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Research Article

Pumped-Storage Energy Systems for the Drin River Cascade: A Case Study

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Abstract

This article investigates the feasibility of implementing pumped-storage hydropower (PSH) systems within the existing hydropower plants (HPPs) of the Drin River cascade in Albania. Currently, five HPPs are operational along the Drin River, two of which are managed by private operators, while the remaining three are operated by the public utility "KESH sh.a". Increasing climate variability necessitates adaptive operational measures to enhance the safety and resilience of these hydropower assets. In parallel, the rapid development of variable renewable energy sources, such as photovoltaic and wind power, has intensified interest in large-scale energy storage solutions. The study evaluates a case scenario involving the installation of a 200 MW pumped-storage system between two existing reservoirs in the Drin River cascade. Based on a hydrological year characterized by high rainfall, the results indicate that the proposed system could reduce downstream discharge by up to 30% while producing approximately 28 GWh of net electrical energy. Beyond energy generation, the assessment highlights broader system-level benefits, including improved flood risk management, enhanced climate resilience, and optimized hydropower operation. The findings suggest that pumped-storage integration could play a strategic role in supporting Albania's energy transition and strengthening the operational flexibility of the Drin River hydropower system.

Keywords: Pump Storage Hydropower; Renewable Energy; Drini River Cascade; Climate Risk.

INTRODUCTION

The Drin River Cascade represents the backbone of Albania's electricity system, comprising five hydroelectric power plants (HPPs) constructed along the Drin River. Three of the largest HPPs "Fierza", "Koman", and "Vau i Dejës" are operated by the Albanian Power Corporation "KESH sh.a.", the country's public utility and largest electricity producer [1-6]. Beyond generation, the Drin River Cascade plays a critical role in ensuring system reliability, as it is currently the sole provider of balancing services for the Albanian power system. Figure 1 depict the scheme of the Drin River cascade.

From a safety and operational perspective, the three main HPPs are classified as first-category hydraulic works [7-11]. The cascade is considered unique in Europe due to its dam heights, reservoir characteristics, installed capacity, and centralized operational management [12]. Together, these three plants have a total installed capacity of 1,350 MW and an average annual electricity production of approximately 4,000 GWh. Fierza HPP, commissioned in 1978, has an installed capacity of 500 MW; Koman HPP, commissioned in 1985, has a capacity of 600 MW; and Vau i Dejës HPP, operational since 1971, has a capacity of 250 MW. All three plants are equipped with Franci's turbines.

