OPEN ACCESS

PUMPED-STORAGE HYDRO POWER PLANTS IN MOLDOVA: BENEFITS FOR GRID RELIABILITY AND INTEGRATION OF VARIABLE RENEWABLES

Valentin Arion, ORCID: 0000-0002-2418-2246,
Cristina Efremov*, ORCID: 0000-0002-6370-0878

Technical University of Moldova, 168, Stefan cel Mare Bd., Chisinau, Republic of Moldova
*Corresponding author: Cristina Efremov *cristina.efremov@ee.utm.md*

Abstract. The present paper deals with the problem of building up a 100 MW hydro pumped storage power plant (PSHPP) in the Republic of Moldova allowing to integrate a larger capacity of renewables. The main technical characteristics of the plant have been determined (quantity of water to be pumped, the upper and the lower reservoir dimensions, etc.). Several possible plant locations were investigated and finally an indicative assessment of the plant economic feasibility has been carried out. The study demonstrates that on the territory of the Republic of Moldova exist the possibility to build a PSHPP, as a commercially proven technology for large-scale electricity storage. Building these types of plants is essential in the context of increasing variable renewable energy sources capacities, which requires the installation of new balancing capacities of the system. Abstract. The present paper deals with the problem of building up a 100 MW hydro pumped storage power plant (PSHPP) able to integrate a larger capacity of renewables. The main technical characteristics of the plant have been determined (quantity of water to be pumped, the upper and the lower reservoir dimensions, etc.). Several possible plant locations were investigated and finally an indicative assessment of the economic feasibility has been carried out. In order to determine the altitude of the slopes near the river were used the possibilities of the *„Google Earth"* software. The study demonstrates that on the territory of the Republic of Moldova there exists the possibility to build a PSHPP, as a commercially proven technology for large-scale electricity storage. Building these types of plants is essential in the context of increasing variable renewable energy sources capacities, which requires the installation of new balancing capacities of the system. By 2050, the country's power system requires capacities for balancing the intermittent production. Hydro pumped storage power plants become necessary in the generation capacity mix for all considered long-term development scenarios after 2030. The building of PSHPP, as the main large-scale energy storage infrastructure, presents an important measure to increase the flexibility of the power system. Thus, the study demonstrates the attractiveness of implementing PSHPP projects.

Keywords: *energy system flexibility; renewable energy sources; electricity storage, hydro pumped storage power plant.*

Introduction

The transition to increasingly renewable power generation combined with electrified forms of transport and heat supply would deliver around 60% of the energy-related CO_2 emissions reductions needed by 2050. If additional reductions from the direct use of renewables are considered, the share increases to 75%. When adding energy efficiency, the share increases to over 90% of the energy related CO_2 emissions reductions needed to set the world on a pathway to meeting the Paris Agreement target [1].

The transformation process in a power system dominated by renewable energy sources (variable photovoltaic and wind sources) will face with increasing challenges, related to the need of balancing the electricity demand and supply for any time moment. According to IRENA [1], by 2050 the share of wind and photovoltaic energy at the global level could reach 35% and 25% respectively in the total final energy consumption. In the context of total installed capacity by 2050, much greater capacity expansion would be needed for solar PV (8 519 GW) as compared to wind (6 044 GW). (figure 1).
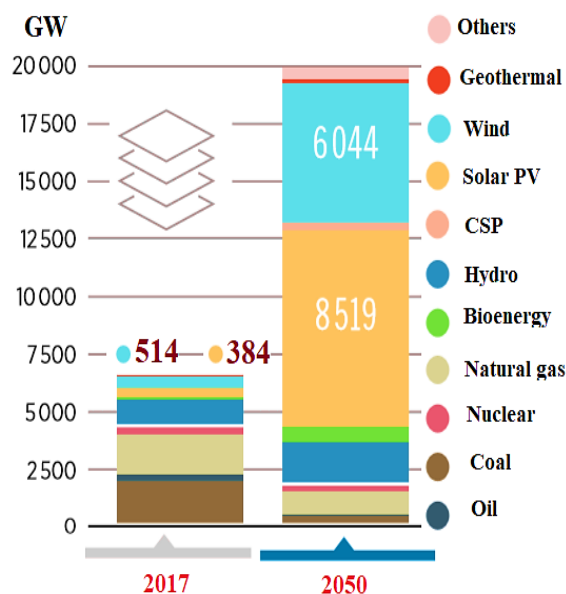

Figure 1. Global electricity generation mix,
IRENA REmap scenario [1].

At the global level the energy demand is increasing constantly and only the energy efficiency and the promotion of renewable energy sources can cope with current and future generation's needs.

The grand challenge is not just the transition to green, non-polluting sources, but mainly ensuring the global energy needs.

Thus, the global development trends in the field of energy are oriented both in the direction of increasing renewable energy production on a large scale as well as in the one of the technological solutions identification, that allow to overcome the barriers caused by the variability of the main renewable energy sources.

In the new conditions of the future, a resilient energy system will be needed with a higher degree of flexibility. In general, energy system flexibility has become a key term afferent to challenges of energy transition.

Flexibility represents a global quality of energy systems that combines both the technical possibilities of all the component elements of the system, as well as the ability to manage it efficiently, based on intelligent systems application. In other context, the flexibility is showing the capacity to control the power system electricity generation and consumption, to reconfigure, if necessary, the structure of operational energy sources as well the structure of the electricity transmission and distribution networks in order to ensure at any time a balance between demand and supply.

