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Hydrological and financial analysis of the possibility for energy utilization of the water of Ivanik River

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Hydrological and financial analysis of the possibility for energy utilization of the water of Ivanik River: *The article presents the investigation and analysis of the development of a Small Hydro Power Plant renewable energy sources (RES). It includes the estimated energy production and the CO2 emission reduction, resulting from the use of ecological power in relation to electricity produced from the hydropower potential. The analysis of the water resource is developed on the basis of preliminary engineering studies for the possibility of energy utilization of the water of Ivanik River. The produced electricity is sold to the National Electrical Distribution Company.*

Key words: *Small hydro power plants, hydrological analysis, financial analyses.*

INTRODUCTION - EXPECTED BENEFITS OF THE PROJECT

The electricity generated by the hydro power plant will be purchased by the National Electric Company, thus decreasing the amount of the electricity produced by thermal power plants, which use fossil fuels. Table 1 summarizes the revenues from the production and sales, and the operational costs, resulting from the project implementation for the whole project lifetime until 2019.

The revenues from electricity sales during the Small Hydro Power Plant (SHPP) Ivanik operation are based on the monthly distribution of the estimated energy production for the period 2010 – 2019.

Table 1. Project Revenues and Production Costs

		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Electricity Sold to NEK	(MWh/yr.)		1,607	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963
Tariff	(EUR/MWh)		49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66	49.66
Revenues	(EUR)		79,775	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804	196,804
Power plant Operation & Maintenance	(EUR)			-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064	-23,064
Gross Profit	(EUR)		**79,775**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**	**173,740**

Replacement of electricity produced from conventional sources by electricity generated by SHPP Ivanik, will result in CO_2 emissions reduction of 8,264 tons for the period 2010 - 2012. Table 2 presents the reduction of CO_2 emissions for the period 2010 - 2012.

Table 2. Carbon Dioxide Emissions Reduction (tons)

Emission characteristics			2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	**Total**
Electricity sold to NEK	(MWh/yr)			1,607	3,963	3,963	3,963	3,963	3,963	3,963	3,963	3,963	**33,313**
Carbon Emission Factors for Electricity	(tCO_2/MWh)		0.947	0.908	0.884	0.833							
CO_2 Emissions Reduction from electricity	(tCO_2/yr.)		0	1459	3504	3301							**8,264**
CO_2 Emissions Reduction total	**(tCO_2/yr.)**			**1,459**	**3,504**	**3,301**							**8,264**

PROJECT BASELINE AND PROBLEM IDENTIFICATION

This project was developed on the basis of a feasibility study and working design of SHPP Ivanik by a team of professional engineers.

The project was based on the results of the hydrological analysis made for SHPP Ivanik, with main objective to define the authoritative hydrological characteristics of Ivanik

Rivers' run-off for the water intake cross section. The developed hydrology analysis is the basis for the assessment of the expected energy production for a mean run-off year.

The foreseen project for energy utilization of the water of Ivanik River covers the section from elevation 710.70 a.s.l. down to elevation 400.00. Ivanik River is a little and short right tributary of Strumeshnitsa River in the very South-West corner of the country. It takes the waters from the North flank of the Belasitsa Mountain. The Ivanik River flows in narrow and deep valley in North direction. The average slope of the river is big. The catchment area of the river is mountainous, well wooded with significant altitude. To the South, the water catchment of Ivanik River spreads to the Greek border.

The envisaged water intake is situated in the mountain upon village Belasitsa and consists of water-catchment area of 9.8 km^2 at average altitude of 1,120 m.

Table 3 shows the hydro graphic characteristic of the rivers reservoirs.

Table 3. Hydrographic Characteristics of the River's Reservoirs

Water intake	F (km^2)	Hav (m)	Qo (m^3/s)	Mo ($l/s.km^2$)	Cv	Wo ($mil.m^3$)	$W_{95\%}$ ($mil.m^3$)
Ivanik River – elevation 1,1200	9.8	1,120.0	0.220	22.0	0.38	6.938	4.083

The monthly distribution of the outflow is typical for a mean year at the point of the water intake at Ivanik River. It is shown in Table 4 (in percentages and water amounts).

