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THE MODEL OF REGION APPLICABILITY OF A SMALL HYDROELECTRIC POWER PLANT IN SLOVAKIA

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The Small hydroelectric power plant (HPPs) is usually not associated with negative impacts on the environment within their operation and construction. To produce electricity, hydroelectric power plants make use of the hydroelectric power potential of rivers (HP), which is the product of mean flow rates and heads of a particular river stretch. The big advantage is that they are decentralized energy sources. In addition they can be installed in remote areas where they can provide opportunities for development and energy self-sufficiency mostly in countryside areas. The aim of this article is to develop the model for cost-benefit analysis and environmental impact assessment of a small hydroelectric power plant in the conditions of the Kosice region in Slovakia.
Key words: small hydroelectric power plant, water energy, water slope, hydroenergetic potential.

Model regionalne primjenjivosti malih hidroelektrana u Slovačkoj. Mala hidroelektrana obično nije povezana s negativnim utjecajem na okoliš glede svog rada i konstrukcije. Za proizvodnju električne energije hidroelektrane iskorištavaju hidroelektrični energijski potencijal rijeka predstavljen produktom vrijednosti srednjeg protoka i nagiba riječnog korita. Velika prednost malih hidroelektrana je da se radi o decentraliziranim izvorima energije. Osim toga, mogu biti instalirane na udaljenim područjima gdje mogu pružiti mogućnosti za razvoj i energijsku samodostatnost promatranog regionalnog područja. Na primjeru moguće instalacije male hidroelektrane na području regije grada Košice u Slovačkoj, cilj ovog rada je razviti model za analizu troškova i isplativosti promatrane investicije te procjenu utjecaja na okoliš.
Ključne riječi: mala hidroelektrana, vodna energija, nagib rječnog korita, hidroenergetski potencijal.

INTRODUCTION

Hydropower is the most effective energy source of all energy sources from the technological, energy-conversion point of view (over 90 per cent usability). To produce electricity, hydroelectric power plants (HPPs) make use of the hydroelectric power potential of rivers (HP), which is the product of mean flow rates and heads of a particular river stretch. The economic system providing goods and services for people exhausted the Earth's reproduction biocapacity in the 1980s, and today it exceeds our planet's absorption capacity by 30 per cent.

Ecological analyses point to the fact that exceeding Earth's biocapacity is found to correlate well with a temperature growth above the long-term standard in the 1980s and with a significant increase in the greenhouse gas emissions of carbon dioxide during the same period. Unless this trend is reversed, within approximately 20 years' time, in about 2030, man will need two planets of Earth's current biocapacity for his economic activities. All the indications are opposite, so solutions are being sought and put into practice to restore the balance of ecological systems [1].

WATER ENERGY AND THE UTILIZATION OF HYDROPOWER POTENTIAL IN SLOVAKIA

Rivers have traditionally been the basic and most widely used form of energy. In the Slovak Republic hydroelectric power plants (HPPs), and particularly small hydroelectric power plants, i.e. hydroelectric power plants with an installed capacity under 10 MW (SHPPs), were among first to generate electricity. The primary hydro-power potential (HP) used in HPPs and SHPPs is the natural wealth of every country. HP can be defined as the sum of average annual production capacities of all built and technologically utilizable HPPs and SHPPs of a particular territory.

However, its exploitation for power generation varies amongst countries and continents. To a great extent it depends on natural conditions and the level of economic, technological and social development of each country. Highly developed European countries make use of the hydropower river potential of between 65 and 95 per cent. In Slovakia, despite its excellent natural conditions, the hydropower potential of rivers is exploited to only 56 per cent of its full potential capacity [2]. The utilizable hydropower potential of Slovak rivers amounts to 7,361 GWh.r-1 of energy.