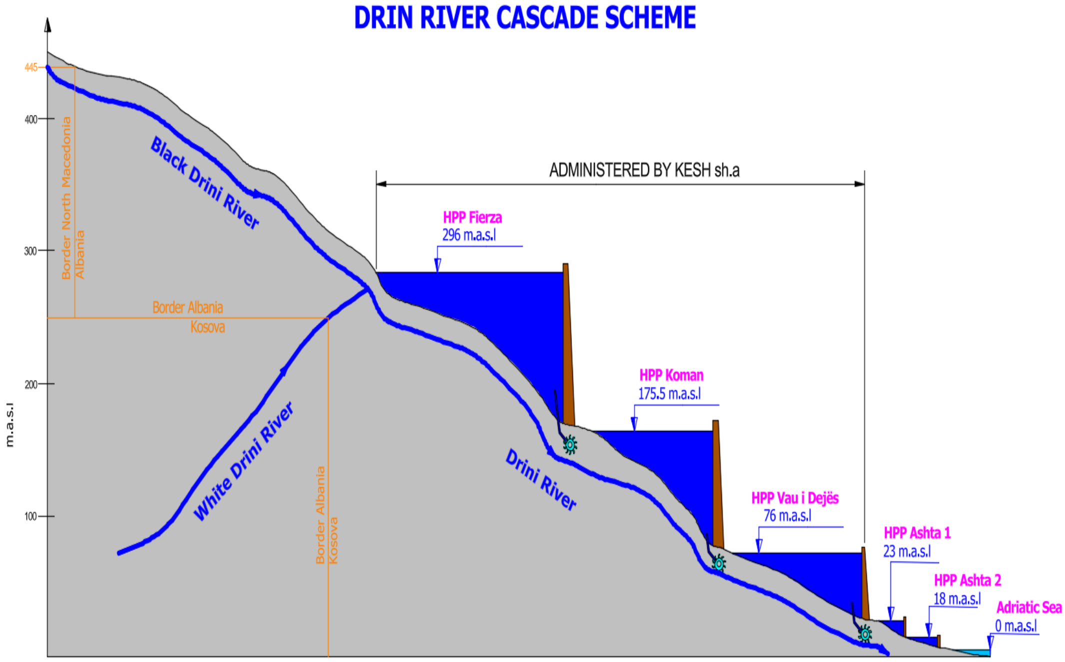

Figure 1. Scheme of the Drin River cascade

Furthermore, electricity production in Albania has relied almost entirely on hydropower. In recent years, however, the contribution of photovoltaic generation has increased steadily and is expected to grow further, as several large-scale solar projects are currently under construction or have already obtained development permits [13-15]. Despite this expansion, Albania remains a net importer of electricity in most years. In 2024, total electricity production amounted to 7.84 TWh, while consumption reached 8.17 TWh [16]. Due to the strong dependence of hydropower generation on hydrological conditions, Albania becomes a net exporter only in years with exceptionally high rainfall. For example, in 2018, total electricity production reached 8.55 TWh, exceeding consumption of 7.64 TWh [17].

Even under favorable hydrological conditions, the variability of inflows requires "KESH" to export electricity during periods of high-water availability and import electricity during dry months to satisfy domestic demand. This operational pattern is expected to intensify as climate change increases hydrological uncertainty and as variable renewable energy sources, particularly photovoltaic plants, gain a larger share in the national energy mix.

Considering the strategic importance of the Drin River Cascade, its role as the sole balancing provider, the increasing impacts of climate change, and the rapid expansion of intermittent renewable generation, there is a growing need to assess additional storage and flexibility solutions. In this context, the integration of pumped-storage hydropower systems within the existing Drin River Cascade emerges as a promising investment option to enhance system flexibility, improve flood management, and strengthen the overall resilience of Albania's energy sector. This study examines the feasibility and potential benefits of implementing pumped-storage solutions in the existing hydropower infrastructure of the Drin River Cascade.

CHALLENGES IN THE SAFE AND EFFICIENT MANAGEMENT OF THE DRIN RIVER CASCADE

The dynamic development of the electricity sector, the increase of demand for energy and balancing services, climate change, and the integration of new sources of electricity production from renewable sources, impose major interventions in the Drin River cascade.

Safe Flood Management of the Drin Cascade Hydropower Plants

From the point of view of safety and impact, the three main HPPs of the cascade are classified as first category works. The water discharge systems must guarantee the controlled discharge of the excess water that may enter the reservoirs of these hydropower plants.

Currently, additional discharge capacities need to be installed at the Koman HPP and Fierza HPP to cope the Probable Maximum Flood (PMF) [1].

The measures that should be taken to reduce the risk are:

- Reducing the level of reservoir operation during the flood season;
- Construction of additional discharge capacities;
- Construction of the Skavica HPP, etc.

Table 1. Additional discharge capacities need to be installed [1].

	Fierza	**Komani**	**Vau i Dejes**
Max. outflow after routing	5250 m³/s at 306.5 m asl	7150 m³/s at 175.5 m asl	7740 m³/s at 77.0 m asl
Available discharge capacities	2970 m³/s	3460 m³/s	7740 m³/s
Additional discharge capacities required	2280 m³/s	3690 m³/s	no additional capacities required

Climate Change

Today we are all witnesses to say that the climate is changing. Hydroelectric power plants will be most impacted by climate change. The Drin River cascade is also estimated to be negatively impacted by these climate changes. It is estimated that in the short- and medium-term future in the Drin River watershed the following will be observed:

- Increase in the average temperature level;
- Decrease in the amount of precipitation;
- Prolonged drought periods;
- Short periods of very high rainfall intensity.

The projected decrease in precipitation and the expected increase in temperatures will cause increased evaporation losses and reduced snowpack. This will cause a decrease in the average annual flow by approximately 5% in the short term and up to 10% in the medium term. Using the average annual production of the last 10 years as a reference (~4400 GWh), this decrease in flow is equivalent to a loss in average annual production of approximately 220 GWh (short term) to 440 GWh (medium term), see Figure 2 [3].