Table 4. Monthly Distribution of the Outflow of Ivanik River

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Σ
P (%)	6.57	6.18	12.87	16.50	18.21	14.33	3.25	2.94	3.37	4.25	5.39	6.15	100
Q (m^3/s)	0.170	0.177	0.333	0.441	0.471	0.383	0.084	0.076	0.090	0.110	0.144	0.159	

These values serve as a basis for the calculation of the expected average annual energy production of the SHPP.

SUMMARY OF PROJECT BACKGROUND

The project of SHPP Ivanik aims at the use of the hydropower potential of part of the Ivanik River's runoff that covers the section from elevation 710.70 a.s.l. down to elevation 400.00.

The SHPP is envisaged with installed power of 1,173 kW. It consists of 1 turbine. The total water discharge of the turbines is 0.320 m^3/s. The total expected energy production from the plant is 3.963 GWh per year under the conditions of a mean water year.

The expected annual production of electricity is 3,963 MWh, which corresponds to the feasibility study. The analysis shows that the production in March, April, May and June is the highest (Figure 1).

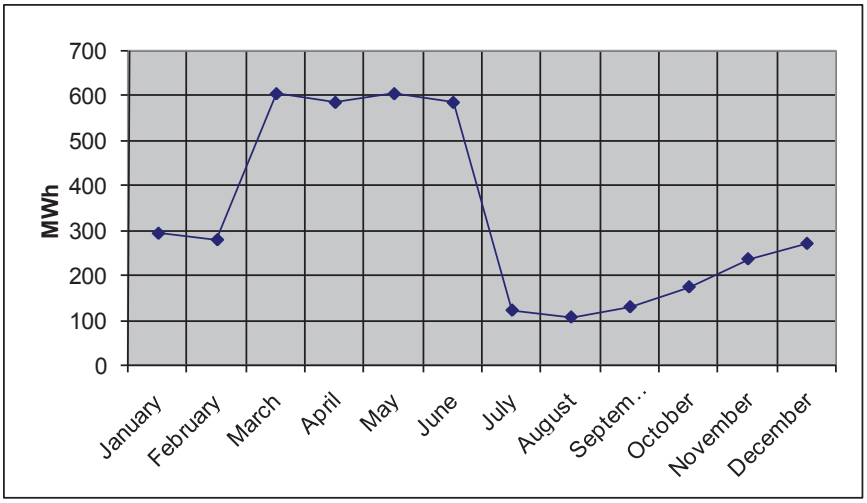

Figure 1. Estimated Annual Production of Electricity MWh

DESIGN AND IMPLEMENTATION OF THETECHNICAL MEASURES

The project of SHPP Ivanik aims at the use of the hydropower potential of part of the Ivanik River's run-off.

The planned SHPP Ivanik operates as a derivation run-off the river power plant with installed power of 1,173 kW. The best possible hydropower use of the varying natural river run-off at an almost constant head is planned to be performed by means of equipment of the power plant with 1 turbine. The total water discharge of the turbines is 0.320 m^3/s. The total energy production from the plant is expected to be 3.963 GWh per year under the conditions of a mean water year.

The system of SHPP Ivanik consists of the following main facilities according to the supplied design documentation:

- Water intake – alpine type on Ivanik River with the following facilities: diversion weir composed of massive and washing part, water intake facility, settling basin, and relief chamber and fish passage.
- Pressure penstock, which follows an already existing road. The penstock is almost 2540 m long.
- Powerhouse of the small hydropower plant in a terrace on the left riverside of Ivanik River.

Intake facility

The planned intake facility on the Ivanik River has to be constructed according to the supplied design documentation at elevation of 710.70 of the river bed. As already mentioned above, it is planned as a common massive weir with a bottom intake facility. The deflected water discharge is conveyed into a settling basin. The maximum operating discharge of the intake is 0.320 m^3/s, according to the presented design documentation. For mitigation of the environmental impact of the planned SHPP system on the ecosystems in the affected river reach beside the intake, the permanent release with highest priority is a minimum discharge of 0.022 m^3/s., specified in hydrological report.

The following main facilities are planned within the frame of the water intake:

- Massive concrete weir with total height measured from the bottom of the river bed is 2.60 m. Under these conditions the overflowing front is in length of 8.00 m. It is designed to pass through the 1% water discharge, without any threat of undesired overflowing. The overflowing edge is at elevation of 711.70 a.s.l. and ensures an overflowing height of 1.00 m.
- The intake structure is designed as a bottom water intake opening. The intake opening is equipped with rough grid for enabling the entering of massive floating structures

from the river into the channel and the repair openings.

