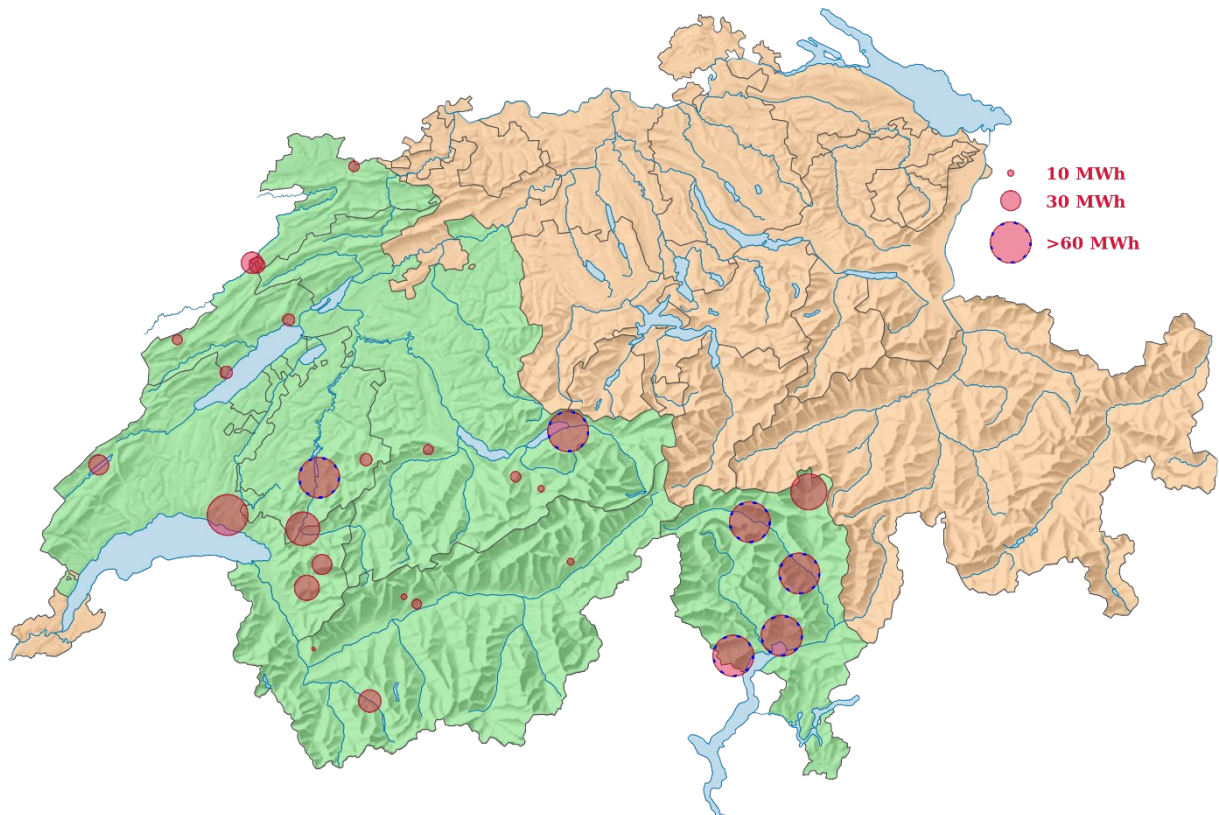




Final report from 7 November 2025

HiDeStor

Identification of hidden renewable and sustainable solution for decentralized electricity storage at the distribution grid level:
medium and small pumped storage hydropower plants



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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.





Summary

Pumped-storage hydropower is currently the most efficient and economical electricity storage solution, accounting for nearly 96% of global storage capacity. In Switzerland, 20 large facilities provide around 4,000 MW of installed capacity. With the expansion of photovoltaic generation and the growth of electric mobility, the ability to store surplus energy locally and release it quickly, at high power, in a renewable and sustainable way has become essential for grid stability. An analysis of distribution system operators' needs, conducted through interviews and a survey, identified a maximum storage requirement of 60 MWh. In this context, the HiDeStor project assessed the potential of small and medium pumped-storage plants, primarily using existing hydraulic infrastructure across seven cantons that cover about 50% of Switzerland's territory. A total of 27 sites were identified, representing a technical potential of 895 MWh when storage is limited to the identified needs, with a LCOS of 0.08 CHF/kWh. Finally, a national extrapolation based on a geospatial analysis of reservoirs, considering a maximum distance of 2 km between them, suggests a theoretical storage potential of approximately 1.7 GWh across Switzerland.