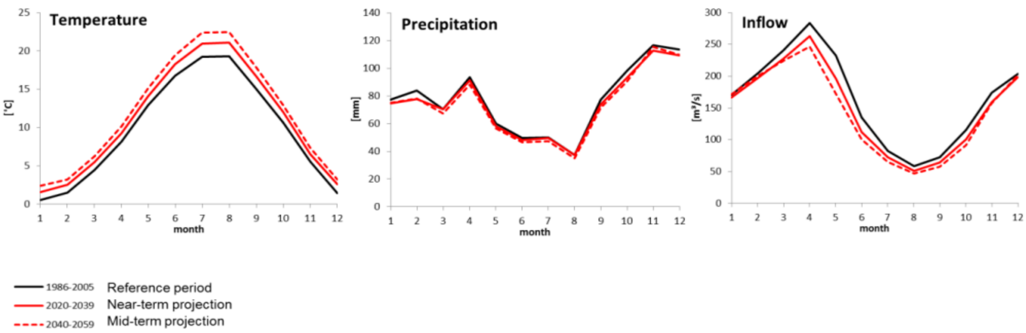

Figure 2. Projections of future hydro-meteorological characteristics in the Drin Basin u/s of Fierza [3].

Integration of New Sources of Electricity Production from Renewable Sources

The production of electricity from renewable energy sources, mainly from the photovoltaic (PV), is constantly increasing globally. In many countries that have had incentive policies in this direction, the production of electricity from these sources covers a significant part of the energy need. This development has also been accompanied by problems, mainly in terms of balancing the grid or overproduction of electricity at certain periods of the day (during specific hours of the day). Faced with these problems, in many countries the interruption/shutdown of power plants at specific times or the sale of electricity at a negative price has begun to be applied.

A considerable increase in the production of electricity from photovoltaic plants has been observed in our country too. The amount of electricity produced by photovoltaic plants in Albania has been increasing at a high rate.

The photovoltaic plants in Albania produced in 2022, 2023 and 2024 respectively nearly 50,092 MWh, 80,874 MWh and 225,800 MWh, see Figure 3 [4-6]. These data indicate a very large increase in electricity production from photovoltaic power plants in 2024. This increasing trend is expected to continue as many other photovoltaic power plant construction projects are being developed and are expected to be put into operation.

The increase in electricity production from photovoltaic plants in Albania, as has happened in many other countries, may cause overproduction of energy at certain hours of the day, mainly at midday in the summer months. This will be accompanied by decrease in the price of electricity at those hours, even though consumption increases in this time band.

The graph below shows the amount of electricity traded and its average price for 15.08.2025 from the HUPX exchange. This graph clearly shows that in the time band 11:00-15:00 the price of electricity trading is almost 0 €/MWh because of overproduction from photovoltaic plants [7].

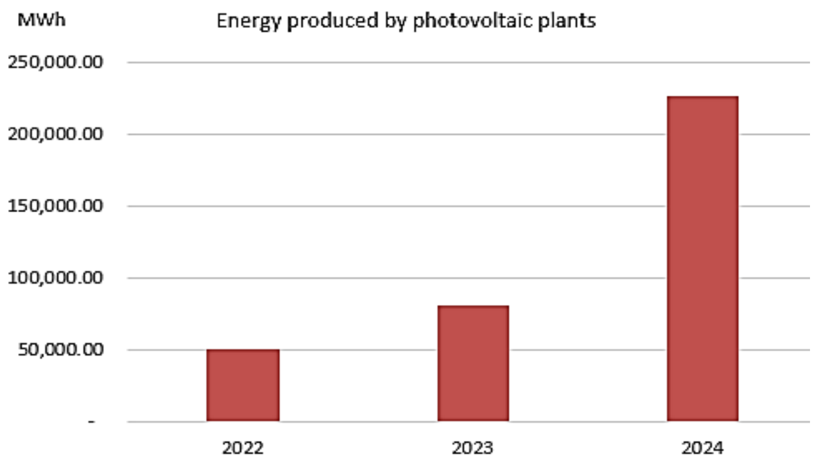

Figure 3. Energy produced by photovoltaic plants, data from [4-6]

