SUITABILITY OF ACHIEVING A HYDROPOWER DEVELOPMENT AT MĂCIN ON THE DANUBE RIVER

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The paper presents a possibility to achieve a hydropower development on the location of Măcin, on the Danube River. The conclusion is that the investment would be profitable if the price of energy valuation were much higher than the one currently obtained in similar types of developments. Only reasons far more important than energy generation could justify the construction of Măcin hydropower development.

Keywords: hydropower development, hydro-technical complex, economic analysis, water use.

1. Introduction

The Danube river, second largest in Europe after The Volga, has a catchments area surface of 805,300 km^2, out of which about 28% on Romanian territory.

Danube's hydrographic basin is divided into three main sectors: the upper sector (headwaters-Bratislava), the middle sector (Bratislava-The Iron Gates), and the lower sector (The Iron Gates-The Black Sea).

By building the hydropower and navigation system of The Iron Gates I and II, a potential of 6,400 GWh was put to good use, representing 54% of the technically usable potential of the Danube that belong to Romania.

Negotiations (unsuccessful ones, unfortunately) took place with Bulgarian counterparts, on the issue of achieving a hydroelectric complex (HC) at Turnu Măgurele-Nicopol, which would have put to good use a potential of 1,800 GWh.

The sector downstream from Turnu Măgurele-Nicopol was scheduled to be developed in two stages: Călăraşi-Silistra together with Bulgaria, and Dinogeția situated exclusively on Romanian territory, fig. 1.

The Dinogeția (Măcin) development, in the adopted alternative having the normal retention level (NRL) of 12.50 mABSL (meters above the Baltic Sea level) would have put to good use part of the common Romanian-Bulgarian

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hydropower potential on the Turnu Măgurele-Silistra sector, until the Călăraşi-Silistra hydro-technical complex had supposedly been achieved together with the Bulgarian counterparts. Under such circumstances, the Călăraşi-Silistra development, presumed to be achieved later, would have heads and energy productions diminished by approximately 50%, due to the drowning caused by the Dinogeția (Măcin) storage lake, which had a negative impact on the negotiations with Bulgaria.

Considering the impossibility of concluding the discussions with the Bulgarian counterpart, the project focused on the development of the Romanian sector.

2. Hydropower schemes

Due to the Danube's reduced natural bottom slope of about 3 cm/km on the Călăraşi-Galați Romanian sector, the storage lake will also cover the Romanian-Bulgarian sector upstream from Silistra, even at retention levels situated below the technical level of turbine functioning, thus involving the Bulgarians in any development plan of Danube's hydropower potential on the Romanian sector, fig. 1.

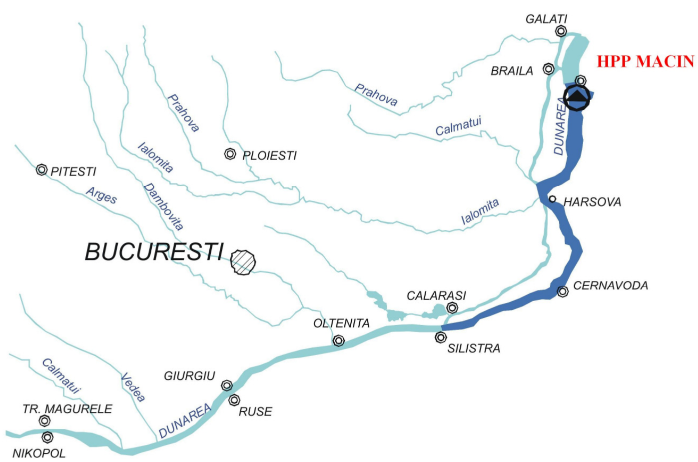

Fig. 1. Layout with the analyzed sector of the Danube.

This sector was studied in three alternative approaches for the normal retention level (NRL): 8.50, 10.50 and 15.50 mABSL. The highest retention level values the Romanian and Bulgarian hydropower potential at HC Turnu Măgurele-Nicopol, eliminating the section Călăraşi-Silistra, [1]/1985. Low retention levels values the Romanian and Bulgarian hydropower potential, allowing the future construction of HC Călăraşi-Silistra, [1]/1986.

Brăila and Măcin (Dinogeția) were analyzed simultaneously as possible locations, the Măcin option proving to be more profitable (the retention level 15.50 mABSL), [1]/1987; a year later, an optimization study was performed, [2].