Currently, it is exploited in 243 hydroelectric power stations and accounts for 57.5 % of national capacity. The potential to be utilized in the future is 2,500 GWh.r-^{1}. There are two dominant projects to increase the exploitation of the Slovak hydropower potential, namely HPP Sereď (51 MW) and HPP Nezbudská Lúčka (22.5 MW) on the river Váh. There are a number of locations in the Slovak Republic for small hydroelectric plants (SHPPs) on the rivers Hron, Horný Váh, Poprad, Hornád etc. with a capacity of 0.1 to 5 MW.

The greatest potential is in the river Hron where 23 SHPPs could be constructed with a total capacity of 35 MW and a power generation capacity of 200 GWh.r^{-1} [3, 4]. Neither is the potential of micro-resources on smaller rivers in Slovakia, insignificant.

DESIGN OF A SMALL HYDROELECTRIC POWER STATION IN THE SLOVAKIA REGION

In power engineering, the study of the power utilization of a stretch of river looks at various conceptual models. It is clearly desirable that an optimum solution should be found to make it possible to utilize the full hydropower potential of a particular location while taking into account all limiting factors and conditions.

The construction of a small hydroelectric power station consists of the following phases:

1. SHPP preparation;
2. Selection of a suitable location with its preliminary

technological and cost-benefit assessments;
3. Design stage;
4. Construction stage.

Basic construction data

- ✓ *Designed SHPP head: 3,2 – 3,7 m;*
- ✓ *Maximum absorption capacity of one turbine: 20 $m^3.s^{-1}$;*
- ✓ *Turbine type: straight-flow Kaplan's turbine;*
- ✓ *Number of turbines: 2;*
- ✓ *Impeller diameter: 2,0 m;*
- ✓ *Maximum output of the generator clamps: 2 x 0,475 MW.*

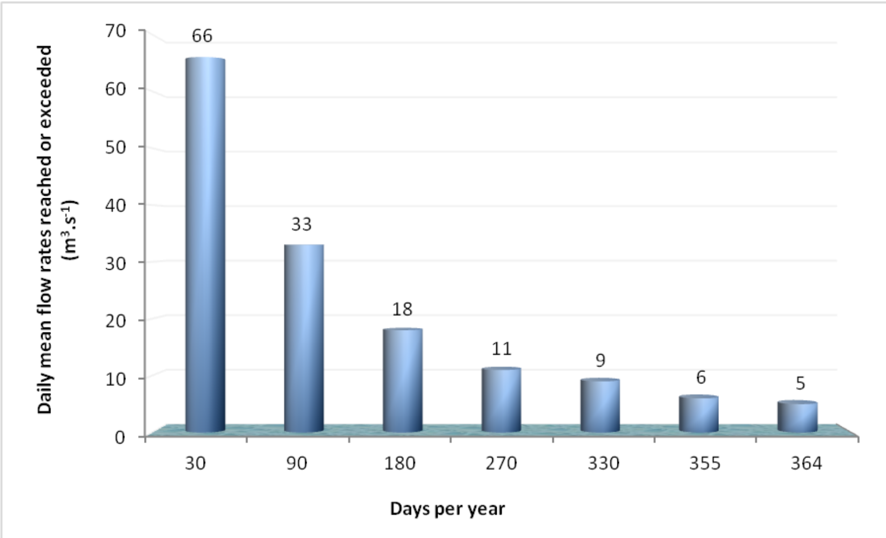

Figure 1. Hydrological data for the SHPP section
Slika 1. Hidrološki podaci za male hidroelektrane