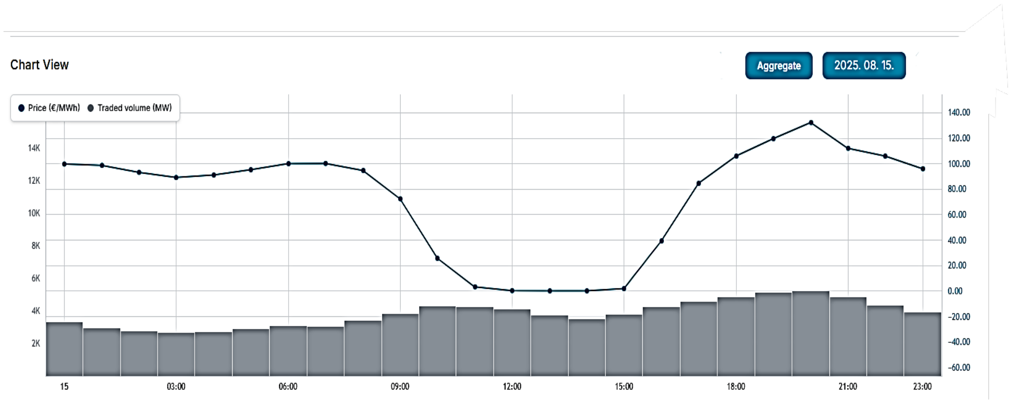

Figure 4. Average price and volumes of electricity traded on 15.08.2025 on the HUPX stock exchange [7]

The increase of electricity production in Albania from photovoltaic plants is expected to cause the same behavior of the energy market as in other countries. The following figures 5 until t present the average monthly data of the amount of traded energy and its price, for a typical month of the summer season according to the Albanian stock exchange Alpex [8-10].

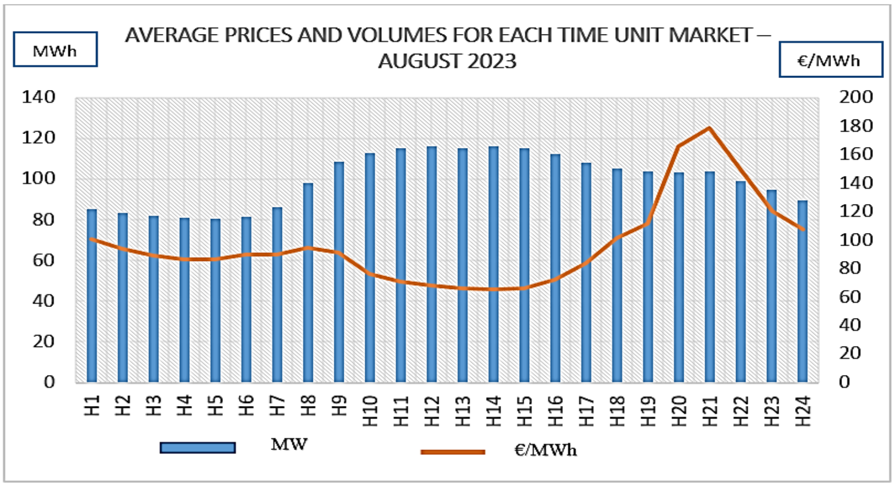

Figure 5. Average prices and volumes for each time unit Albanian market (August 2023) [8]

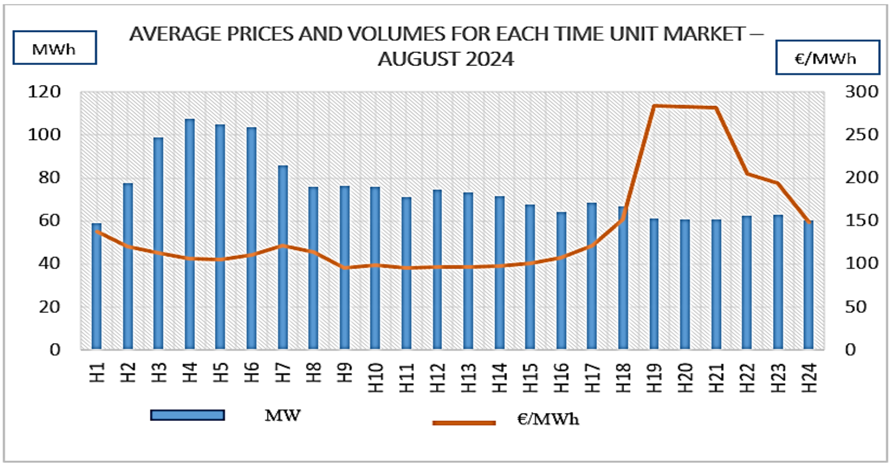

Figure 6. Average prices and volumes for each time unit Albanian market (August 2024) [9]

