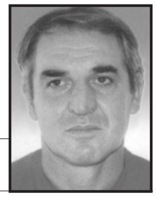
Hydropower Potential of Montenegro



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Abstract: As the existing total hydropower potential of Montenegro is outdated, an attempt is made to re estimate the potential and also to assess the possibility of the utilization of the total hydropower potential in Montenegro in newly created conditions and opportunities. The methodology used is based on energy potential for each watercourse individually taking account of the total amount of water from precipitation and transit waters at the territory of Montenegro. This paper for the first time integrally analyses hydropower potential in both gauged and ungauged major watercourses and their tributaries. It provides insight into the total hydropower potential and technically exploitable hydropower potential for both Run-of-River and storage projects, which may serve as a good basis for strategic planning of exploitation of this resource. It bears specific importance since hydropower exploitation of the remaining 82% of this potential is expected in the near future. The technically exploitable hydropower potential is assessed as 9840 GWh in a year.

Key words: Hydropower potential, Electricity, Theoretical model, Hydropower plants, Montenegro

Introduction

Montenegro covers an area of about 13,812 km^2.There are several important watercourses that drain into two directions: towards Black Sea and Adriatic Sea. The total area of Black Sea part of the catchment area amounts to 7454 km^2. From this basin, through Zapadna Morava River, the river Ibar drains, while in the direction of River Drina, drain River Lim and River Cehotina, followed by Tara and Piva Rivers.

The total catchment area of Adriatic Basin is about 6275 km^2. River Moraca drains towards the Adriatic Sea with its tributaries Rivers Zeta and Cijevna, as well as Rivers Rijeka Crnojevica and Orahovstica. All three watercourses are actually drained in the Skadar Lake, where from they flow to Adriatic Sea via River Bojana. Except for River Bojana, several torrential flows also drain in the Adriatic Sea, which are not permanently monitored or hydrologic regime parameters on them measured.

The hydropower potential (here in after: HEP) based on discharge parameter (Q) directly depends on the total water potential. According to existing hydrological studies of the surface watercourses network, we may determine that we have large number of watercourses, with large discharge compared to relatively small area of Montenegrin territory. These watercourses and large discharge of surface waters results in availability of respective water potential, which may be transformed into the hydropower potential. In this regard, based on determined hydrological balance of surface water streams in Water Management Plan of Montenegro (WMPM 2001) we may verify the conclusion about the large discharge of surface waters and availability of the total water potential at the territory of Montenegro.

Analysis of Hydropower Potential (HEP)

Hydropower potential definition model

To get more realistic insight into HEP, we need to start with the basic postulate: that water potential or the existing water as physical category is determined with matrix trio:-

- Three attributes: location (L), amount (Q) and quality (K).
- On the other hand, *water resource* (Vr) is a social, economic and ecological category,
- The fourth one, which is extremely important: *existence of conditions for water exploitation* (Uk).

This is why, while defining the water resources, matrix structure "existing waters" needs to be extended with attribute (Uk). The task to plan water management systems is then reduced to logistic structure $V_p: \xrightarrow{U_k} VS \xrightarrow{U} V_z$, which marks that present water (existing water) V_p, through conditions for exploitation (Uk), enables development of water management system (VS), through which, by applying adequate management (U), we transform it to the matrix structure *necessary – demanded water* (V_z) (Dordevic 1997a; Dordevic 1997b) . Conditions for exploitation (Uk) are multidimensional vector size, since they comprise of several components, from which possibility to utilize water depend. For example, in case of utilization of HEP the important components Uk are as follows:

- geotechnical conditions (GU),
- hydro-construction conditions (HGU),
- economic conditions (EU),
- interaction with social and urban surrounding (SU) and with surrounding of cultural-historical goods (KUID),
- environment protection conditions (EKU),
- conditions stemming from inter-country obligations (MDU).