- Settling basin with regular form in layout, consisting of one chamber with the option for a periodical flushing. The working length is 12.00 m and the width is 2.00 m, dimensioned for the operating discharge of 0.320 m^3/s, in order to retain flowing particles with size greater than 0.50 mm.
- The fish passage is situated in the right part of the intake structure. The fish passage ensures the passing of the fish upstream and downstream. It is composed of separate basins with width of 0.80 m and length of 2.00 m, steeply situated, connected to each other by openings and overflows. The water from the last basin goes directly to the riverbed at elevation of 709.10 m. As already mentioned above, the minimum residual water discharge to be permanently released through the weir is 0.022 m^3/s, and is not exactly specified in the issued Water Permit (the regulation norms are in progress now and the estimated value in hydrological report is to be revised.)

Pressure Penstock

The penstock starts from the intake facility and consists of steel penstock conveying the water from the intake facility of the powerhouse. The total length of the penstock is about 2540 m and is of steel pipes with diameter of 600 mm. The penstock is to be constructed in an excavated trench, with width of 1.50 m. The penstock has supporting reinforced concrete blocks with average dimensions 1.40/1.10 m, anchored to the excavation for the trench.

Equipment and powerhouse of the SHPP

Hydro-mechanical equipment (complete turbine, asynchronous generator including all electrical equipment and transformer) are presented with the following equipment:

- Turbine Pelton with maximum output 1,173 kW. The maximum / minimum discharge values for the turbine is 0.040 and 0.465 m3/s for rated net head of 289.43 m and rated speed of 1,900 min^{-1}. The main electrical equipment consists of one asynchronous generator for parallel operation with common power grid with total rated power output of 1,173 kW.

Furthermore, all necessary additional components of the mechanical and electrical equipment are also specified in the cited specifications and belong to the list of the complete SHPP equipment.

The connection of the SHPP units to the common grid is planned to be performed by means of one power transformer with transmission ratio 0.4/20 kV, i.e. the connection has to be carried out at the so called middle voltage. The construction of 20 kV air transmission line is planned for connection to an existing such line.

Hence, the expected energy production with the contracted equipment parameters is estimated. The corresponding parameters of the performed analysis are based on the following assumptions as well:

- For the annual energy production estimation further below, the calculated net head is used as a constant: 305.20 m. The gross (geodetic) head of the power plant is defined as a difference between the upper water level elevation at the intake facility (pressure chamber before the penstock inlet): 710.70 and the lower water level elevation at the beginning of the tailrace canal – 400.00, i.e. 310.70 m. Thus, the rated net head of the power plant will be 305.20 m according to the calculated hydraulic losses (5.50 m) in the presented design report for the rated discharge of the SHPP. Further in this analysis, this constant net head value is assumed for estimation of the expected annual energy production. This assumption is safe in the sense of energy production since smaller discharge values will lead to a bit smaller hydraulic losses and some bigger net head, respectively. The relative head changes under real operating conditions are small and may be neglected.

- The maximum water discharge for the planned power plant equipment is 0.320 m^3/s.

Furthermore, the efficiency of the generator is 96 % (shown in the offer) and of power transformer 98 % assumed to be constant on the base of analogous equipment data. With these values, the total efficiency of the power plant is calculated for estimation of the expected annual energy production.

The outlet of the cross-flow turbine has to be connected to the tailrace canal of the SHPP. No further information is available about the inflow of the short tailrace canal into the river bed of Ivanik River.

The energy potential of the project (power and energy production) is to be evaluated with respect to the following quantities:

- Water resources – discharge and total water volume processed by the hydropower units of the power plant as well as its distribution within an average year (i.e. water volume usable for energy production).
- Topographic (geodetic) resource – gross (geodetic) head and rated net head of the power plant.
- Equipment parameters – the turbine, generator and transformer efficiency values depend on the actual operation mode (load).

The usable water volumes for the hydropower and the corresponding energy production as well as their monthly distribution are presented in Table 5.