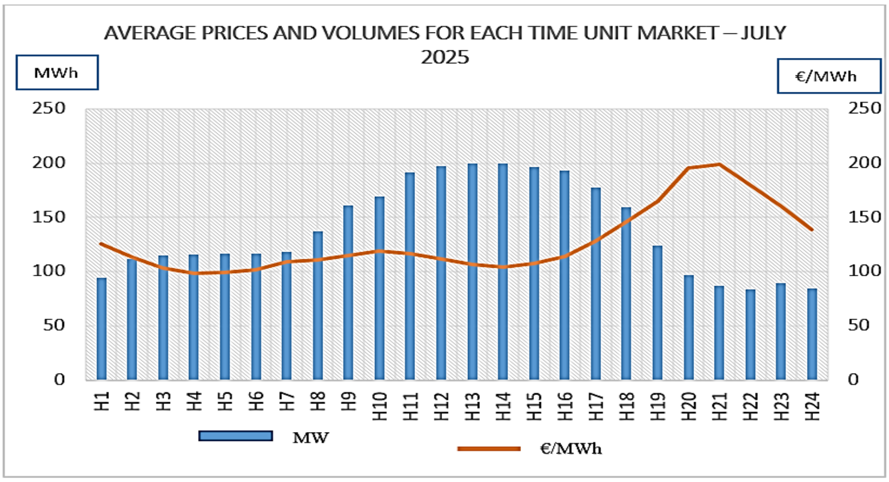

Figure 7. Average prices and volumes for each time unit Albanian market (July 2025) [10]

The analysis shows domestic market behavior similar to that seen in other countries with renewable energy power plants development. The midday peak hour (H11-H14) when consumption is high, is accompanied by a drop in price, due to the increase in production from photovoltaic power plants in this time band.

ANALYSIS OF THE INSTALLATION OF A PUMP-STORAGE SYSTEM IN THE DRIN RIVER CASCADE

Pump-storage hydropower systems are well-known and applicable in many countries around the world. Generally, these systems are designed and built during the construction phase of the hydropower plant. However, technically, the installation of pump-storage systems can be carried out even after the construction of a hydropower plant. Given the size and complexity of the Drin River cascade HPPs, it turns out that the implementation of pump-storage hydropower (PSH) systems in their existing infrastructure is impossible. In such conditions, the most optimal way to install PSH systems is to build a new infrastructure independent of the existing infrastructure, which will use only the water accumulated in the current reservoirs. The main characteristics of the "Fierza" and Koman HPPs is shown in the Table 2, Table 3, and Figure 8.

Table 2. Main characteristics of the "Fierza" HPP [18]

Technical Parameters HPP			
Installed Power	4 x 125 MW	Crest width	13 m
Number / Type of Turbines	4 Vertical "Fiancis"	Volume of the Dam	8 million m^3
Weter Processing Capacity	4 x 123.5 m^3/sec	Maximum Water Level	296.0 m asl
Average Annual Production	1300 GWh	Minimum Operating Level	241.6 m asl
Risk Classification	Class 1	Catchment Area	11829 km^2
Construction Period	1971-1980	Average AnnuaI Inflow'	202 m^3/sec
Year of Reservoir Filling	1978	Total Reservoir Volume	2.7 billion m^3
Type of Dam	Clay-core Dam	Active Reservoir Volume	2.3 billion m^3
Location	V42°J5'05"/L20°02'32"	Spillway Capacity	2670 m^3/sec
Dam Beight	166.5 m asl	Number of Spillways	2
Crest of the Dam	312.0 m asl	Type of Spillways	Shaft/Gated Spillways
Crest Length	380.0 m	Nominal Head	118 m

Table 3. Main characteristics of the Koman HPP [19].