In respect to catchment area, the total runoff volume from Adriatic basin amounts to 11.814 billion m^3(internal waters 11.353 billion m^3), and from the Black Sea Basin the total runoff volume is 7.85 billion m^3 (internal waters 7.401 billion m^3). The total amount of water from precipitations and transit waters at the territory of Montenegro is about 26 billion m^3, out of which 6.32 billion m^3 evaporates. The very high loss is due to Southern part of Montenegro is being a karst area. Further more, the total drain from Montenegrin territory in volume amounts to19.7 billion m^3, while from internal waters it amounts to 18.75 billion m^3 or 595 m^3/sec.

Figure 1. Illustrates the main watercourses in Montenegro and the position of the major planned hydropower plants (HPP) that need to be constructed in the near future.

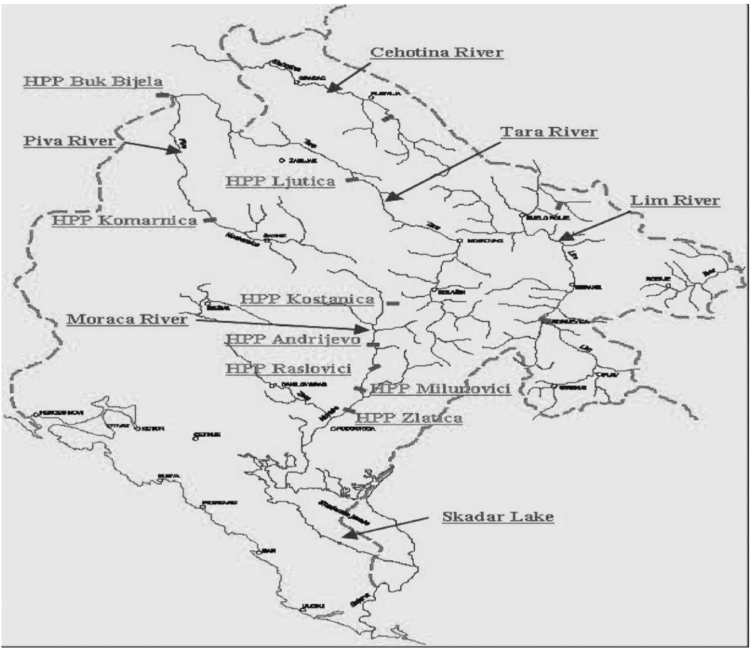


Figure 1. Main watercourses and the position of major projected hydropower plants in Montenegro

Value Vp represents the drain of the watercourses in the Black Sea catchment area and drain in the Adriatic Sea for water courses: Moraca River, Zeta River and River Cijevna and others. On the other hand, the total water potential (Vp) or existing water as physical category is determined by matrix trio i.e. location (L), amount (Q) and quality (K): $V_p = \{L, Q, K\}$. In respect to the preceding paragraph, the estimated volume value of the existing water Vp = 18.75 billion m^3 or total water potential, is believed to be only a physical category, and not a water resource (V_r). Namely, only with the existence of the conditions for exploitation (Uk), Vp may be transformed to the partial HE potential. On the other hand, the total Vp is decreased due to various physical water losses (Đorđević 1997a). Losses are mainly due to geological and hydrological features of the terrain, then water that directly fall to the surface of the Skadar Lake and the outflow of the river Bojana in the Adriatic sea. The height difference between lake Skader and the Adriatic Sea is very small. In this regard, the volume value of the existing water (Vp = 18.75 billion m^3) is decreased by the estimated value of those losses to the amount: V_{ps}= 13.3 billion m^3. The adopted value V_{ps} is the total water potential, which with existence of conditions for exploitation (Uk) may be transformed to the partial HP potential. Volume value V_{ps}= 13.34 billion m^3 results in the secondary discharge to the amount of Q = 423 m^3/s, or 71.1% of internal surface waters of Montenegro. The value V_{ps} represents the drain in the catchment areas of the water courses of Black Sea basin plus drain into the Adriatic Sea catchment area for water courses of River Moraca and Zeta with their tributaries (Figure 1), without voluminous part of the drain towards Boka Kotorska bay, River Trebisnjica, City of Ulcinj and Budva (5.41 billion m^3).