In 2006, the study regarding the development of Măcin hydro-technical complex was resumed, [3]. The technical solutions and the hydropower parameters were taken as a whole from the 1988 study, as well as the investment figures, which were updated considering the inflation index corresponding to the 31st of December 2005.

The storage lake unfolds on the Danube channels on the right (Măcin and Cernavodă), between dam-dykes that protect the agricultural lands and the adjacent villages and towns, a layout which allows keeping the channels on the left for evacuating the turbinate discharges and the floods through the four hydroelectric complexes placed along the storage lake: Măcin, Giurgeni, Bala and Borcea. The hydroelectric complexes include: hydropower plants, overflow dams and earth fill dams, locks, fish passes, tailrace channels and transforming stations (figure 2).

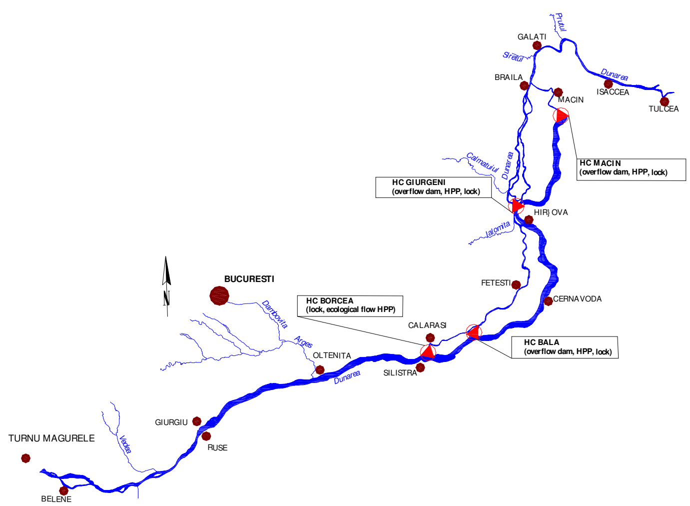

Fig. 2. Location of hydroelectric complexes (HC).

The Măcin hydroelectric complex is placed on the left bank of the Măcin channel, at km 29 on a 40 m high rocky hill, called Piatra Blasova. The Măcin hydroelectric power plants built of blocks of two bulb units Ø 7.50 m and has 18 units for level 8.50 mABSL, and 14 for levels 10.50 and 15.50 mABSL, respectively.

The Giurgeni hydroelectric complex is located at km D 236 right downstream from the existing bridge Giurgeni-Vadu Oii. The hydropower plant takes this location only for the NRL 15.50 mABSL alternative and has 6 units bulb Ø 7.50, with the installed discharge 2,700 m^3/s, grouped in pairs on a block plus an erection block.

The Bala hydroelectric complex is located at km D 342 on the right hand of the Bala (Răul) channel, a channel that forks more than half of Danube's flow. The hydropower plant is placed in this hydro-technical key point only for the NRL 8.50 mABSL (18 units) and 10.50 mABSL (16 units) alternatives.

The Borcea hydroelectric complex is located on the Borcea channel at km Borcea 96, upstream from Călăraşi harbor, right downstream from the Călăraşi Siderurgical Factory navigable channel entrance. The compensation discharge of minimum 150 m^3/s for water supplies, irrigations and sewers on the Călăraşi-Bala sector are put to good use from the energy perspective in a small hydropower plant provided with 2 bulb units Ø 4.00 m at NRL 8.50 and 10.50 mABSL and with 1 bulb unit Ø 4.20 at NRL 15.50 mABSL.

3. Hydropower parameters for alternative approaches

Table 1 contains the design head, the installed discharge, the installed head and the installed capacity for the alternative approaches for the NRL.

Table 1

Installed capacity for alternative approaches

NRL alternative / HPP	Design head	Installed discharge	Installed head	Installed capacity
	(m)	(m^3/s)	(m)	(MW)
NRL 8.50 (mABSL)				**288**
- HPP Măcin (Igliţa)	3.14	4,500	3.44	118
- Bala	4.14	4,500	4.48	165
- Borcea	3.94	150	-	5
NRL 10.50 (mABSL)				**387**
- HPP Măcin (Igliţa)	4.75	4,500	5.23	196
- Bala	4.60	4,500	5.06	185
- Borcea	4.33	150	-	6
NRL 15.50 (mABSL)				**825**
- HPP Măcin (Igliţa)	9.61	6,300	10.20	550
- Giurgeni	10.74	2,700	11.51	260
- Borcea	10.64	150	-	15

The following compensation water and water supply are envisaged:

- 150 m^3/s on the Borcea channel, through the Borcea hydropower plant (HPP);
- 200 m^3/s for the Danube-Black Sea canal, taken from the Danube in the Cernavodă sector.