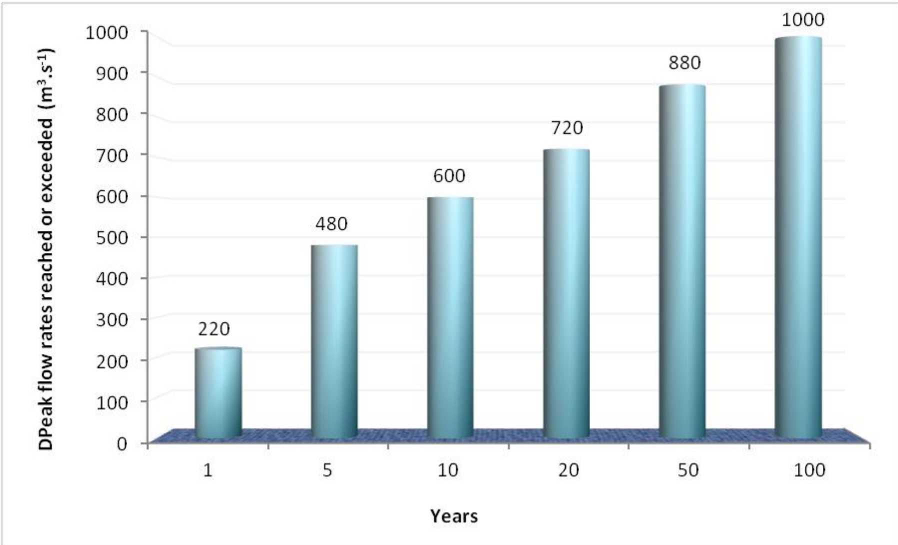

Figure 2. Peak flow rates reached or exceeded per years
Slika 2. Vršne vrijednosti dosegnutih ili premašenih protoka po godinama

Location of a small hydroelectric station

A small hydroelectric power station is situated on the river Hornád at the tributary junction with the river Torysa. It is a small straight-flow causeway-of-timber hydroelectric power station. Electricity will be powered by two generators connected to Kaplan's turbines and carried to the adjacent 22-kV public electrical distribution network of VSD a. s. (East Slovak Distribution Company).

The obtained head of causeway of the small hydroelectric power station is used to calculate the annual power production. Adjusted hydrological data from the Slovak Hydro-meteorological Institute (SHMÚ) and the data for the sections of the River Hornád from the Branch Office of the Bodrog and Hornád River Basin Agency (SVP OZ PBaH)) served as a basis for the previous calculations [5, 6].

Based on these adjusted hydrological data for the design of SHPPs, the distribution line of the achievement and excess of flow rates was determined followed by additional calculations to construct the area of the utilizable hydropower potential. Moreover, with

- ✓ the turbine efficiency $\eta_t = 0.84$;
- ✓ the generator efficiency $\eta_g = 0.93$;
- ✓ average efficiency coefficients and acceleration due to gravity g was calculated as:

$$k = \eta_t \cdot \eta_g \cdot g \qquad (1)$$

$$k = 0{,}84 \cdot 0{,}93 \cdot 9{,}81 = 7.7$$

Then, after the calculations, using the power formula

$$P = \rho \cdot M \cdot H \cdot k \qquad (2)$$

and considering that:

- ✓ the total absorption capacity of all turbines = 40 $m^3.s^{-1}$,
- ✓ the heads ranging within an interval between 3.2 and 3.7 m,
- ✓ the minimum flow rate per turbine = 3.5 $m^3.s^{-1}$

The probable energy indicators were specified:

1. Realizable power outputs utilizing the hydropower potential of the river

a) With respect to the minimum given flow on the river of 5 $m^3.s^{-1}$, the estimated sanitary flow rate in the biocorridor profile (fish pass) of 0.5 $m^3.s^{-1}$, and the minimum absorption capacity per turbine of 3.5 $m^3.s^{-1}$, the minimum operational output P_{min} = 124.6 kW.

b) In the predicted area of maximum river flows in the positions where the maximum head cannot be guaranteed due to the rising of the water level downstream under the causeway as high as the regime level of the causeway bag tilt during high water periods (excluding flooding), the maximum operational output P_{max} = 985.6 kW.

2. Power production after the beginning of the SHPP operation

The essential variable in the calculations of power production is the river aquosity that is almost wholly given by climatic conditions and the amount, rate and duration of rainfall in a specific area. These are rather unpredictable for a specific river in the medium or long terms, including floods.

Methodologically, forecasting models are then based on the quantification of probable flow rates characterised by the amounts of water supply given as a percentage during the period of 365 days in a year.