Theoretical hydropower potential of the main water courses (Et)

Energy potentials may be calculated for each version of the exploitation of the total potential of the water potential of the catchment area. In this regard, as the first step in hydropower planning, we have estimated the hydropower potential of a watercourse, catchment area or specific territory. Each profile of a watercourse is defined by

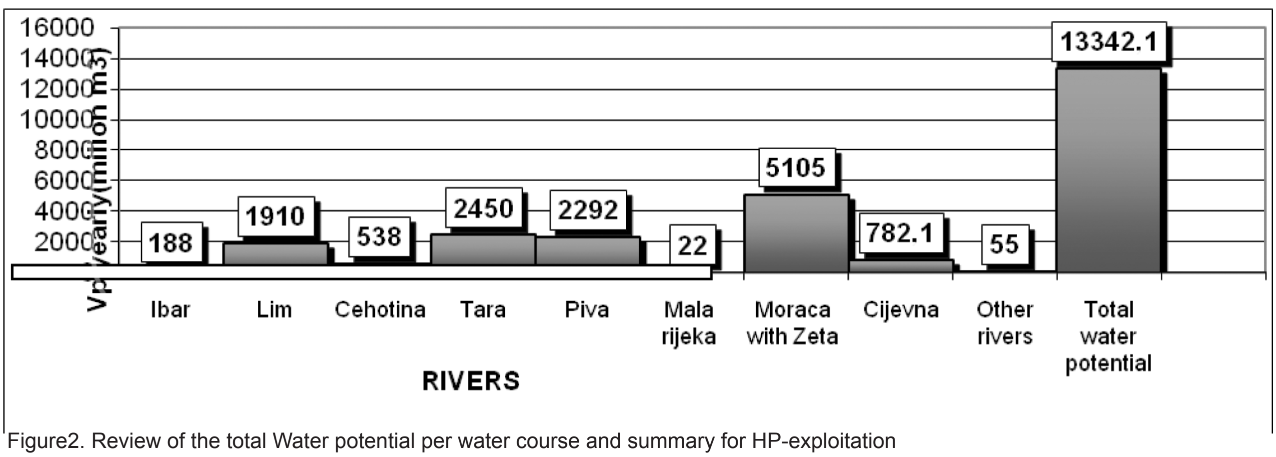
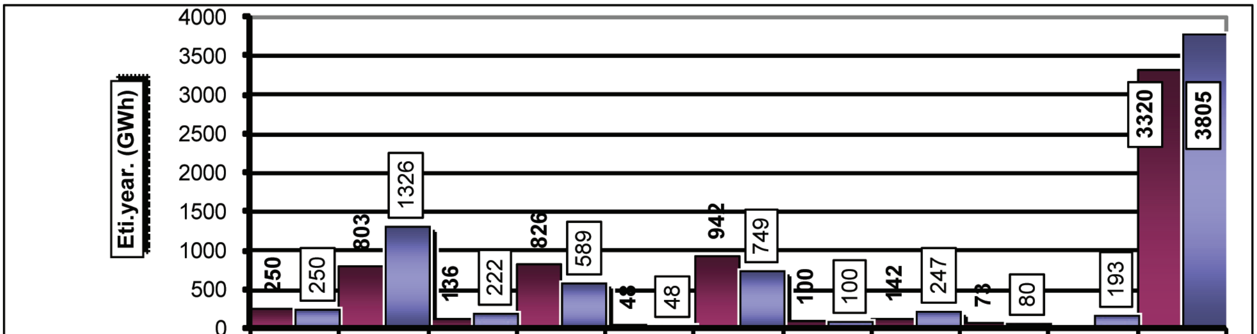