With increasing share of electricity produced from variable renewable energy sources (PV and wind turbines) grows the importance of balancing the national electrical power system. The gap that occurs every time between the energy demand and energy supply is commonly being solved by applying a series of different measures including as well by usage of electricity storage facilities and providing it at the right time.

The main large-scale electricity storage technology is represented by *hydro pumped storage plants*, which include two water reservoirs, positioned at different altitudes (the upper reservoir and the lower reservoir) and connected by a pipeline system [2-10].

A pumped storage hydro power plant (PSHPP) is equipped with reversible hydro-aggregates, which, during peak-off hours, consume system electricity at low prices to pump water from the lower reservoir to the upper reservoir, as subsequently, at peak hours in the market, to produce energy for sale on the balancing market. The short start-up time and the high loading / unloading speed of the hydro-aggregates provides flexibility in the HPSPP's operation. According to a report by Global Market Insights Inc., regarding the global trends in the PSHPP development, the total global market of PSHPP has exceeded $ 300 billion investments, and by 2026 the installed annual capacity will reach 200 GW [10]. The PSHPP capacity share in a power system is recommended to be about 10-15 % of the total [7].

Building PSHPPs, in open or closed cycle, is essential in the context of the continuous capacities increasing of the uncontrollable / variable renewable sources, which requires an endowment of the power system with new balancing capacities.

1. **Possible locations for Pumped-Storage Hydro Power Plant in the Republic of Moldova**

The technical evolution of the energy sector in the Republic of Moldova could be put in increased difficulty in the medium and long-term period due to the lack of electricity storage capacities. Pump storage is the only commercially proven technology available for large-scale storage of electricity in an energy system, from which Republic of Moldova (RM) could benefit fully. This type of the plant was and remains imperative for the future energy system of the Republic of Moldova.

In order to justify the possible locations, at least three important arguments are put forward, namely:

1. The average water flow of the river Nistru is considerably higher than that of the river Prut - about 310 m^3/s versus 30 m^3/s. Thus, on the river Nistru there is a considerably higher hydrological potential, which allows the building of PSHPP with much higher storage capacities, without significantly damaging the hydrological regime of the river;

2. The height of the slopes at the points where a PSHPP could be located along the river Nistru is higher than in the case of the river Prut, and the points of maximum height are located closer to the riverbed which will reduce the length of the

pipeline that will unite the lower and upper reservoirs. From an economic point of view this will lead to a reduction in building and operating costs, but from a technical point of view – to a reduction of hydraulic losses through pipes;

3. Another important argument would be that on the river Nistru in Ukraine, already it partially is built and operates one of the largest PSHPP in Europe and even the world.
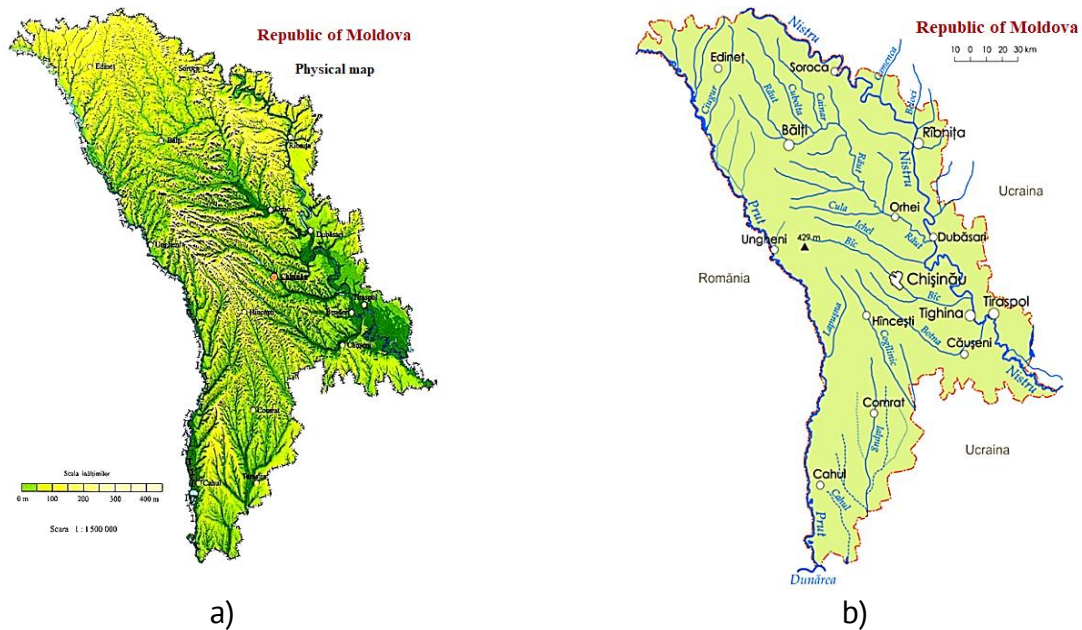

a)   b)

Figure 2. Physical map (a) and map of the main rivers (b) of the Republic of Moldova.