Technical Parameters HPP			
Installed Power	4 x 150 MW	Crest width	10 m
Number / Type of Turbines	4 Vertical "Fiancis"	Volume of the Dam	5 million m^3
Weter Processing Capacity	4 x 184.0 m^3/sec	Maximum Water Level	175.5 m asl
Average Annual Production	1800 GWh	Minimum Operating Level	160.0 m asl
Risk Classification	Class 1	Catchment Area	12850 km^2
Construction Period	1981-1988	Average AnnuaI Inflow'	289 m^3/sec
Year of Reservoir Filling	1985	Total Reservoir Volume	500 million m^3
Type of Dam	Rockfill Dam & Concrete Screen	Active Reservoir Volume	188 million m^3
Location	V42°J5'05"/L20°02'32"	Spillway Capacity	3600 m^3/sec
Dam Beight	115.5 m asl	Number of Spillways	2
Crest of the Dam	185.7 m asl	Type of Spillways	Radial Gates Tunnels
Crest Length	290.0 m	Nominal Head	96 m

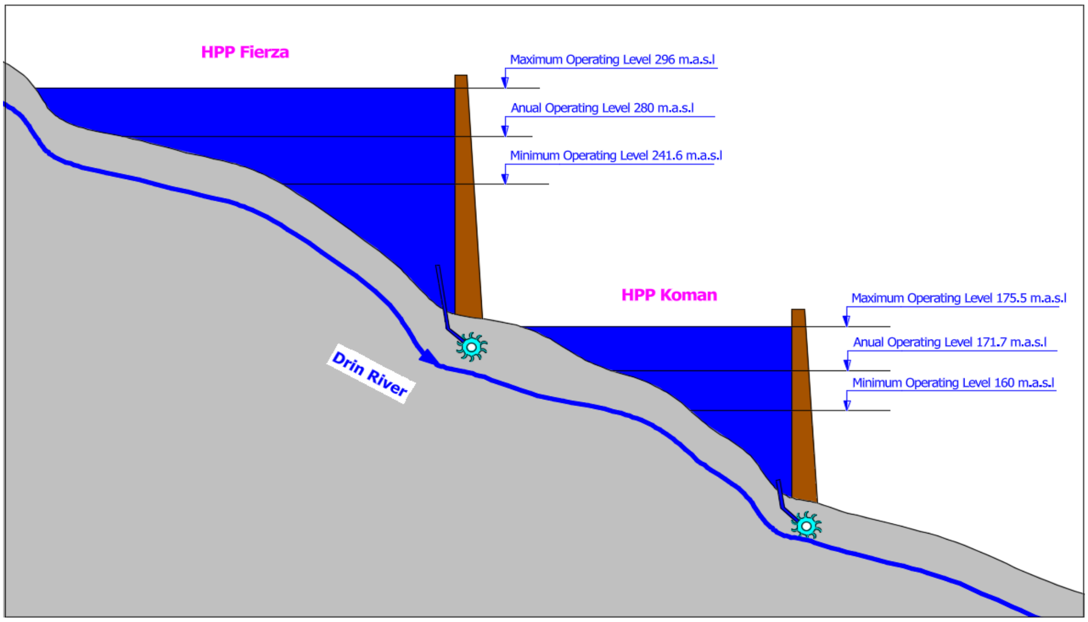

Figure 8. Operating levels in the reservoirs of "Fierza" HPP and "Koman" HPP

Installation of a Pumped-Storage Hydropower System Between HPP Koman - HPP Fierzë

Considering all indicators, it results that the installation of a PSH system between the reservoirs of HPP Fierza and HPP Koman seems more feasible. The PSH system should be installed on the right slope by building a completely new infrastructure.

Determining the optimal capacity of a PSH system is a complicated process, which requires the analysis of many variables. Based on the water flow rate and head, geological conditions, the need for additional discharge capacity, etc., according to a preliminary assessment, the optimal installed capacity is 200-300 MW [2].

Multi Criteria Analyses

A multi-criteria analyses (MCA) has been performed to compare the four alternatives of pump storage development, and the economic criterion is accepted as decisive in the selection of the alternative, see Table 4, Table 5 and Figure 9. The operation period considered in the analysis is 30 years [2].

Table 4. Comparing alternatives from an economic perspective [2].

Alternative	IRR (%)	NPV discount rate = 6% (M€)	NPV discount rate = 8% (M€)	NPV discount rate = 10% (M€)
PSH 200 MW	9.2	73.2	23.4	12
PSH 300 MW	8	58	-0.5	-42

Table 5. Characteristics of the 200 MW pumped storage hydropower system [2].