From the Danube's inflows, the compensation water and water supply are subtracted, the remaining quantity being shared by the hydropower plants of the ensemble: 50% for Măcin (Igliţa) and 50% for Bala for NRL 8.50 and 10.50 mABSL and 70% for Măcin (Igliţa) and 30% for Giurgeni for NRL 15.50 mABSL.

For NRL 15.50 mABSL the option was limitation to level 16.00 mABSL in the Cernavodă sector.

For the generator efficiency, 96% and 96.5% were used as values.

The annual average produced energy is presented, taking into account the unavailability of the units, for the 3 alternative approaches are presented in table 2 and graphical represented on the figure 3.

Table 2

Annual average energy output for the different alternative approaches for NRL

NRL [mABSL]	8.5	10.5	15.5
Total annual average energy output, *E* [GWh/year]	1,770	2,332	4,529
Romania	1,351	1,749	3,219
Bulgaria	419	583	1,310

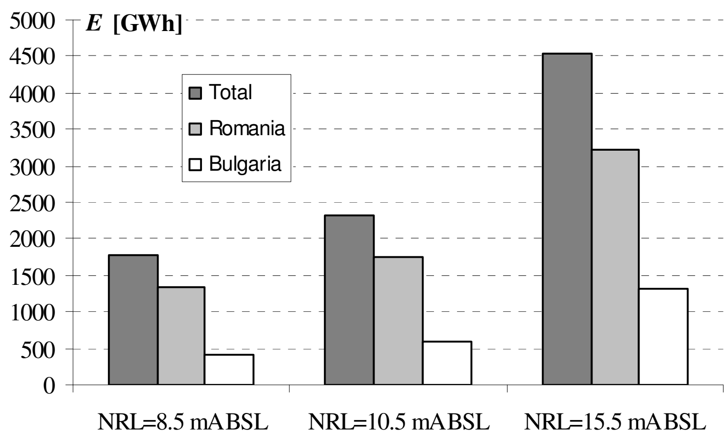

Fig. 3. Annual average energy output.

4. Energy-Economy Indicators

On basis of the total costs required by the construction and the operation of the Măcin hydro-technical complex and on basis of the income obtained from selling the energy produced in the two hydropower plants, Măcin (Igliţa) and Bala, Giurgeni and MHC Borcea respectively, the energy-economy efficiency indicators were calculated: the cost-benefit rate – B/C, the discounted net income – DNI and the internal rate of return, IRR..

The cost-benefit ratio is by definition the ratio of the discounted total incomes and discounted total costs and can be calculated with the relation:

$$B/C = \sum_{k=1}^{n} \frac{V_k}{(1+r)^k} \Bigg/ \sum_{k=1}^{n} \frac{C_k}{(1+r)^k}, \qquad (1)$$

where: V_k is the income in the current year k, C_k – total cost in the current year k, k – current year, n – number of years within the study period, r – discounted rate.

For Romania, the discounted rate varies between 8-12%.

The discounted net income, DNI, or the discounted benefit, is by definition the difference between the discounted total incomes and discounted total costs and can be calculated with the relation:

$$B/C = \sum_{k=1}^{n} \frac{V_k}{(1+r)^k} - \sum_{k=1}^{n} \frac{C_k}{(1+r)^k} = \sum_{k=1}^{n} \frac{V_k - C_k}{(1+r)^k} = \sum_{k=1}^{n} \frac{B_k}{(1+r)^k}, \qquad (2)$$

where B_k is the benefit in the current year k.

By definition the internal rate of return, IRR is the discount rate corresponding to B/C=1 or DNI=0, so it can be calculated from the equation:

$$\sum_{k=1}^{n} \frac{V_k}{(1+r)^k} = \sum_{k=1}^{n} \frac{C_k}{(1+r)^k}, \qquad (3)$$

and it results: $r = IRR$.

The values of these indicators, give an answer as if the investment is efficient from the economical point of view:
- if B/C > 1, VNA > 0, the investment is efficient;
- if B/C < 1, VNA < 0, the investment is not efficient.

As for the internal rate of return (IRR), values are good if well over 10%, considered as low limit of economic efficiency.