Possible locations along the Nistru and Prut rivers

In order to determine the altitude of the slopes near the river were used the possibilities of the „Google Earth" software. This software uses widely geographic information system (GIS) and it is possible to determine the altitude of a point. It enables to create, store, view, and interact with data as it relates to location.
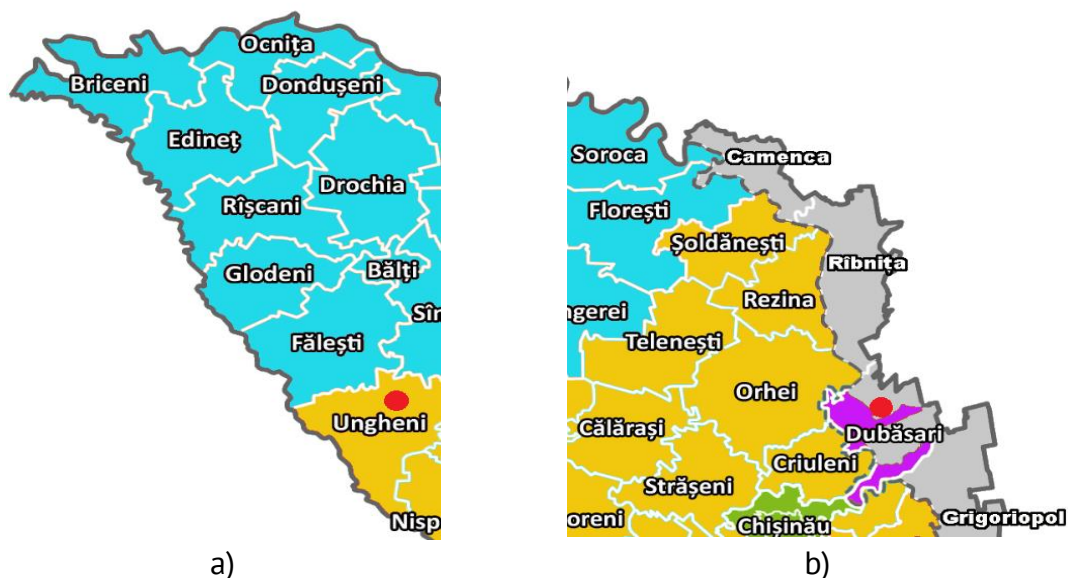

a)   b)

Figure 3. Suitable locations for HPSPP in the northern part
of the country on the Prut (a) and Nistru (b) rivers.

Consequently, the research of the relief related to the flow of the rivers Prut and Nistru indicates that favourable locations for building HPSPP along the river Prut with the height of the slopes or neighbouring territories higher than the river level are in the northern part of RM - after the city Ungheni (Figure 3 a). Respectively, along the river Nistru with the height of the slopes or neighbouring territories higher than the river level are in the northern part of RM - after the city Dubasari (Figure 3 b). During the study, several possible locations of PSHPP along the river Nistru were identified, the basic criterion being the maximum height difference between the river level and the slopes or adjacent territory.

The software possibilities were used to determine the altitude of the slopes near the river. This makes it possible to determine the altitude of a certain point in the space relative to sea level. Using the aforementioned software „Google Earth" (Figure 4), having as a reference point the sea level and the altitude of two arbitrary points in the plan, it was possible to find the height drop between these points by their simple differentiation.

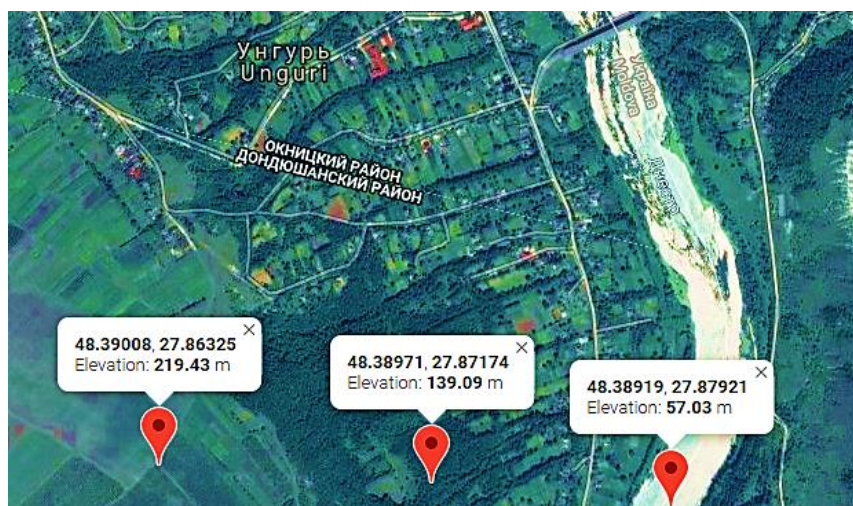**Figure 4.** Location of the upper reservoir on the right bank of the Nistru river, on the hills of Unguri village, Ocnita.

Finally, a series of geographical sites along the river Nistru have been identified, in which the net height drop would be suitable for PSHPP.

| a) | b) |

Figure 5. Two nice locations for a PSHPP on Nistru river: Soroca district, villages Inundeni (a) and Vertiujeni (b)

Possible locations for PSHPP near some lakes in Republic of Moldova:

- There are 57 natural lakes with a total area of 62.2 km²,
- There are about 1.6 thousand lakes and reservoirs, which have a total volume of about 1.8 km³ and an area of about 160 km².
- Most of natural lakes are located in the valleys of the Prut and Nistru rivers.
- The largest lakes in Moldova stretch along the river Prut, in its lower part: Beleu – 6,26, Dracele – 2,65, Rotunda – 2,08, Manta – 2,1, Fontan – 1,16 km².
- In the valley of the Nistru river there were kept the lakes Bîc – 3,72, Crasnoe — 1,6 km² and others.
- The water level in the lakes, especially in plains, depends on the water level in rivers, but also on the season. The influx of water can be observed twice a year - in February-April and in June-July.

