

# The analysis of the hydropower potential in Podkarpackie Voivodship

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**Abstract.** The paper presents an analysis of the use and potential of hydropower in Podkarpackie (Subcarpathian) Voivodship. The current usage of hydropower in the Region is presented, divided for range of generated power, geographical location and given rivers. Existing and planned artificial water reservoirs are taken into consideration in frame of hydropower development in the Region. Selected case studies related to varied hydropower plants are discussed. Problems connected with development of the hydropower were identified and considered. For each county in the Region theoretical available power possible to install in the main rivers was indicated, taking into account environmental aspects, technical problems with connection to the electrical grid and overall possibility of the facility installation. For each county communities with the best favorable situation are indicated. It is discussed the analysis of the evaluation of the use of hydropower in Podkarpackie Voivodship and provided information on planned and considered investments in hydropower plants. In addition, an analysis of the energy potential of the main rivers of the Podkarpackie Region have been proceed to indicating the most favorable areas for location of hydropower plants. Moreover, given the environmental conditions, an analysis of the power estimation of the hydropower plants were made.

## 1 Introduction

Podkarpackie Voivodship is located in south-eastern Poland and it borders with Slovakia and the Ukraine. In terms of size, it is the eleventh region in Poland, and in terms of the population ninth. Population is over 2 million, the population density is 119 people/km<sup>2</sup>. The biggest city in the Region is Rzeszow with a population over 180 thousand [1].

Climate has transitional character between lowland and mountain. Average rainfall is 700 - 800 mm and 800-1000 mm in the northern part and in the southern part, respectively. In some parts of the Bieszczady Mountains rainfall increases up to 1200 mm [2].

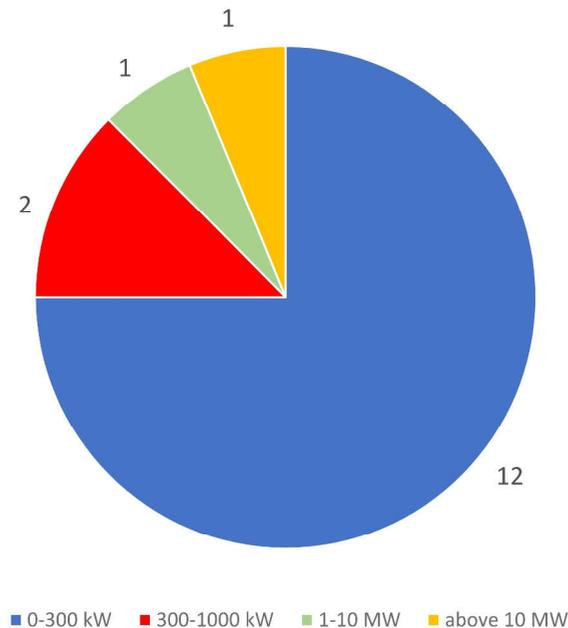
Podkarpackie Voivodship has three distinct physiographic regions. The northern part of the Region is Sandomierz Basin Plain, the central part the Carpathian Foothills, while the southern part the Low Beskids and Bieszczady Mountains.

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Generally, Poland has a small technical potential of hydropower of approx. 8.3 TWh/year [3] compared to other European countries: Switzerland 41 TWh/year, Austria 56 TWh/year [4], France 100 TWh/year [5], Norway 240 TWh/year [6]. Moreover, in Poland annual electricity generation is 2.1 TWh, Switzerland 34.5 TWh, Austria 37.6 TWh, France 69.8 TWh and Norway 116.3 TWh [7]. This is caused mainly by the fact that Poland is a lowland country. The greater the difference in height between the upper and lower reservoir then the power of the hydropower plant is higher. Unfortunately, in order to obtain optimum operating conditions for water turbines it is required to build a very expensive dam, which are designed not only to accumulate water to yield more energy, but also to regulate the flow of the river and serve as a flood protection. The largest number of hydropower plants in Poland are located in the southern part, mainly in the region: Malopolska, Lower Silesia, Silesia and Podkarpackie. Hydropower plants over 5 MWe are usually a pumped storage hydroelectric plants, while small hydropower plants are mainly the run-of-river hydroplants.

In the Podkarpackie Voivodship it was able to identify 16 operating hydroelectric power plants of different sizes [8,9], it is planned to build five more. There exist 26 potential locations for next hydropower plants. Figure 1 presents the number of hydropower plants in case of the installed power.



**Fig. 1.** Number of hydropower plants in Podkarpackie Voivodship in case of installed power

Some of the existing hydropower plants are a few dozen kW, where the produced energy is consumed nearby. Due to the installed power, the vast majority plants are so-called small hydropower plants which has less than 5 MWe installed power. These include hydropower plants in Wilcza Wola, Żołyńia, Krempna, Sieniawa, Radawie and Nienowicach which are connected to the medium voltage distribution network. The total installed power of small hydro power plants is estimated several MWe.