Figure2. Review of the total Water potential per water course and summary for HP-exploitation



	Piva	Tara	Cehotina	Lim	Ibar	Moraca	Zeta	M.rijeka	Mrtvica	Cijevna	TOTAL
VARIANT-1 (GWh)	250	803	136	826	48	942	100	142	73		3320
VARIANT-2 (GWh)	250	1326	222	589	48	749	100	247	80	193	3805

Figure 3. Review of the remaining technically exploitable E_{ti} (GWh) along major watercourses in natural flow direction, according to Version-1 and Version-2\

height datum (average head) H and average annual water discharge Q(m³/s). This enables us make *Q-H* diagram for some reach framed between two profiles, then the average power between the two considered profiles has been defined with relation: $\overline{N}_t$ (1/2) = 9.81. Q.H.Theoretic HP potential of the reach on an annual basis (8760 hours) is defined by relation: $E_t = 8760\overline{N}$ (kWh). With the help of Q-H diagram we may show available average potential of watercourses without limitations in regard of usability of the average head and discharge. In the profiles of potential hydropower plants in ungauged water courses, we have used analogue (comparable analyses of discharge on the multi-annual gauge profile and on the profile we want to estimate discharge at) method to determine flow at specific profiles in this study.

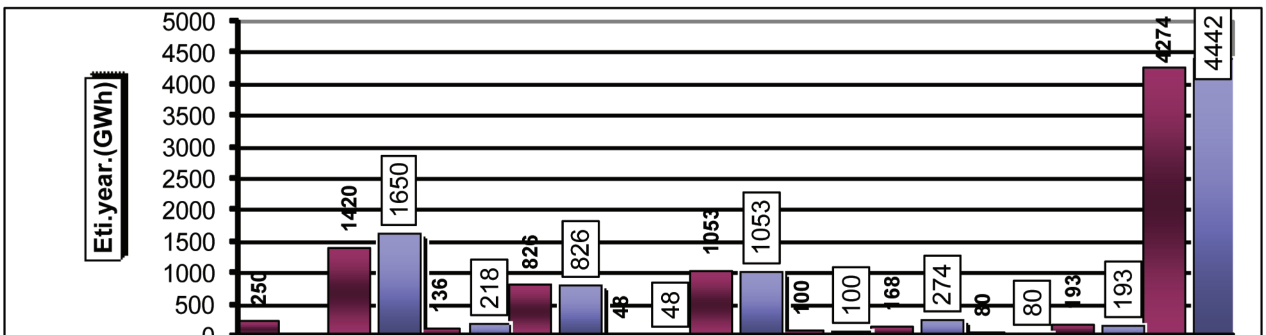
According to Water Management Plan of Montenegro (2001) in form of the line potential with step of five kilometers along nine water courses, we have calculated the average theoretical HEP (Figure 2).

Technically exploitable potential (Eti)

Technically exploitable potential represents the part of the hydropower potential for which we have determined with adequate technical documentation that it could be technically implemented. To determine this potential, the following conditions need to be met:

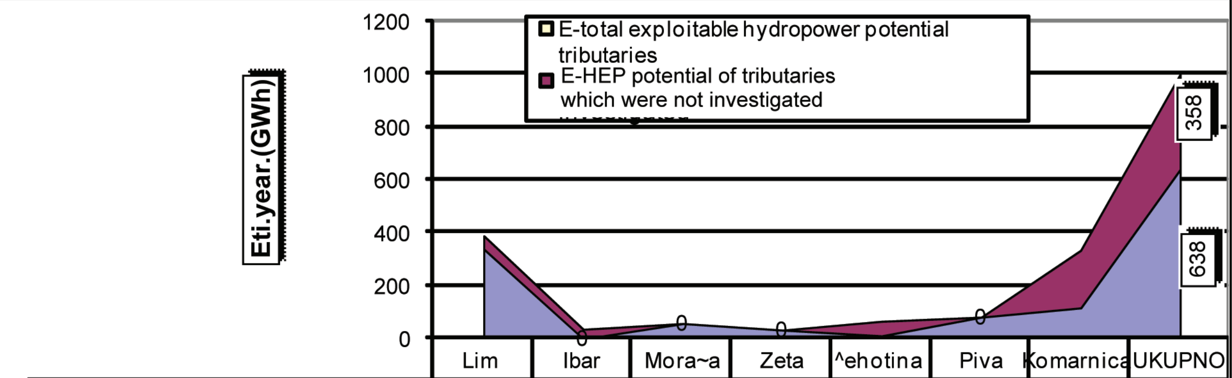
- The study level and project documentation need to be such that they enable reliable proof that the considered hydropower facilities are technically feasible.
- That the facilities and the equipment have been examined to the level at which we may reliably determine the average possible annual production.