The fundamental hypotheses for this calculation are:
- total investment for the Romanian part (table 3) including power investment (hydro-technical complexes and the reservoir) and adjacent (other works);
- investment scheduling: 10 years;
- operation expenses: for the total investment: 1.2 % of the investment; for the power investment: 1.5 % of the investment; for the investment in the hydro-technical complex: 1.3 % of the investment.
- the energy taken into account in calculating the efficiency indicators is the delivered one, without the energy losses at HPP Silistra (for NRL 8.50 and 10.50 mABSL), at HPP Turnu Măgurele – Nicopol (for NRL 15.50 mABSL) respectively;
- the income comes from selling the energy for 84.4 lei/MWh (22.95 €/MWh)
- discount rates: 8%, 10% and 12%;
- analyzed time interval: 60 years (10 years – construction, 50 years – average life span of the objects in the ensemble);

- exchange rate on the 31st of December 2005: 1 € = 3.6771 lei.

Table 3

Necessary investment for the achievement of Măcin hydropower development, in (mil. €, year 2005)

NRL (mABSL)	8.50	10.50	15.50
A. Hydropower works			
A1. Hydroelectric complexes	3,478.14	3,310.91	3,132.73
A2. Reservoir	1,311.64	1,425.49	3,896.12
TOTAL A	4,789.77	4,736.40	7,028.85
B. Other works	2,898.68	2,912.13	3,272.13
TOTAL B	2,898.68	2,912.13	3,272.13
TOTAL A + B (România + Bulgaria)	7,688.45	7,648.53	10,300.99
România	7,368.29	7,292.09	9,572.67
Bulgaria	320.16	356.45	728.32

The efficiency indicators for NRL 15,50 mABSL alternative approach, the best one from this point of view, are presented in table 4.

Table 4

Efficiency indicators for the best alternative approach: NRL 15,50 mABSL.

1.	B/C (r = 10%) – *total investment* DNI (mil. RON) IRR (%)	0.045 < 0 < 1
2.	B/C (r = 10%) – *hydropower investment* DNI (mil. RON) IRR (%)	0.065 < 0 < 1
3.	B/C (r = 10%) – *CH investment* DNI (mil. RON) IRR (%)	0.134 < 0 < 1

In order to compare other ensembles situated on the inner territory rivers and studied before 1989, still in the project stage, the specific investment in installed capacity and the specific investment in energy were determined, in other words the static technical-economical indicators, table 5 and table 6.

Table 5

Static efficiency indicators: specific installed capacity investment and specific output average energy investment resultant from the feasibility study for HC Măcin.

Specific installed capacity investment (€/kW)	8,520
Specific output average energy investment (Romania+Bulgaria) (€/MWh)	1,560
Specific output average energy investment (Romania) (€/MWh)	2,059

It is worth mentioning that these indicators do not reflect the annual dynamics of investment and operation expenses, the distribution in time and the production quality, nor do they reflect the impact of time on the economic parameters, but they are sufficient for this comparison.

For the power investment (the Romanian part) to be efficient (B/C > 1) at an updating rate of 10%, a price of about 400 €/MWh for the sold energy is required far bigger than the present price, 22.95 €/MWh.

Table 6

Specific output average energy investment for other hydropower development projects studied before 1989 and in project phase.

Hydroelectric complex	Specific output average energy investment (€/MWh)
HC Vişeu – Iza	420
Buzău – HPP Mlăjet	485
HC Mureş R. on the Răstoliţa-Reghin sector	476
Bistriţa – HC Vatra Dornei – Borca	743

5. Conclusions

After analyzing the results obtained from the studied ensemble, results which took into account selling energy at the current price, it has become obvious that the ensemble is far from being efficient. The suitable price for the energy sold in order to make the investment profitable was also determined and it is significantly higher than the one obtained at present.

Achieving the Măcin ensemble is not justified from the power generation point of view exclusively. For the investment to be profitable it is necessary to take into account other uses as well: insuring the cooling water supply required by the Cernavodă Nuclear power plant, providing the necessary amount of water for irrigation in the low plains of the Danube and the drainage of the adjacent areas, navigation increase in Danube harbors, in shipyards and downstream traffic on the Danube-the Main-the Rhine route, insuring bank protection and preventing the floods in the lower Danube basin, development of tourism, fishing, fast road and railway transportation on routes parallel to the Danube.

Investment amortization will be done mainly by selling an important amount of clean and cheap electrical energy, which will immediately be absorbed into the Romanian, Bulgarian and neighboring countries' power systems, but also by increasing the income of operation by taxes (for lockage, transit, water supply etc.).

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