893 economically active inhabitants, of which, 5 871 inhabitants live in town settlements Sjenica and Nova Varoš. It needs to be pointed out that 255 inhabitants are employed in sector of electricity supply and production, of which, 143 inhabitants live in the Nova Varoš. Other significant settlements are Vraneša, Burađa, Radoinja and Vilova. In these settlements, more than 6% of the population is employed in the sector of electricity supply and production. It is worth pointing out that the largest hydropower plant in the Uvac basin, HP „Kokin Brod“ is located on the territory of Nova Varoš municipality. This hydropower plant was built in 1962. A year earlier, the settlement Kokin Brod was sunk, and the inhabitants moved to Nova Varoš. At that place, Zlatar Lake, an accumulation that is used for electricity supply and tourist-recreational purposes, was created. The second hydroelectric power plant, in this area, was built in 1979. Since that year, downstream of Sjenica Lake, Uvac, as a river, no longer exists. Water is trapped, and 400 ha of land are left below the surface of artificial lake. The construction itself lasted for five years.

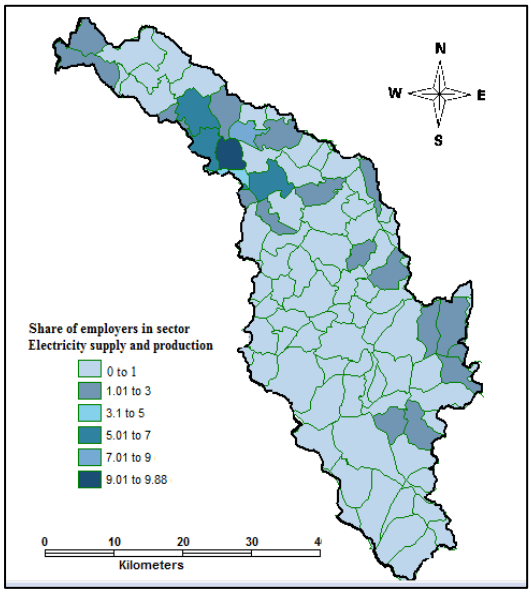

Fig. 5. Settlments by share of employers in Electricity supply and production (Source: Author)

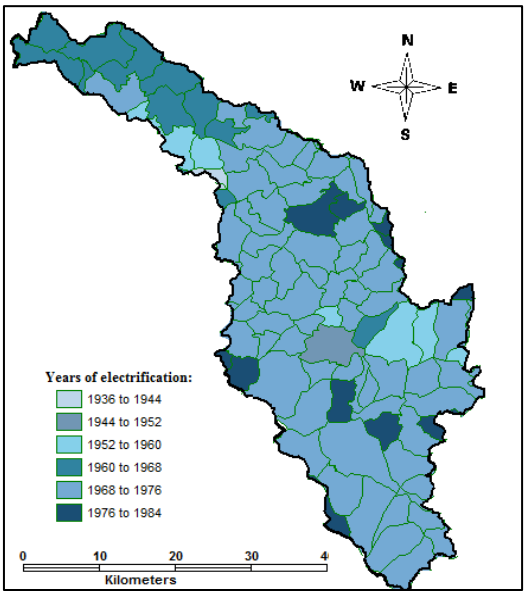

Fig. 6. Settlments by year of electrification (Source: Author)

The construction of these hydropower plants directly relate to the electrification of a large number of settlements in this area. Before the Second World War, only Nova Varoš was electrified. Further electrification was carried out gradually, so that by 1960, eight more settlements in this region were electrified. After the construction of hydropower plant „Kokin Brod“, most of the settlements in the territory of Sjenica municipality received electricity, while complete electrification was completed in 1984, when settlement Boljare was electrified.

Conclusion

The aim of this paper was to examine all the geographical conditions for the usage of hydropower energy in the Uvac River basin. There are currently two hydropower plants in this area: "Kokin Brod" and "Uvac", while the construction of small hydropower plants is in the future plans. Physical-geographical conditions fall into the most important conditions during the construction of hydropower plants. Among them, the most important conditions are: mean annual flow (if there is not enough water, the construction of a hydroelectric power plant is impossible) and the total and average falls of the river course (the greater the fall, the greater the speed, and therefore the hydroelectric potential is higher). Apart from physical-geographical, there are also socioeconomic conditions. They include the number of inhabitants, future consumers of electricity, as well as the economic situation of the region itself.

The construction of hydroelectric power plants was conditioned by the industrialization process that began after the end of the Second World War. In order to further develop the economy, it was necessary to perform, first, electrification of all settlements in Serbia. The river Uvac, like a mountain river, with high water speed and a large drop in flow, was chosen as ideal for the construction of a hydroelectric power plant. During the 60s and 70s of the 20th century, industrialization has reached its maximum, and a large number of these settlements has been electrified thanks to the construction of HPPs "Kokin Brod" and "Uvac", and a certain number of people from the settlements of this area have found employment in these hydroelectric power plants. However, along with the process of industrialization, processes of depopulation and urbanization were taking place. Depopulation is characteristic for all settlements of the observed territory, and is caused by: negative natural increase and emigration of the population (the most frequent cause of relocation is the search for employment in the city.

In the future, the reduction of rural population and the extinguishing of some rural settlements are expected (especially in the territory of the municipality of Sjenica, because these settlements are very far from the administrative and economic center, the city settlement Sjenica). Also, it is very important to ensure the continued safe operation of existing hydroelectric power plants, and if the conditions (primarily financial) are created, several small hydropower plants will be built that will provide additional energy stability to this region.

However, besides financial, there are other obstacles to the realization of this project. First, it is estimated that this project would endanger the environment around the river Uvac, change its course and endanger the living world. Also, there is a potential conflict with the Special Nature Reserve "Uvac", a protected area inhabited by a protected bird specie, a griffon vulture.

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