Generally speaking, in the current time of technological advances, it is possible to technologically perform the most complex hydropower systems. Technically available potential is equal to the hydro potential of the river, decreased by losses, which at today's level of development, may be generally considered to be about 13%, so that technically exploitable power is expressed with relation: $N_{ti} = 8.5 \times Q_p \times H_n$ (kW), where: Q_p - average multi-annual discharge available for energy generation (m³/s), H_n- net head of the facility in (m). Corresponding energy during the year amounts to: $E_{ti} = 8760\ N_{ti}$ (GWh).



	Piva	Tara	Ceh.	Lim	Ibar	Moraca	Zeta	Mala rijeka	Mrtvica	Cijevna	Total
VARIANT-1 (GWh)	250	1420	136	826	48	1053	100	168	80	193	4274
VARIANT-2 (GWh)		1650	218	826	48	1053	100	274	80	193	4442

Figure 4. Review of technically exploitable Eti (GWh) along major watercourses with partial transfer of water from Tara River into Morača River (Q=22m3/s), according to Version-1 and Version-2



	Lim	Ibar	Mora~a	Zeta	^ehotina	Piva	Komarnica	UKUPNO
E-total exploitable hydropower potential tributaries	0							
E-HEP potential of tributaries which were not investigated	50	36			55		217	358
E-HEP potential of tributaries at the level of preliminary studies	338		58	33	12	82	117	638

Figure 5. Review of the exstimate of the technically exploitable at tributaries in the basin of major surfaces water courses Montenegro

According to the current studies and project documentation, technically exploitable potential (E_{ti}) will be expressed based on two versions of HEP usage.

Version 1- exists in numerous developmental programs, plans and project documentation for hydropower plants of Montenegrin Electricity Authority that manages the overall electricity system of Montenegro.

Version 2 – exists in the newest water management plans of Montenegro (along with version 1), (Figure 4). Versions 1 and 2 consider using HEP in natural water flow directions and transferring partial flow of the River Tara into the River Moraca (Q =15.2 i, Q= 22m3/s) (Energoproject 2000; MASA 2004) (Figure 5). (With version 1 backwater elevation of reservoir Andrijevo at River Moraca is 285 m.n.m. elevation above sea level, and with version 2 – 250 m.n.m). Figures 3 and 4 illustrate the remaining available technically exploitable potential. We have considered only HEP that could be implemented with HE facilities within the borders of the territory of Montenegro.

Hydropower Potential of Tributaries

Technically exploitable potential of tributaries surveyed within studies for development of small hydropower plants (SHP)

Up-to-now research of HEP potential of tributaries were at the level of preliminary designs, mainly originating from period 1980-1986. These studies analyze electroenergetic values of hydro potential at the specific number of small watercourses, through construction of small hydropower plants under the then existing concepts and technical solutions. The table below illustrates the review of the number of SHP which may be constructed in Montenegro, their installed power as well as annual power generation.