Using the distribution line of the achievement and excess of flow rates previously mentioned, and by their transformation into electric energy parameters, probable amounts of power were estimated as follows:

- ✓ **E = 5,200.00 MWh year^{-1} – for average flow rates – 1st variant**
- ✓ **E = 4,000.00 MWh.year^{-1} – for high flow rates – 2nd variant**

Given the flow rates above as well as the hydro-technological and safety parameters of the waterworks, it can be expected that with average flow rates in the river, the operation of the hydroelectric power plant will have to stop for 15 days in the year due to high water levels.

Peak flood flow rates were not considered for the purpose of the calculations.

The utilization of the hydropower potential means that part of the water flow in a river is removed and directed towards turbines.

Turbines convert the energy of flowing water into mechanical energy and then by generators into electricity.

The water depleted of power, is naturally returned to the river and the power generated, to the consumer network.

COST-BENEFIT AND ENVIRONMENTAL ASSESSMENTS

Cost-benefit analysis

Because it is a special kind of power production from an unpredictable power source – the rate of flow and the hydropower potential of a river depend on atmospheric conditions [7, 8]. The cost-benefit analysis is also dependent on statistics and the probability of weather events (precipitation volume and flow rates) in the past.

In the cost-benefit analysis, mathematical models of value analysis and financial economics were used to assess the effectiveness of the investment, according to which

Input calculation data:

1. The investment costs total 5,000,000.00 €, while 50 % of the costs are assumed to be covered from the European Union structural funds. Thus, the calculations focused on the internal investor’s funds, therefore the calculations included:

$$IC_i = \frac{IC}{2} = \frac{5\ 000\ 000\ €}{2} = 2\ 500\ 000\ €$$

These the investor decided to provide from its own resources and loans from a commercial bank.

2. The expenses were estimated in the usual manner of the economically common structure, and they are identical for both designed variants.

3. The useful life of a hydroelectric plant was determined as T_l = 25 years, which a common estimate for plants of this type.

4. A discount rate was determined as r = 5 %.

5. The volume of sales and sales revenues were calculated as a product of annual power production in the individual

designed variants of plants and the unit price (UP) stipulated by the Regulatory Office for Network Industries (ÚRSO) in Decree No. 7/2009 for small hydroelectric power stations up to 1 MW, which is 109.08 €.MWh^{-1} [9, 10, 11, 12].

Subsequently, according to Decree No. 2/2008 of the Regulatory Office for Network Industries, the price was reduced by 12 per cent for non-refundable loans = 50 %:

$$UP = 109.08\ €.MWh^{-1} - 0.12 \cdot 109.08\ €.MWh^{-1} = 95.99\ €.MWh^{-1}.$$

Sales - Revenues	1st variant	2nd variant
Annual yield in €	499,148.00	383,960.00

6. The simple pay-back period, the time required to recover the amount of investment $T_s = \frac{IC_i}{CF}$ was quantified in the denominator with an average value of net cash flow during its service life.

7. The discounted pay-back period (T_{sd}), i.e. the payback period where the future cash flows are discounted in order to express their present values to properly determine the value of the project under consideration as a whole, can be calculated from the condition of:

$$\sum_{t=1}^{T_{sd}} CF_t(1+r)^{-t} - IC_i = 0 \tag{3}$$

8. Then, the net present value (NPV) is given by the formula:

$$NPV = \sum_{t=1}^{T_\check{z}} CF_t(1+r)^{-t} - IC_i \tag{4}$$

9. The internal rate of return (IRR) was determined from the following condition:

$$\sum_{t=1}^{T_\check{z}} CF_t(1+IRR)^{-t} - IC_i = 0 \tag{5}$$

Table 1. Selected financial-economic indicators
Tablica 1. Odabrani financijsko-ekonomski pokazatelji

Indicator	1st variant E = 5 200 MWh.r^{-1}	2nd variant E = 4 000 MWh.r^{-1}
Simple pay-back period T_S in years	8	13
Discounted pay-back period T_{SD} in years	14	22
Net present value(NPV) in €	1,613,839	298,842
Internal rate of return (IRR) in %	4.47	0.870

From the financial-economic point of view, the first variant is viable as the net present value is positive.