As a result of the study, the possible locations for the building HPSPP on the territory of the Republic of Moldova were listed in the Table 1.

Table 1

Possible locations for Pumped-Storage Hydro Power Plant in Moldova

No	Locality, district		Altitude of the upper reservoir surface, m	Altitude of the river water surface, m	Net fall height, m
	Locations on the NISTRU river				
1	Verejeni,	Ocnița	196	63	133
2	Ungari,	Ocnița	242	60	182
3	Tătărăuca Veche,	Soroca	160	55	105
4	Șeptelici,	Soroca	202	58	144
5	Inundeni	Soroca	196	40	156
6	Vărăncău	Soroca	180	40	140
7	Sănătăuca,	Florești	145	30	115
8	Poina,	Șoldănești	220	28	192
9	Rezina,	Rezina	185	25	160
10	Saharna,	Rezina	227	25	202
11	Țipova,	Rezina	204	25	179
12	Lalova,	Rezina	200	24	176
13	Oxentea,	Dubăsari	122	24	98
	Locations on the PRUT river				
14	Cuconeștii Vechi,	Edineț	180	82	98
15	Lucăceni,	Fălești	160	48	112
16	Leova		120	16	104
	Locations near lakes				
17	Dănceni Lake		250	78	172
18	Ghidighici Lake		175	53	122

The distance between the reservoirs - up to 1,000 m.

2. Determination of the main technical characteristics of 100 MW HPSPP

In order to create favourable conditions for an increase of renewable energy sources capacities and especially of photovoltaic installations and wind turbines, in the Republic of Moldova there is an urgent need to build some HPSPP - as an important infrastructure for electricity storage with its delivery in the peak hours.

Starting from the existing recommendations in the specialized literature (figures 6 and 7), in this paper a 100 MW HPSPP is considered for which has been found be several potential locations along Nistru and Prut rivers as well as around some lakes inside the country. The waterfall's height could vary from 70-80 up to 140-150 meters. The distance between the hydro power plant reservoirs for most all locations is below 1000 meters, but for some of them it can reach up to 1500 m.
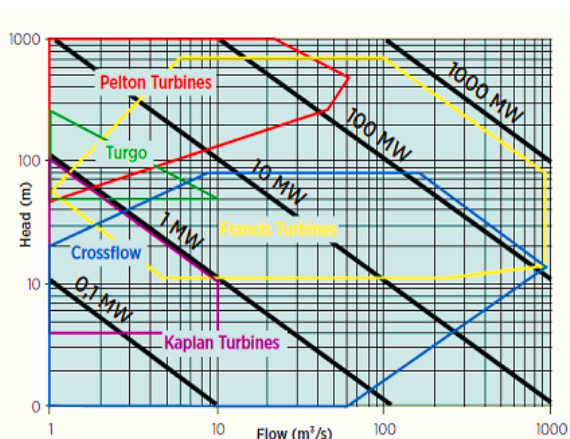

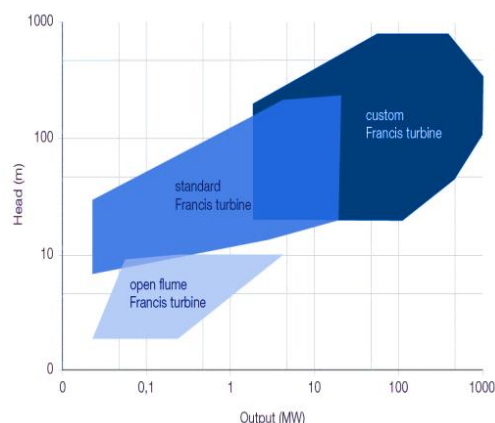**Figure 6.** Diagram for selecting turbine type [2].

Figure 7. Operating range for Francis turbines [4].

From consideration to increase the flexibility of the plant, it has been decided that the HPSPP will be equipped with 4x25 MW hydro-aggregates (a Francis-type turbine-pump coupled with motor-generator). The operating time in the generation regime can vary from few minutes to 8-10 hours per day, but in pumping regime - up to 14-16 hours per day. In the calculations there were admitted three values of power generation duration - 4, 8 and 10 hours / day. The energy efficiency of the aggregates in the turbine regime is about 0,8, and in pumping regime – 0,7 (see table 2).

It was assumed that the upper reservoir represents a hydrotechnical construction of cylindrical shape (with diameter d_{sup} and height h), but the lower one - has a semi-cylinder form, integrated into the riverbed or shore of a lake.

Table 2

Data underlying the calculations

No.	Indicator	Notation	Unit	Value
1	Number of working days per year of HPSPP	Nd	days/tr	360
2	Waterfall's height	H	m	100-150
3	Hydro-aggregate's efficiency, generation regime	η_g	r.u	0,8

4	Hydro-aggregate's efficiency, pumping regime	η_p	r.u	0,7
5	Upper reservoir depth	h	m	25
6	Water density	ρ	kg/m3	1000
7	Gravitational acceleration	g	m/s2	9,81
8	Water velocity inside the pipe	v	m/s	4

The water flow rate Q_w, necessary for the HPSPP 's development of an expected power P, is determined by the formula

$$Q_w = \frac{P}{g \cdot H \cdot \rho \cdot \eta},$$

where g represents gravitational acceleration, H - waterfall's height, ρ - water density and η_p - hydro-aggregate's efficiency in generation regime.