Name of River/Watercourses	Power	Annual Electricity Generation	No. of small Hydro Project
River Piva	74.055 MW	198.21 GWh	23 SHP
River Lim/part Zlorecica – Ljesnica	67.835 MW	175.34 GWh	19 SHP
Plav region	45.485 MW	135.59 GWh	15 SHP
Bijelo Polje region	4.125 MW	26.723 GWh	1 SHP
River Morača	23.35 MW	47.5 GWh	6 SHP
River Zeta	7.43 MW	33.6 GWh	3 SHP
Ćehotina	3.95 MW	12.7 GWh	1 SHP
Old Project and Otilovića	2.961 MW	11.52 GWh	1 SHP
Total	**226.23 MW**	**638.05 GWh**	**68 SHP**

Totally projected 68 SHP with installed power 226.23 MW and annual electricity generation of 638.05 GWh. On the other hand, technically exploitable potential of tributaries in main water courses, according to VOCG solutions, forecast construction of hydropower plants at 10 tributaries of Lim with total Ni=175 MW and E=344 GWh, and seven tributaries in the catchment area of River Morača with total Ni= 293MW and E=584 GWh. Installed power of hydropower plant ranges from 10 to 26 MW in tributaries of the catchment area of River Lim and range 9 to 28 MW in tributaries of catchment area of River Moraca. Since these are hydropower facilities that do not belong to the category of SHP up to 10 MWh or near to this limit, according to study »Guidelines to development and construction of small hydropower plants (SHP) in Montenegro", presents separately the technically exploitable potential for three main tributaries of River Moraca: Mala Rijeka, Cijevna and Mrtvica. Of course, HEP tributaries cover the domain of small hydropower plants (SHP) and large hydropower plants (HEP)

(MEA 2001; Đorđević 1997a; MASA 2004).

Technically exploitable potential of non-gauged tributaries

Starting from the fact that up to now researches do not consider the overall HEP potential of tributaries in the catchment area of River Tara, or the specific number of tributaries in other catchment areas, the estimate of the available and technically exploitable potential has been made in an indirect way. In this regard, the estimate has been made as the product of surface net potential (ε_{ti}) and the surface of the catchment area of specific tributary (A km²): $E_{ti}. = \varepsilon_{ti} \cdot A$, where: ε_{ti} - available average annual HE potential (GWh), ε_{ti} - specific available surface potential (GWh/km²). Value ε_{ti} was calculated based on technically exploitable surface potential of River Lim tributaries (A=1164.8km²) which have been discussed in up to now studies on SHP in catchment area of River Lim, ε_{ti} = 337/1164.80=0.355 GWh/km². For the territory of former Yugoslavia y ε_{ti} =*0.36* GWh/km².

Estimates of the technically exploitable potential of tributaries

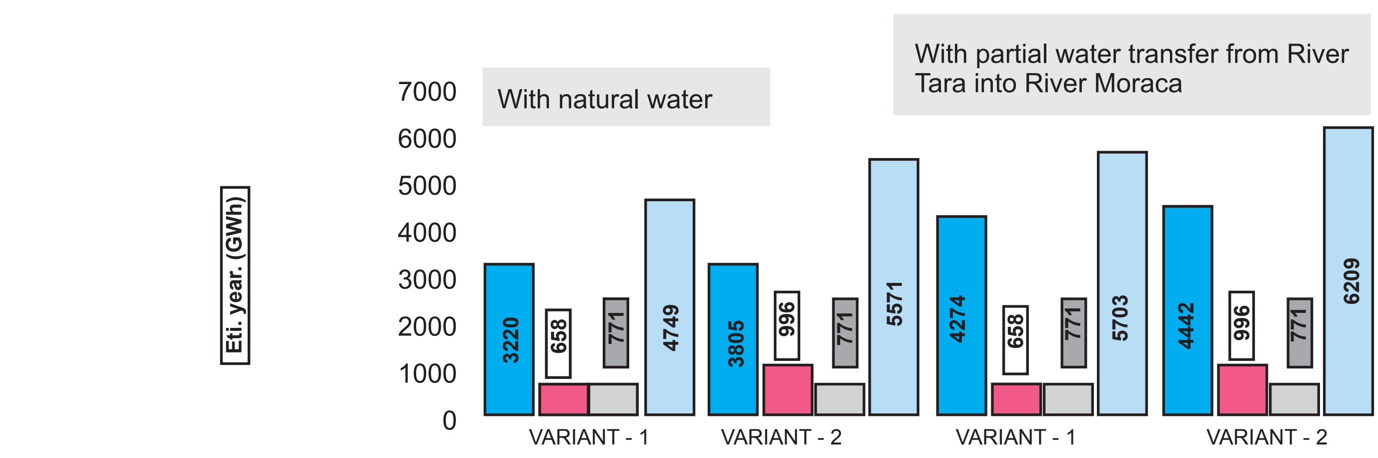
Based on the results of the estimate of the exploitable potential within the up-to-now studied tributaries at the level of studies "Guidelines to development and construction of small hydropower plants (SHP) in Montenegro" (MEA 2001). Water Management Plan of Montenegro (2001), and indirect calculations of the up-to-now of un-gauged tributaries, the technically exploitable hydropower potential of tributaries amounting to 995.81 GWh per year has been calculated (Figure 5).