Environmental impact assessment

The designed project of a small hydroelectric power plant concerns construction work whose operation does not pollute the environment. Specific measures to produce “green energy“ are implemented, making use of the primary renewable energy resource of the river Hornád.

There are no emissions produced, and this is exactly what should be aimed at within the framework of governmental subsidies for the construction of hydropower stations [13].

The annual reduction in CO_2 emissions due to the operation of the designed small hydroelectric power station, compared to carbon energy resources in Slovakia, expressed in terms of the amount of reduced CO_2 production, the volume/amount of the energy produced E = 4 000 $MWh.rok^{-1}$ and 5 200 $MWh.year^{-1}$ is as follows:

Table 2. The annual reduction in CO_2 emissions
Tablica 2. Godišnje smanjenje emisija CO_2

Power generating technology	Combined steam and gas cycle	Thermal power plants coal + gas	Coal fired power plants	Lignite fired power plants
CO_2 emissions reduction in a small hydroelectric power station expressed in tonnes/year when E=4 000 $MWh.year^{-1}$	1 114	1 322	3 990	4 232
Power generating technology	**Combined steam and gas cycle**	**Thermal power plants coal + gas**	**Coal fired power plants**	**Lignite fired power plants**
CO_2 emissions reduction in a small hydroelectric power station expressed in tonnes/year when E=5 200 $MWh.year^{-1}$	1 456	1 738	5 216	5 533