The minimal volume of the upper reservoir is determined by the expression:

$$V_{w,day} = Q_w \cdot T_{days}.$$

The upper reservoir's surface is calculated as follows:

$$S = V_{w,day} / h,$$

where for depth *h* was accepted - h = 25 m.

The diameter of the upper reservoir is determined by the expression: $d = \sqrt{S/\pi}$, but the pipe diameter, which will connect the upper reservoir with a hydro-aggregate, by the formula:

$$d_{cond} = \sqrt{4Q/(\pi \cdot \upsilon)}.$$

Figure 8 the pipe diameter dependence on the water velocity through it, and figure 9 - the main dimensions of the upper reservoir.
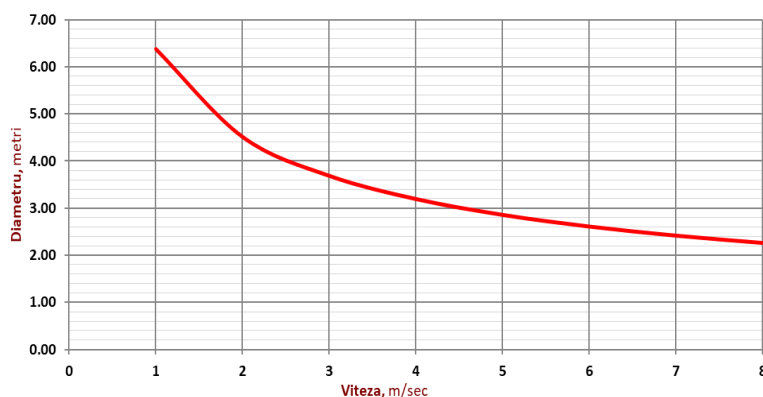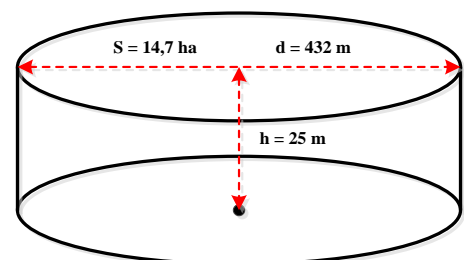

Figure 8. Dependence $d_{cond}(v)$.

Figure 9. Dimensions of the upper reservoir.

The results of the calculations for a possible HPSPP, built in the Republic of Moldova, are presented in the tab. 3.

Table 3

The main characteristics of the 100 MW Hydro Pumped Storage Power Plant

N	Indicator	Notation	Unit	Capacity, MW					
				25			**100** (4 x 25)		
1	Water flow	Q_w	m³/s	32			127		
2	Operational time (generation)	T_{day}	h/day	4	8	10	4	8	10
		T_{an}	h/yr	1 440	2 880	3 600	1 440	2 880	3 600
3	Electricity produced over a day, year and 30 yrs period	W_{day}	MWh/d	100	200	250	400	800	1 000
		W_{an}	GWh/yr	36,5	73,0	91,3	146,0	292,0	365,0
		WTA	GWh	508,8	1017,6	1272,7	2035,2	4070,4	5088,0
4	Electricity consumed (for water pumping)	W_{day}	MWh/d	130	260	325	520	1040	1300
		W_{an}	GWh/yr	47,45	94,9	118,625	189,8	379,6	474,5
		WTA	GWh	661,4	1322,9	1653,6	2645,8	5291,6	6614,5
	Waterfall's height			H = 100 m					
5	Water volume	V_{day}	mil. m³/day	0,46	0,92	1,15	1,83	3,67*	4,59
		V_{an}	mil. m³/yr	165	330	413	661	1321	1651
6	Surface of the upper reservoir	S_w	th m²	18 349	36 697	45 872	73 394	146 789	183 486
		S_w	ha	1,8	3,7	4,6	7,3	14,7	18,3
7	Diameter of upper reservoir	D	m	153	216	242	306	432	483
8	Diameter of pipe thread	d	m	3,19					
	Waterfall's height			H = 150 m					
9	Water volume	V_{day}	mil. m³/day	0,46	0,92	1,15	1,83	3,67	4,59
		V_{an}	mil. m³/yr	165	330	413	661	1321	1651
10	Surface of the upper reservoir	S_w	th. m²	18 349	36 697	45 872	73 394	146 789	183 486
		S_w	ha	1,8	3,7	4,6	7,3	14,7	18,3
11	Diameter of upper reservoir	D	m	153	216	242	306	432	483
12	Diameter of pipe	d	m	3,19					

* Lake Danceni, Ialoveni district, volume- 22 mil. m³, surface - 420 ha; surface of the upper reservoir – 14,7 ha.