Two large hydropower plants located in the Podkarpackie Voivodship, Solina are Myczkowce hydropower plant on the San river (Solina – 200 MWe, Myczkowce – 8.3 MWe).

## 1.1 Hydro turbines types

The most the most commonly used hydro turbines in the Podkarpackie Voivodship are Kaplan and Francis turbines. In some small hydropower plants also propeller turbines are used. Below, short description of the particular turbine type [10,11]:

### 1.1.1 Kaplan turbine

Rotor of the Kaplan turbine is constructed as a propeller with 2 to 8 adjustable (rotated on shaft neck) blades. Pin blades are mounted in the hub of the rotor. This is the vertical type of turbine. Recently it is spread a new type of Kaplan turbine - tubular turbine which is placed in the tubular housing. Water supply to the stator blades take place parallel to the turbine axis.

In the bulb turbine water flows through the support blades, keeping the turbine in the axis of the pipe and then through the stator blades and rotor blades, where water transfer its energy and flows straight to the axial suction pipe.

One of the variants – the Staflo turbine is a turbine with the external generator which is installed outside the water channel and possible transmission in the engine room, where they are easy to maintenance.

### 1.1.2 Francis turbine

The water flows to the rotor through a spiral casing and then, radially through the variable blades placed on the outer perimeter of the rotor. Francis turbine's rotor consists of two rims and blades. They are used for creation of variable cross-section channels in the direction of water flow. The blades in the Francis turbine are not adjustable. The most common configuration is a horizontal single-rotor. This version is relatively easy to install and maintain. The version with double rotor is used to larger flows. The vertical version is used to the larger generated powers.

### 1.1.3 Propeller turbine

Can be considered as a Kaplan turbine with non-adjustable blades, in particular, is very sensitive to changes in flow rate, because the slower flow cannot strikes the blade at the correct angle

## 1.2 Hydropower potential in Podkarpackie Voivodship

The main rivers of the Podkarpackie Region are: right-bank tributaries of the Vistula River (San and Wisłoka), left tributary of the San (Wisłok) and left-bank tributary of the Wisłoka (Ropa).

Energy resources of major rivers are determined by tributaries of the following rivers:

- San: Hoczewka, Osława, Sanoczek, Magierówka, Baryczka, Łubienka, Wiar, Wisznia, Szkło, Lubaczówka, Wisłok, Trzebońnica, Tanew i Bukowka;
- Wisłok: Pielnica, Morwawa, Lubatówka, Stobnica, Strug, Świerkowica, Mlecza;
- Wisłoka: Kremrna, Wilsznia, Iwielka, Kłopotnica, Żółków, Ropa, Jasiołka, Czarna, Wielopolka, Tuszynka i Breń;
- Ropa: Sękówka, Moszczanka, Lubuszanka, Olszynka, Bednarka and 7 unmarked, on available maps, small rivers and torrents.

## 2 Estimation of available hydropower generation

For each county in the Region theoretical available power possible to install in the main rivers was indicated, taking into account environmental aspects, technical problems with connection to the electrical grid and overall possibility of the facility installation.

**Table 1.** Theoretical and available hydropower in Podkarpackie Voivodship (only rivers with theoretical generation power larger than 0.5 MW are listed)