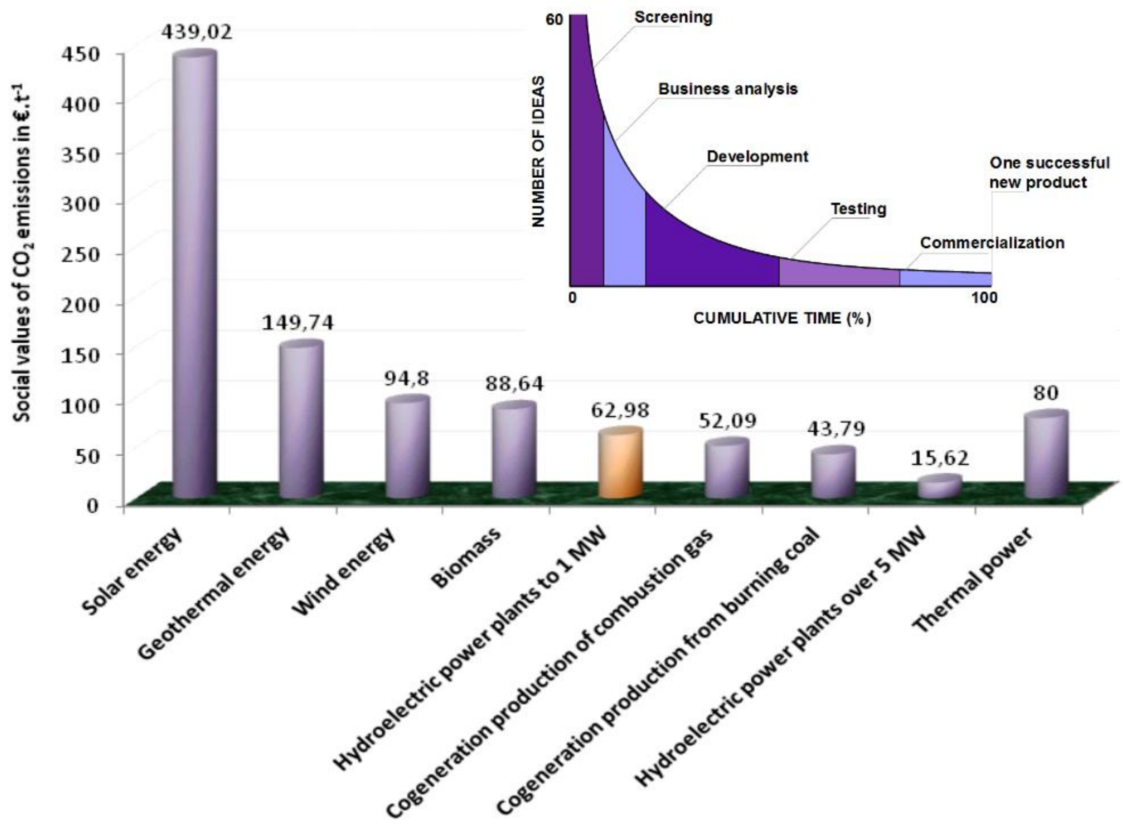

Figure 3. Comparison of different sources for power generation in Slovakia with regard to CO2 emissions

Slika 3. Usporedba različitih izvora za proizvodnju električne energije u Slovačkoj obzirom na emisije CO_2

Comments:

1. *The knowledge curve provides the correlation between the social values of CO_2 emissions in €.t^{-1} CO_2 during the production of electric energy using a specific power generating technology.*

2. *The social value of CO_2 emissions represents the additional costs which society needs to bear in order to prevent the production of emissions. For the Slovak Republic, the present value was calculated by "the Centre" in accordance with the governmental subsidies system for renewable resources and cogeneration power production by Act No. 309/2009 Coll. of the National Council of the Slovak Republic, following the minimum purchase electricity prices stipulated by Decree No. 7/2009 of the Regulatory Office for Network Industries, and CO_2 emissions coefficient in kg.kWh^{-1} in typical power plants in Slovakia.*

The values of pollutant emissions calculated for a comparable power plant in t.MWh^{-1} were confronted with zero emissions produced in the process of power generation in a small hydroelectric power station and the product of a particular pollutant emission coefficient and the annual power production.

Regarding environmental protection, the following benefits can be found:

Table 3. Emission productions in the individual design variants of SHPPs
Tablica 3. Redukcije emisija pojedinih onečišćujućih tvari gledano po pojedinim konstrukcijskim varijantama malih hidroelektrana

Reduction of emissions expressed in tonnes.year^{-1}	Solid pollutants	SO_2	NO_x	CO	CO_2
1st variant E = 5 200 MWh.year^{-1}	0.338	11.69	7.82	1.98	5 650
2nd variant E = 4 000 MWh.year^{-1}	0.245	8.48	5.69	1.42	4 095

CONCLUSION

The conclusions arising from the modelling of the economic effectiveness of the investments into small hydroelectric power stations can be summarised as follows:

1.) Taking into consideration the contribution from the Structural Funds of the European Union amounting to 50 per cent of the whole, it is viable to make an investment providing that there are naturally average water supplies and flow rates in the river (excluding flooding).

2.) Another significant economic fact is that Slovak legislation, in Act No. 309/2009 Coll. and subsequently in Decree No. 7/2009 of the Regulatory Office for Network Industries, stipulates that the compulsory purchase of electricity from small hydroelectric power plants, with an installed capacity under 1 MW, will be at a fixed price for a period of 15 years, thereby creating conditions for the reduction of market risk involved in the purchase of electric energy.

3.) A small hydroelectric power plant with an operating period of 10 years, for instance, in comparison with a lignite fired power plant, makes it possible to reduce carbon dioxide greenhouse gases by 42,320 to 55,330 tonnes.
According to the assessment criteria regarding the social value of CO_2 emissions, a small hydroelectric power station with its value of 62.98 €.t^{-1} of carbon dioxide is among the most effective power stations in terms of the allocation of investment means compared to other renewable energy resources for power production.

4.) The construction of a designed small hydroelectric power station using the water energy of the river Hornád will increase employment in the selected region by two employees directly and further staff in connection with the construction and operational services, thereby contributing to the growth of national power security by the exploitation of national, natural primary energy sources.

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