Zusammenfassung

Pumpspeicherkraftwerke stellen derzeit die effizienteste und wirtschaftlichste Lösung zur Stromspeicherung dar und machen rund 96 % der weltweiten Speicherkapazität aus. In der Schweiz verfügen 20 große Anlagen über eine installierte Leistung von etwa 4 000 MW. Mit dem Ausbau der Photovoltaik und der zunehmenden Elektromobilität wird die Fähigkeit, lokale Energieüberschüsse erneuerbar und nachhaltig zu speichern und anschließend schnell mit hoher Leistung bereitzustellen, zunehmend entscheidend für die Netzstabilität. Eine Analyse des Speicherbedarfs der VNB, basierend auf Interviews und einer Umfrage, zeigte einen maximalen Bedarf von 60 MWh. In diesem Zusammenhang untersuchte das Projekt HiDeStor das Potenzial kleiner und mittlerer Pumpspeicherkraftwerke, die hauptsächlich auf bestehender Wasserinfrastruktur in sieben Kantonen beruhen, welche rund 50 % des Schweizer Territoriums abdecken. Insgesamt wurden 27 Standorte identifiziert, mit einem technischen Potenzial von 895 MWh bei einer Begrenzung des Speichers gemäß dem ermittelten Bedarf und einem LCOS von 0,08 CHF/kWh. Abschließend zeigt eine nationale Extrapolation auf Basis einer georäumlichen Analyse der Reservoirs und unter Berücksichtigung einer maximalen Entfernung von 2 km ein theoretisches Speichervolumen von rund 1,7 GWh für die gesamte Schweiz.

Résumé

Le pompage-turbinage constitue aujourd'hui la solution de stockage d'électricité la plus efficace et la plus économique, représentant près de 96% de la capacité mondiale de stockage. En Suisse, 20 grandes installations totalisent une puissance installée d'environ 4 000 MW. Avec l'essor de la production photovoltaïque et le développement de la mobilité électrique, la capacité à stocker localement les excédents d'énergie puis à les restituer rapidement, à forte puissance, de manière renouvelable et durable, devient essentielle pour la stabilité du réseau. Une analyse des besoins des GRD, menée par interviews et questionnaire, a mis en évidence un besoin de stockage maximal de 60 MWh. Dans ce contexte, le projet HiDeStor a évalué le potentiel des petites et moyennes centrales de pompage-turbinage reposant principalement sur l'utilisation d'infrastructures hydrauliques existantes dans sept cantons couvrant environ 50% du territoire suisse. 27 sites ont ainsi été identifiés, représentant un potentiel technique de 895 MWh en limitant le stockage selon les besoins, pour un LCOS de 0,08 CHF/kWh. Enfin, une extrapolation nationale, basée sur l'analyse géospatiale des réservoirs et en considérant une distance maximale de 2 km entre ceux-ci, permet d'estimer un potentiel théorique d'environ 1,7 GWh pour l'ensemble du territoire suisse.



Main findings («Take-Home Messages»)

- Hidden potential for decentralized storage: The project identified a significant untapped potential for medium and small pumped storage hydropower plants (MS-PHS) using existing reservoirs of almost 1 GWh with 27 sites in seven Swiss cantons, that cover about half of the national territory.
- Contribution to the Swiss energy transition: MS-PHS enable local, renewable, and flexible electricity storage, supporting grid stability, solar and wind integration, and the goals of the Energy Strategy 2050 for secure winter supply.
- Economic and technical feasibility: Updated methods and cost analyses show that several MS-PHS configurations are economically competitive under current electricity market dynamics and ancillary-service mechanisms.
- Nationwide mapping through graph theory: A new graph-theory-based approach identified all possible pairs of existing reservoirs across Switzerland, optimizing either head or storage energy for distances up to 25 km - providing the first consistent national map of hidden pumped storage potential.



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List of abbreviations

Abbreviation	Meaning
AI	Artificial intelligence
aFFR	automatic Frequency Restoration Reserve (secondary frequency control)
AS	Ancillary Services
ASP	Ancillary Service Provider
BG	Balance Group
BGC	Balancing Group Coordinator
BGM	Balance Group Manager
BE	Bern Canton
BSP	Balancing Service Provider
CAPEX	Capital expenditure
CAES	Compressed air energy storage
COGENER	Comité Genevois pour l'utilisation du Fonds SIG NER = Geneva Committee for the use of the SIG NER Fund
DSO	Distribution System Operator
EM	Electromechanical
ENTSO-E	European Network of Transmission System Operators for Electricity
FCR	Frequency Containment Reserve (primary frequency control)
FR	Fribourg Canton
G	Generator
H&E	Hydro, mechanical and electrical
HiDeStor	Hidden storage potential using medium and small pumped storage hydropower plants
IEA	International Energy Agency
IHA	International Hydropower Association
JU	Jura Canton
LCOS	Levelized Cost Of Storage
LFC	Load frequency controller
M	Motor
mFRR	manual Frequency Restoration Reserve (tertiary frequency control)