Table 5. Electricity Production of SHPP Mugla-Yug by Months

Month	[%]	[m3]	MWh
January	7.34%	0.418	290.963
February	6.98%	0.397	276.593
March	15.21%	0.857	602.884
April	14.72%	0.829	583.436
May	15.21%	0.857	602.884
June	14.72%	0.829	583.436
July	3.00%	0.177	119.089
August	2.62%	0.155	103.803
September	3.20%	0.187	126.746
October	4.32%	0.249	171.315
November	5.90%	0.337	233.857
December	6.77%	0.386	268.280
Total	**100.00%**	**5.678**	**3963.285**

The following conclusions can be drawn: the hydropower parameters of SHPP Ivanik are good, and the sufficient permanently available water resources allow its operation during the whole year.

CONCLUSIONS - ASSESSMENT OF IMPACT OF PROJECT ON ENERGY BALANCE OF BULGARIA

Table 6 presents the overall energy balance of Bulgaria for 2002 based on data of Statistical Yearbook of National Statistical Institute published in 2002.

According to the design documentation and the feasibility study, SHPP Ivanik will have installed rated power of 1,173 kW and will produce 3,963 MWh of electricity per year.

According to the published energy balance, the total annual primary energy production in the country is 10,761 K tons of crude oil equivalent (or 125,170 GWh at 11.63 GWh per toe).

The electric energy produced by the Small Hydro Power Plant Ivanik would be 0.0031% of the annual primary energy production from hydro power and other fuels.

Table 6. Overall Energy Balance Sheet of Bulgaria for 2002

(Thousand tons of oil equivalent)	Total	Coal	Fuels of coal	Natural gas	Crude oil and feedstock	Petroleum products	Biomass	Hydro-energy	Nuclear energy	Other fuels	Electricity	Heat
Primary production	10761	4428	-	16	38	-	627	189	5463	-	-	-
Recovered products	24	-	-	-	-	-	16	-	-	8	-	-
Import	11338	2418	106	2498	5346	795	-	-	-	-	175	-
Stock change	-461	-382	21	-110	-20	28	2	-	-	-		-
Export	2355	-	22	-	-	1610	6	-	-	-	717	-
Bunkers	105	-	-	-	-	105	-	-	-	-	-	-
Gross inland consumption	**19205**	**6464**	**106**	**2404**	**5365**	**-892**	**639**	**189**	**5463**	**8**	**-541**	-
Transformation input	18978	6123	717	965	5477	228	-	-	5463	5	-	-
Transformation output	11076	-	1396	-	-	5069	-	-	-	-	3437	1174
Exchanges and transfers, returns	8	-	-	-	124	-116	-	-189	-	-	189	-
Consumption of the energy branch	1131	6	79	205	-	191	-	-	-	-	486	164
Distribution losses	752	-	-	68	-	2	-	-	-	-	531	151
Available for final consumption	**9427**	**335**	**706**	**1167**	**12**	**3639**	**639**	**-**	**-**	**3**	**2067**	**859**
Final non-energy consumption	795	-	-	407	-	388	-	-	-	-	-	-
Final energy consumption	8520	333	694	741	6	3177	639	-	-	3	2067	860
Industry	3255	233	441	706	6	794	44	-	-	3	729	299
Iron and steel industry	718	2	338	237	-	-	-	-	-	-	141	-
Non-ferrous metal industry	126	-	27	7	-	39	-	-	-	-	53	-
Chemical industry	918	22	69	157	-	271	21	-	-	-	132	246
Non-metallic mineral products	549	125	1	155	-	215	-	-	-	-	52	1
Ore-extraction industry	109	3	-	9	-	19	-	-	-	-	77	1
Food, drink and tobacco industry	291	25	2	62	3	86	6	-	-	-	74	33
Textile, leather and clothing industry	115	2	-	24	3	38	-	-	-	-	38	10
Wood material and products without furniture	54	-	-	-	-	28	13	-	-	-	13	
Paper and printing	140	49	-	21	-	32	-	-	-	3	34	1
Engineering and other metal industry	120	-	3	24	-	24	-	-	-	-	66	3
Transported devices	17	-	-	-	-	2	-	-	-	-	15	
Other industry (icl. construction)	96	5	-	11	-	38	3	-	-	-	36	3
Transport	2055	-	-	-	-	2016	-	-	-	-	39	-
Households, commerce, public authorities, etc. of which:	3210	100	253	35	-	367	595	-	-	-	1299	561
Households	2193	96	250	1	-	22	585	-	-	-	800	439
Statistical difference	**110**	**2**	**11**	**19**	**6**	**73**	**-**	**-**	**-**	**-**	**-**	**-1**

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