Fierza	No. of Units (-)	Speed (rpm)	Runner Outlet Diameter (m)	Turbine axis (m asl)	Rated discharge (m3/s)	Rated Capacity el (MW)	Max Discharge (m^3/s)	Max. Capacity el. (MW)
Altern. A1 2 x 100 MW	2	250	3450	129.1	Turbine Operation 107.9 Pump Operation 91	Turbine Operation 99.6 Pump Operation 110.5	Turbine Operation 126.5	Turbine Operatio n 113.5

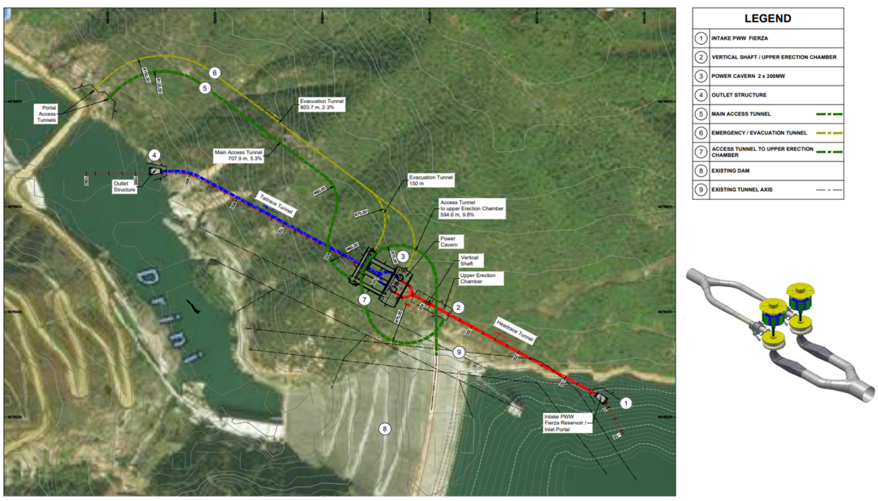

Figure 9. Layout of the hydropower pump storage system 200 MW

Increasing Safe Flood Management and Mitigating Climate Risk

The installation of a PSH system between the reservoirs of the Koman HPP - Fierza HPP will positively impact the increase of the hydrotechnical works safety and the mitigation of the negative effects of climate change. The need for increasing the discharge capacities at the Fierza HPP and the Koman HPP are evident. In situations where discharge from the Fierza HPP reservoir is required, the installation of the PSH system would result in an increase in the discharge from this reservoir (turbine regime) by about 182 m^3/s. Due to the large volume of the Fierza HPP reservoir and the complex hydraulic and topographic nature of the Koman HPP, there are increasingly frequent cases where the Fierza HPP reservoir has storage capacity, while water needs to be discharged from the Koman HPP. In such situations, the installation of the PSH system would improve safety and increase electricity production since a portion of the flow that would be discharged to the Koman HPP could be stored in the Fierza HPP reservoir. In fact, the benefit in this case would be threefold since the water flow, if discharged at the Koman HPP, this would cause the discharge of water flows from the "Vau i Dejes" HPP as well, so it would be a discharge without energy production. In the case where the flow is not discharged at the "Koman" HPP, but is stored at the "Fierzë" HPP, this would be used to produce electricity in all three HPPs of the cascade.

The following tables analyses the discharge data from the Koman HPP during 2022 [11], see Table 6 and Table 7.

Table 6. Discharge flow from the Koman HPP during 2022 [11].

Water discharges during 2022 at Koman HPP and HPP Vau i Dejës			
Date	HPP Fierza Discharges (m^3/s)	HPP Koman Discharges (m^3/s)	HPP V. Dejës Discharges (m^3/s)
19-Nov-22	0	81	139
20-Nov-22	0	1192	1389
21-Nov-22	0	842	1366
22-Nov-22	0	370	810
23-Nov-22	0	80	370
24-Nov-22	0	0	104
15-Dec-22	0	322	529
16-Dec-22	0	500	900
17-Dec-22	0	244	433

Table 7. Discharge flow from the Koman HPP during 2022 (With pumped storage scenario)