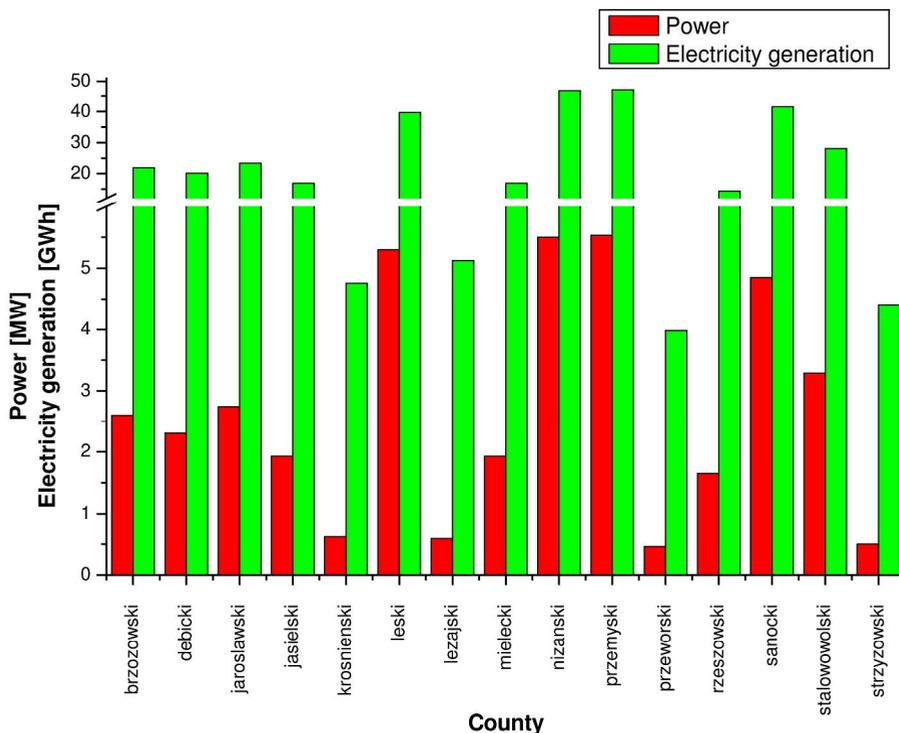
County	River with $P \geq 0,5 \text{ MW}$	Theoretical potential in river flow [MWh/a]	Average usage hydropower [MW]	Possible electricity generation [MWh/a]
brzozowski	San, Wisłok	91 156.18	2.60	21 877
dębicki	Wisłoka with the Wielopolka river estuary	83 770.02	2.30	20 105
jarosławski	San with the rivers estuary: Lubaczówka, Szkło, Wisznia	97 528.31	2.74	23 407
jasielski	Wisłoka with the rivers estuary: Jesiolka, Ropa	70 523.31	1.93	16 925
krośnieński and Krosno city	Wisłok	22 497.94	0.62	4 760
leski	San with the Hoczewka river estuary and Myczkowce Dam	165 340.09	5.30	39 682
leżajski	San, Wisłok	21 355.00	0.59	5 125
mielecki	Wisłoka with the Tuszyńska river estuary	70 338.29	4.93	16 881
niżański	San with the Tanew river estuary	195 761.30	5.50	46 983
przemyski	San with the Wiar river estuary	196 878.46	5.53	47 251
przeworski	San, Wisłok with the Mlecza river estuary	16 576.98	0.46	3 979
rzeszowski and Rzeszów city	San, Wisłok with the Strug river estuary	59 836.96	1.65	14 361
sanocki	San with the Osława river estuary, Wisłok	173 203.21	4.85	41 569
stalowski	San with the Bukowa river estuary	117 087.26	3.29	28 101
strzyżowski	Wisłok with the Stobnica river estuary	18 367.02	0.50	4 408
<b>Sum</b>		<b>1 400 220.33</b>	<b>39.83</b>	<b>335 414</b>

The available power was estimated based on assumption that in natural flow of the river the hydraulic losses are compensated by potential energy and kinetic energy decrease of the water flow. According to the assumption of the model, the theoretical construction of the densely located weirs will transform the hydraulic losses into the estimated, useful energy resource. Model estimated the resource of useful energy and the expected electricity generation from hydropower. The model simplified calculations, assuming that the 50% of the energy potential of the river is possible to use for electricity generation. The model indicators were adopted and tested for the average flow of the Dunajec river, between the water dams: Rożnów – Czehów [12].

Analyzing the potential of tributaries of major rivers in the Voivodship, such as San Wisłok, Wisłoka, Ropa it should be noted that the total theoretical potential in the river stream is 1 400 220.33 MWh/year, which provides a principle for the small hydropower plants construction with a capacity of 0, 8-1,0 MW (data for each rivers in the Table 1).

Nowadays, in Podkarpackie Voivodship over a dozen hydropower plants are in operation which are located in i.a. Wilcza Wola, Żołyńia, Krempana, Sieniawa, Radawa, Nienowice.

The special importance has the Solina Dam, which is the biggest hydraulic engineering structure in Poland. Moreover, hydropower plant located in the Solina Dam is the biggest storage hydroelectric plant working on natural water flow. Among the working small hydropower plants in Podkarpackie Voivodship it is worth to mention about the Klimówka Hydropower Plant with 1.1 MWe (generated electricity is putted to electric grid Gorlice – Wysowa of 15kV), small hydropower plant Pilzno with 825kWe and Tabor with 30kWe. The river which energy potential is used in greatest extent is San – Water Power Station Solina – Myczkowce and to a much lesser extent Wisłoka i Wisłok. The Table 1, presented the theoretical and usage potential for each county in Podkarpackie Voivodship.