3. Power plant feasibility study

The economic feasibility of an investment project is determined based on *net present value* (NPV) evaluation [13, 14].
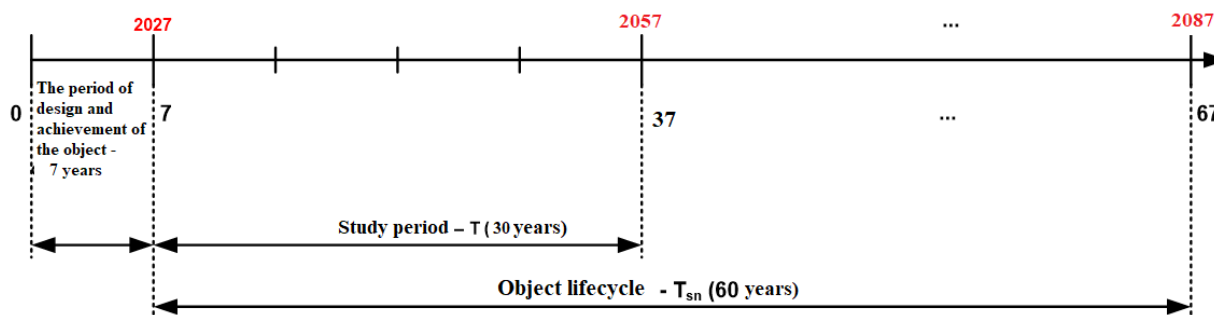

Figure 10. Time axis with the appropriate the time periods.

In order to find the project NPV below the total discounted cost (CTA) for building and operating the power plant over the study period of 30 years (figure 10) as well as the total gross revenue VTA have been determined.

The table 4 presents initial data used in economic calculations.

Table 4

Data used for economic evaluation

No	Indicator	Notation	Unit	Value
1	HPSPP Power rating	P_{nom}	MW	100
2	Specific investment	i_{sp}	mil.€ /MW	2
3	HPSPP construction period	d	ani	3
4	Study period	T	years	30
5	Electricity produced over a year on the BM	W_0	MWh/yr	292000
6	Electricity consumed over a year for water pumping off-peak	$W_{0,pump}$	MWh/yr	379600
7	Time duration of the maximal power rate utilization	Tu	h/yr	2880
8	Efficiency of power generation	η_{gl}	%	0,8
9	Annual O&M costs	$k_{O\&M,0}$	% from I	0,015
10	Discount rate	i	r.u.	0,08
11	Annual growth rate of O&M costs	$r_{O\&M}$	%/yr	0,04
12	Annual average electricity cost on DAM[1], 2019		€/MWh	52,83
13	Annual average electricity cost on DAM , 2019, off-peak		€/MWh	36,89
14	Annual average electricity cost on BM[1], 2019		€/MWh	121,96
15	Annual electricity cost growth rate on BM	$r_{W,BM}$	%/yr	0,02
16	Annual electricity cost growth rate on DAM	$r_{W,DAM}$	%/yr	0,02

[1]Day ahead market; [2]Balancing market.

3.1. The PSHPP total costs assessment

The plant total cost over the study period includes three components:
- investment cost (CTA_I);
- operation and maintenance cost ($CTA_{O\&M}$);
- plant electricity consumption cost for water pumping (CTA_{pomp}).

Thus, for the project total cost CTA one can write:

$$CTA = CTA_I + CTA_{O\&M} + CTA_{pump} \tag{1}$$

Investment costs
The investment cost can be determined based on the average value of the specific investment cost

$$I = i_{sp} \cdot P_{inst} = 2mil.€ / MW \cdot 100MW = 200 \ mil€, \tag{2}$$

where: i_{sp} - specific investment cost; P_{nom} - nominal power rating of the plant.

In the absence of specific data, the investment is staggered in a uniform way over the construction period of 3 years. Under this hypothesis for CTA_I results:

$$\text{CTA}_{\text{I}} = \sum_{t=-(d-1)}^{0} I_t \cdot (1+i)^{\theta-t} = \text{Io} \cdot \vec{T}_{d,i} = 50 \cdot 3,2464 = 216,43 \text{ mil. €,} \qquad (3)$$

where: I_t represents the investment realised in the year t, $I_t = I_0$ - for all years t of the construction period d, $\text{Io} = I/d = 200$ mil. € / 3 years = 66,67 mil. €/yr.;

$\overline{T}_{d,i}$ - discounted duration of the construction period:

i- discount rate, i = 0,08.

$$\overline{T}_{d,i} = [1-(1+i)^d]/i = \left[1-(1+0,08)^4\right]/0,08 = 3,2464 \text{ yr.;} \qquad (4)$$

Operation and maintenance costs during the study period

$$\text{CTA}_{\text{O\&M}} = C_{\text{O\&M},0} \cdot \overline{T}_{T,x1} = 2,885 \cdot 17,62 = 50,83 \text{ mil €} \qquad (5)$$

where: $C_{O\&M,0}$ represents the equivalent O&M annual costs, determined:

$$C_{\text{O\&M},0} = k_{\text{O\&M},t_0} \cdot I \cdot (1+r_{\text{O\&M}})^{-t_0} = 0,015 \cdot 200 \cdot (1+0,04)^{-1} = 2,885 \text{ mil. €}. \qquad (6)$$

$k_{O\&M,t_0}$ - the reference value of the O&M annual cost - as percentage of the total investment nominal cost, $k_{O\&M,t_0} = 0,015$;

I- total investment nominal cost;

$\overline{T}_{T,x1}$ - discounted (reassessed) duration of the study period, which reflects the calendar duration of the study period, the discount rate and the dynamics of annual O&M costs:

$$\overline{T}_{T,x1} = [1-(1+x_1)^{-T}]/x_1 = \left[1-(1+0,0385)^{-30}\right]/0,0385 = 17,62 \text{ yrs;}$$

x_1- Synthetic (or equivalent) discount rate for study period duration reassessment:

$r_{O\&M}$- annual growth rate of O&M costs.

$$x_1 = (1+i)/(1+r_{\text{O\&M}})-1 = (1+0,08)/(1+0,04)-1 = 0,0385;$$

PSHPP electricity consumption cost for water pumping

$$\text{CTA}_{\text{W-Pump}} = C_{\text{W},0} \cdot \overline{T}_{T,x2} = 16,41 \cdot 13,94 = 228,71 \text{ mil €,} \qquad (7)$$

where: $C_{W,0}$ represents the equivalent annual electricity cost,

$$C_{\text{W},0} = c_{\text{W},0} \cdot W_{\text{an,pump}} = 43,22 \cdot 379600 = 16,41 \text{ mil. € /yr;}$$

$W_{an,pump}$ - annual electricity consumption for pumping, $W_{\text{an,pump}} = 379,6 \text{ GWh/an,}$

$c_{W,0}$ - electricity cost on the DAM in off-peak hours;

for known $c_{\text{W},2019} = 36,89 \text{ € / MWh}$, one can obtain

$c_{\text{W},0} = c_{\text{W},2019} \cdot (1+r_{\text{dam}})^{27-19} = 36,89 \cdot (1+0,02)^8 = 43,22 \text{ € / MWh};$

$\overline{T}_{T,x2}$ - the discounted (reassessed) duration of the study period:

$$\overline{T}_{T,x2} = [1-(1+x_2)^{-T}]/x_2 = \left[1-(1+0,0588)^{-30}\right]/0,0588 = 13,94 \, \text{yrs};$$

x_2- synthetic discount rate:

$$x_2 = (1+i)/(1+r_{W,dam})-1 = (1+0,08)/(1+0,02)-1 = 0,0588;$$

$r_{W,dam}$ - annual growth rate of the electricity price on DAM, $r_{W,dam} = 0,02$;

Thus, for the total costs related to HPSPP construction and operation over the study period one can got:

$$CTA = CTA_I + CTA_{O\&M} + CTA_W = 216,43+50,83+228,71 = 495,97 \, \text{mil. Euro.}$$

3.2. The evaluation of gross income VTA got on the BM

The gross income VTA may be determined as follows: $VTA = WTA_{BM} \cdot LCOE_{W,BM}$, where WTA_{BM} represents the total (discounted) volume of electricity produced by PSHPP and delivered on the BM during the study period, and $LCOE_{W,BM}$ - the levelized cost of electricity on the balancing market during the HPSPP's operation period.

1. The volume of electricity produced by the plant WTA_{BM}

The total discounted volume of electricity produced by the plant over the study period [13]:

$$WTA_{BM} = W_0 \cdot \overline{T}_{T,i} = 292000 \cdot 11,26 = 3287273 \, \text{MWh}, \tag{8}$$

W_0- the annual electricity production,

$\overline{T}_{T,i}$ - the discounted duration of the study period:
i - the discount rate;

$$\overline{T}_{T,i} = [1-(1+i)^{-T}]/i = \left[1-(1+0,08)^{-30}\right]/0,08 = 11,26 \, \text{years.} \tag{9}$$

2. The levelized cost of electricity $LCOE_{W,BM}$ on the balancing market (BM) during the HPSPP's operation period

The evaluation of $LCOE_{W,BM}$ is based on knowing:
- the annual average electricity cost on BM (reference year - 2019),
- the annual growth rate of electricity cost on BM over the retrospective period ($r_{w,BM}$),
- the forecasted energy cost on BM in the year preceding the first year of plant operation $c_{W,0,BM}$,

and can be calculated, according to the formula:

$$LCOE_{W,BM} = c_{W,0,BM} \cdot \overline{T}_{T,x3}/\overline{T}_{T,i} = 142,896 \cdot 13,94/11,26 = 176,939 \, \text{Euro/MWh},$$

where: $c_{W,0,BM}$ - the forecasted value of the electricity cost on the balancing market in 2027,

$$c_{W,0,BM} = c_{W,BM,19} \cdot (1 + r_{W,BM})^{27-19} = 121,96 \cdot (1 + 0.02)^8 = 142,897 \text{ Euro/MWh,}$$

$c_{W,BM,2019}$ - the known reference value of the electricity cost on the BM in 2019,

$$c_{W,BM,2019} = 121,96 \text{ Euro/MWh;}$$

$\overline{T}_{T,x3}$ - the discounted duration of the study period:

$$\overline{T}_{T,x3} = [1 - (1 + x_3)^{-T}] / x_3 = \left[1 - (1 - 0,0588)^{-30}\right] / 0,0588 = 13,94 \text{ years;}$$

x_3 - the synthetic discount rate:

$r_{W,BM}$ - the annual growth rate of the electricity price on BM, $r_{W,BM} = 0,02$;

$$x_3 = (1 + i) / (1 + r_{W,BM}) - 1 = (1 + 0,08) / (1 + 0,02) - 1 = 0,0588.$$

To be noted that the actual levelized cost of electricity produced by PSHPP during the study period constitutes

$$LCOE_{HPSPP} = CTA_{HPSPP} / WTA_{BM} = 495,97 \cdot 10^6 / 3287273 = 150,87 \text{ Euro/MWh.} \quad (10)$$

3. Calculation of the gross income VTA obtained from the electricity generation on BM
Finally, for the total revenues from the electricity supply on the balancing market results

$$VTA = WTA_{BM} \cdot LCOE_{W,BM} = 3287,273 \cdot 176,939 \cdot 10^{-3} = 581,65 \text{ mil. Euro} \quad (11)$$

where: $LCOE_{W,BM}$- the levelized cost of electricity on the balancing market;

WTA_{BM}- The total discounted volume of electricity produced by HPSPP during the study period.