Water discharges during 2022 at the Koman HPP and the use of electricity from accumulated water (with a pump storage system)							
Date	HPP Fierza	HPP Koman	HPP V. Dejës	HPP Fierza	HPP Koman	HPP V. Dejës	PUMP STORAGE
	Discharges (m^3/s)	Discharges (m^3/s)	Discharges (m^3/s)	Energy produced by the volume of accumulated water (MWh)	Energy produced by the volume of accumulated water (MWh)	Energy produced by the volume of accumulated water (MWh)	Energy consumed by the pumped storage system (MWh)
19-Nov-22	0	0	58	1,767	1,600	810	2352
20-Nov-22	0	1010	1207	3,971	3,620	1,820	5304
21-Nov-22	0	660	1184	3,971	3,620	1,820	5304
22-Nov-22	0	188	628	3,971	3,620	1,820	5304
23-Nov-22	0	0		1,767	1,600	800	2352
24-Nov-22	0	0			-	-	0
15-Dec-22	0	140	347	3,971	3,620	1,820	5304
16-Dec-22	0	318	718	3,971	3,620	1,820	5304
17-Dec-22	0	62	251	3,971	3,620	1,820	5304
TOTAL				27,360	24,920	12,530	36,528
NETO							28,282

Using Cascade as a Battery Storage for the Integration of Renewable Energy Plants

The increase of electricity production from renewable energy plants can cause overproduction of energy at certain times. This is a problem that many countries that have developed this sector are facing. From the results so far and the investments that are in process for the construction of new plants from renewable sources, it results that such a situation is expected to occur in Albania as well. The pump storage system can be applied to realize the storage of electricity from these plants. In the time slots when there are overproduction and the price of electricity is very low; a part of this energy can be consumed by the pumping system by being stored in the form of hydraulic reserve. This amount of energy can be produced and then sold in the time slots when the price of electricity is higher.

Investment costs

The accurate assessment of investment costs requires the implementation of many detailed engineering studies, such as the geology of the area, detailed engineering design for civil works, equipment and machinery, etc.

Referring to similar projects and based on a preliminary assessment of the conditions of the project area, it can be estimated that the development costs of this project are around € 200 million, see Table 8 [2].

Table 6. Cost estimation for the PHS 200 MW alternative [2].

No.	Item	Cost (euro)
1	Upper Intake	4,000.000
2	Headrace Tunnel	6,211.000
3	Vertical Pressure shaft &Tunnel	17,209.900
4	Powerhouse Cavern	46,543.000
5	Tailrace Tunnel	13,155.500
6	EM Equipment	80,970.000
7	Contingency	27,202.000
	Total	195,292.000

Water Level Variation

Installing a fixed-speed pump storage system would reduce the range of water levels in the reservoir, especially in "Fierza" HPP. This would complicate the operation of this hydropower plant. Variable-speed pump storage system technically eliminates this limitation, but are more expensive in terms of costs. A more complex analysis is needed to make this assessment.

SUMMARY AND CONCLUSIONS

Based on the case study analyzed in this paper, the installation of a pumped-storage hydropower (PSH) system between the "Koman" and "Fierza" reservoirs emerges as a strategically beneficial investment for the Albanian power system. The assessment of technical, economic, and environmental factors indicates that the proposed project would deliver the following key impacts:

1. Technical aspect
    - Increasing the use of water flow rate for electricity production in the cascade;
    - Increasing the capacity to provide auxiliary services in the Albanian power system;
    - Increasing the production of electricity in the country and increasing the security of electricity supply in Albania;
    - Increasing the security of the Albanian power system.

2. The economic aspect
    - Creating a new business model for KESH sh.a;
    - Strengthening the positions of KESH sh.a in the energy sector in Albania and the region.
3. Environmental aspect
    - Increasing the safety of hydrotechnical works in the Drin River cascade;
    - Reducing the negative effects on the Drin River cascade as a result of climate change;
    - Reducing water discharges without electricity production.

Despite its clear benefits, the successful implementation of the proposed PSH project is technically complex and requires careful multidisciplinary assessment. To ensure its feasibility and long-term sustainability, the following studies are recommended:

- The development of detailed studies of the geology of the area where the project will be developed;
- The development of detailed topographic and bathymetric studies of the area where the project will be developed;
- The development of detailed engineering studies regarding sediments in the HPP reservoirs, especially in the Koman HPP reservoir in the area where water will be taken for pumping;
- The development of a detailed study regarding the developments of new projects from renewable energies in Albania in the coming years.

Overall, the proposed PSH scheme represents a robust strategic option for enhancing system flexibility, resilience, and sustainability in Albania's evolving energy sector.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interest associated with this publication.

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