**Fig. 2.** Power and possible generation in each county of the Podkarpackie Voivodship

Figure 2 shows the results of the estimation of the potential hydropower in a given county in Podkarpackie Voivodship. There were estimated the power potential of hydroelectric power plants and electricity generation. Plants of the highest installed power could be built in the county of Przemysl, Nisko, Sanok and Lesko. Those plants may have separately up to approx. 5 MW. The situation is similar with electricity generation. Annually it could be generate approx. 40-50 GWh per county. The worst potential is characterized by counties Przeworsk, Strzyżów, Leżajsk and Krosno with total powers possible to install up to 500 kW per each and a total electricity generation of 4-5 GWh. In total, in Podkarpackie Region it could be installed approx. 40 MW of new power where electricity generation could reach up to 335.5 GWh.

The above data show the average possible power to achieve from hydro in a given section of the river and the possible electricity generation annually. For investments, the construction of hydroelectric power plants are more promising where those values are much larger.

The development of hydropower in the Podkarpackie Voivodship is mainly driven by two main factors. The first factor is the hydro potential. The second factor is the flood protection of an areas located close to rivers by building water dams. Next are environmental concerns and possible connection to the electrical grid. Whereas, generally, the possibility of the location of water dams depend largely on local plans and the actual land use nearby the river, the possibility of legal land acquisition, geological conditions and the required number of arrangements, for example opinions of the respective Water Management Authority.

The development of hydropower in a given place usually depends on the following factors: natural, technical, legal and economic.

Regarding environmental factor, it is important to assess the water resources in the given area, the possibility of water damming up, eg. based on topographic maps and geological conditions.

The technical factor is very important to determine the mode of operation of the hydro plant, type and size of the turbines and other auxiliary equipment.

Legal, it is necessary to obtain all necessary permits for the execution of investment in accordance with applicable law. This is one of the most difficult point in the realization of hydroelectric power plant.

Economic, it is needed to perform calculations, eg. the economic efficiency of investment for the various technical options, sources of financing, the dynamics of electricity prices change in the long term.

### **3 Examples of existing hydropower plants**

The total annual generation of electricity from hydropower in Poland is 2 261 GWh [13]. In Podkarpackie Voivodship it is estimated at about 245 GWh: in the Solina-Myczkowce Hydro Power Plant 230 GWh, Mokrzec 5 GWh and other small hydropower plants – 10 GWh. Most of the hydroelectric power plants in Podkarpackie Region has low power of several hundred kilowatts. Only two plants have larger capacities, plants belonging to the ZEW Solina-Myczkowce Those plants are used three types of turbines: the Kaplan, Francis and Propeller [14]. The list of ten hydropower plants is presented in the Table 2.

**Table 2.** Summary of basic information about existing or planned hydropower plants in Podkarpackie Voivodship [14]

Place/River	County	Owner/grid connection	Number of turbines x electrical power [kW]	Type of turbine	Total power [kW]	Built in
Mokrzec/Wisłoka	Dębica	MEW Pilzno	3x275	Kaplan	825	2002
Nienowice/Wisznia	Jarosław	ZKE	3x50+1x100		250	1998
Radawa/Lubaczówka	Jarosław	ZKE	1x300	Propeller	300	1993
Wróblík Szlachecki/Tabori	Krosno	RZE	4x7.5	Propeller	30	2000
Solina/San	Lesko	ZEW Solina-Myczkowce	4x50 000	Francis	200 000	1968
Myczkowce/San	Lesko	ZEW Solina-Myczkowce	2x4100	Kaplan	8 200	1961
Dębiaki/Babulówka	Mielec	Individual person	1x23	Francis	23	
Przeworsk/Młeczka	Przeworsk	Individual person	3x21	Propeller	63	2011
Zaklików/Sanna	Stalowa Wola	Individual person	1x18	Francis	18	1996
Rzeszów/Wisłok	Rzeszów	RZE	1x660	Kaplan	660	2012

It is visible that capacity of the power plants started from 18 kW up to 200 MW. Four installation have power less than 100 kW. Each type of the turbines is commonly popular, however for small installations propeller and Francis turbines are used. Kaplan turbines are installed in medium capacity units and Francis for big installations. All installations are build after 60th of the XX century and the most of the small installations – in last 30 years. Special importance has Solina hydropower plant –third largest pumped-storage electricity in Poland.

## 4 Conclusions

The Podkarpackie Voivodship has large potential of hydropower, however its usage is limited due to significant variation of flow [15]. It is caused by varied hydrologic conditions and hilly type of rivers. However, comparing to wind energy, the water flow is definitely more stable [16], the power usage is 2-3 times larger comparing wind power plants.

The counties przemyski and niżański has the largest potential of power generation – more than 5 MW. The one of the most important factors influencing the development of hydropower are environmental conditions. However, well recognized potential for installation of small hydro-power exists.

The work has been completed as part of the statutory activities of the Faculty of Energy and Fuels at the AGH University “Studies concerning the conditions of sustainable energy development”

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