Remaining technically exploitable hydropower potential (E_{ti}) in main watercourses and tributaries in Montenegro.

Based on the exposed study of the technically exploitable E_{ti}.god.(GWh) for main watercourses and review of technically exploitable E_{ti}.god.(GWh) for tributaries based on the utilization version in natural direction and transfer of the part of Tara river waters in (Q=22m³/s) Morača at Figure 6 we have illustrated the total amount of the remaining technically exploitable hydropower potential (Đorđević 1997a; Đorđević 1997b; Perović, Marković et al 2004; MEA 2000;MASA 2004). E_{ti} (GWh) relates to the average hydrologic year, which may be realized with construction of hydropower plants within the borders at the territory of Montenegro.

Conclusion

Based on previous considerations, we have presented the numerical values of the indices of hydropower potential (HEP). The reliability of the estimated HEP may be examined or corrected through improvement of the elaboration of technical documentation for hydropower facilities and its foundation in direct and quality measurement of Q-H parameters. More realistic consideration of the HEP is expected through planned development of Energetic Basis (Strategy) of the Republic of Montenegro, which, according to our opinion, needs to become priority of the governmental activities, since the existing one is not offering good basis for exploitation of the existing hydropower potentials. The estimated theoretical hydropower potential in Montenegoro is 13342.1 GWh. The remaining potential which needs to be exploited by construction



Eti (GWh) - MAJOR RIVERS	3320	3805	4274	4442
Eti (GWh) - TRIBUTARIES	658	996	658	996
HPPBuk Bijela+HPPGrancarevo+HE Dubrovnik: (Eti) GWh	771	771	771	771
TOTAL Eti (GWh)	4749	5571	5703	6209

Figure 6. Review of the total remaining technically exploitable hydrpower potential (Eti) in major water courses and tributaries according to version 1 and version 2, which may be implemented in HE-facilities.

of new hydro power plants is 6209.0 GWh per annum.

As the hydropower potential of Montenegro has not been estimated well enough, this research presented in this paper is very useful. Only 18% of this resource has been exploited so far compared to realistic possibilities. We wish to exploit this remaining potential in the near future. This paper represents the basis for the future analyses of the hydropower potential of the main watercourses individually and also tributaries, in all with the effort to integrally utilize this resource. In this way, the possible mistakes that often appear when hydropower potential of one watercourse is not analyzed as a whole, but in separate segments, would be avoided. Generally, the study of the hydropower potential, also presents basis for planning and development of electricity sector as a whole. For this reason, the research of this type gains special importance. It is especially important for areas were grids are underdeveloped, and where the significant energy potential exists, as is the case with north part of Montenegro.

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