3.3. Determination of economic efficiency indicators
The discounted net income over the study period is determined by the expression:

$$VNA = VTA - CTA \quad \text{or}$$

$$VNA = WTA_{BM} \cdot (LCOE_{BM} - LCOE_{HPSPP}) = 581,65 - 495,97 = 85,68 \text{ mil. Euro.} \quad (12)$$

Normally, for accepted investment projects VNA is to be positive - the incomes exceed the realized expenditures. VNA is one of the most important investment economic efficiency indicators in the market economy. Generally, it expresses the „up-to-date" situation - the economic profit or loss for a certain period of time.

Payback period
The investment payback period is another economic efficiency indicator, which reflects the project's ability to generate profit and repay the borrowed capital. Generally, the duration of the investment recovery expresses a number of years during which the realized investment recovers from the annual net incomes.

In order to determine the payback period, it is assumed that the annual net income VN_{med} is constant over the study period:

$$VN_{med} = VNA / \overline{T}_{T,i} = 85,68 / 11,26 = 7,61 \text{ mil €/,yrs,} \quad (13)$$

where: *VNA*- the total discounted net income;

$\overline{T}_{T,i}$ - the discounted duration of the study period;

For the simple payback period of investment results:

$$\mathbf{PBs} = \mathbf{I} / \mathbf{VN}_{\mathrm{med}} = 200 / 7,61 = 26,28 \text{ years,}\qquad(14)$$

where: *I* total investment in the generating unit:

VN_t- annual net income.

From the economic point of view an investment project can be accepted only when the following condition is satisfied*: PBs is to be less than the project lifetime.* For the considered facility the lifetime is about 80-100 years; thus, the project can be accepted as a feasible one. In this context it is to be noted that the above presented economic evaluation was carried out for a study period of 30 calendar years, and it demonstrates that the investment effort is recovered from the annual gains. In the case when annual revenues could have been accounted for the entire HSHPP lifetime – the economic attractiveness of the project would only increase.

Conclusion

Building of a pumped-storage hydro power plant (HPSPP), as the main infrastructure for large-scale energy storage, represents a measure to increase the flexibility of the power system. The present study demonstrates the economic attractiveness of the HPSPP-project implementation.

References

1. IRENA, Global Energy Transformation: A Roadmap to 2050, International Renewable Energy Agency, Abu Dhabi, 2019, https://www.irena.org//media/Files/IRENA/Agency/Publication/2019/Apr/IRENA_Global_Energy Transformation_2019.pdf.
2. Renewable energy technologies: cost analysis: Hydropower. IRENA, 2012, 44p.
3. Didik Notosudjono, Evita Wismiana1, Fitrah Alamsyah, Bagus Dwi Ramadhon, Analyzing the potential and the load evaluation on Ubrug hydro power plant of Sukabumi, West Java, MATEC Web of Conf. 154, 01043 (2018), https://doi.org/10.1051/matecconf/201815401043.
4. Linnansaari, T., Wallace, B., Curry, R.A., and Yamazaki, G., Fish passage in large rivers: a literature review, MAES Report Series 2015-016, Canadian Revers Institute, 28 April 2015, 59 p.
5. Assessment of the European potential for pumped hydropower energy storage, Report EUR 25940 EN, European Commission, Joint Research Centre, Institute for Energy and Transport. Petten, The Netherlands, 2013, 74p.
6. International Energy Agency, Technology roadmap: Energy storage, OECD/IEA, Paris, 2014.
7. The world's water battery: Pumped hydropower storage and the clean energy transition, International Hydropower Association working paper, dec.2018, 15 p.
8. Substantiation Study, Tarniţa – Lăpuşteşti Pumped-Storage Hydropower Plant, Bucharest, 2019, 133p.
9. Tarniţa – Lăpuşteşti Pumped-Storage Hydropower Plant. Environmental impact report, S.C. Hidroelectrica S.A., Sucursala Hidrocentrale Cluj, Project 15/2011, 172 p.
10. Efficiency of electricity storage, University of Craiova, 2010, 12 p.
11. Wärtsilä, Flexibility to future-proof the Ukrainian power system Solving the Ukrainian Green-Coal paradox, Wärtsilä Corporation 2018; www.wartsila.com/energy.
12. Implementing sustainable business model for hidro storage, General Electric, White Paper, 16p. https://www.ge.com/.
13. Arion V., Hlusov V., Gherman C., Modelarea economică a obiectivelor şi sistemelor energetice pe termen lung: modelele statice-echivalente şi aplicabilitatea acestora. EMERG 3, Editura AGIR, Bucureşti, 2016, p. 26-63.
14. Arion V., Hlusov V., Gherman C., Şveţ O., Ghid privind evaluarea economică a proiectelor din domeniile eficienţei energetice și energiilor regenerabile. Chișinău, Editura Sirius, 2014.