MS PHS	Medium and small pumped hydropower storage
MV	Medium Voltage
NPSH	Net Positive Suction Head
NE	Neuchâtel Canton
NER	Nouvelles Energies Renouvelables = New Renewable Energies
NREL	National laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
OPEX	OPerating EXpenses
P	Pump
PV	Photovoltaics
PHS	Pumped Hydropower Storage
R	Reversible unit
RR	Replacement Reserve
SA	Synchronous area
SCCER	Swiss Competence Centre for Energy Research
SIG	Services Industriels de Genève = Geneva Industrial Services
SFOE	Swiss Federal Office of Energy
SFOEN	Swiss Federal Office for the Environment
SRL	Sekundärregelleistung = Secondary control power
StromVG	Federal Electricity Supply Act (Stromversorgungsgesetz)
StromVV	Federal Electricity Supply Regulation (Stromversorgungsverordnung)
T	Turbine
TCP	Technology Collaboration Program
TDH	Total dynamic head
TI	Canton of Ticino
TSO	Transmission system operator
VD	Vaud Canton
VS	Valais Canton
WP	Work Package



1 Introduction

Exploring hidden and untapped hydropower opportunities at existing infrastructure offers a promising approach to boost sustainable electricity supply. New power stations can be built at currently unpowered dams, environmental flow outlets, drinking and wastewater systems, ship locks, and irrigation canals. Additionally, existing plants can be upgraded or enhanced by implementing innovative or improved electrical and mechanical components [1]. In addition to electricity generation, hidden and untapped hydropower opportunities can also facilitate electricity storage. Pumped storage is the most efficient and cost-effective method for storing electricity globally, accounting for over 90% of the world's electricity storage capacity [2] [3]. Today, smaller-scale pumped storage is becoming an interesting storage solution, especially when at least one reservoir already exists. This latent potential can use existing reservoirs initially constructed for other purposes or even convert current hydropower plants equipped with turbines into pumped storage facilities. As decentralized solar power generation and electric mobility move forward, it is essential to locally store surplus electricity and quickly release it at high power, on a renewable and sustainable basis.

The objective of the so-called HiDeStor project, for Hidden storage potential using medium and small pumped storage hydropower plants, supported by the Swiss Federal Office for Energy (SFOE), was first to update an inventory of potential medium and small-sized pumped storage sites associated in seven Swiss cantons: Vaud, Valais, Fribourg, Bern, Neuchâtel, Jura and Ticino. Then the objective was to extrapolate the potential of the whole country.

1.1 Global situation

1.1.1. Current energy challenge

Many industrialised countries are facing major challenges linked to the energy transition of even energy revolution considering the changes that need to be made are of the same order than the one of the industrial revolution some centuries ago. The present energy crisis shows us the crucial importance for a country to ensure, as far as possible, an energetic independence to secure not only the energy supply, but also the medium to long term tariffs. In addition, the use of electricity will keep on increasing as our society relies more and more on electric systems (artificial intelligence, mobility, etc.).

Even if progresses must be made in energy conservation, additional needs will appear and new production must be developed, mainly by the integration of intermittent renewable energies as wind and solar PV, that will be in majority implemented at the distribution level. Ensuring the grid stability leads to the development of additional storage capacity, among which one of the most efficient and reliable solution is the pumped storage. If large schemes have been developed to ensure weekly to seasonal storage, there is a strong interest to have storages facilities at the medium voltage grid to answer daily or possibly weekly variations and ensuring the grid stability. By doing that, high voltage transport grid and large storage capacities will be preserved.

1.1.2. Storage solutions worldwide

In front of the current energy challenge, traditional solutions such as pumped hydro storage (PHS) to cutting-edge technologies such as lithium-ion batteries and emerging concepts like hydrogen storage and advanced flywheels, the field of energy storage is expanding and diversifying. These solutions not only enhance the resilience and stability of our energy grids but also play a pivotal role in reducing greenhouse gas emissions, combating climate change, and paving the way for a more sustainable and environmentally friendly energy future.

Nowadays, pumped storage is still by far the largest-capacity form of grid energy storage available, and, as of 2020, accounts for around 95% of all active storage installations worldwide [4].

According to IHA [5] in 2024, the global PSH capacity accounts to 189 GW, while the total hydropower installed capacity reached 1 443 GW. In Europe, the PSH capacity accounts to 56 GW, while the total hydropower installed capacity reached 263 GW.



This technology has one of the lowest LCOS (Levelized Cost of Storage) for short term storage, 0,1 €/kWh [2], with a quite high CAPEX, a small OPEX and a very long lifetime compared to other technologies. Regarding recent technologies, Li-ion battery dominates the electro-chemical energy storage market thanks to its high efficiency, high power and energy density but with a still high LCOS, 0,3 €/kWh, compared to PHS. Compressed air energy storage (CAES) is also a promising and innovative technology with a LCOS similar to PHS, with a long lifetime but a relatively low efficiency (41% - 75%) [6]. The economic analysis led through the HiDeStor project is also based on the LCOS calculation (cf. chapter 2.2.9)

Considering the life cycle assessment of energy storage solutions, PHS is one of the top candidates ([3], [7]), as presented in Figure 1. In case of using existing reservoirs, this footprint could be even smaller for medium or small PHS.

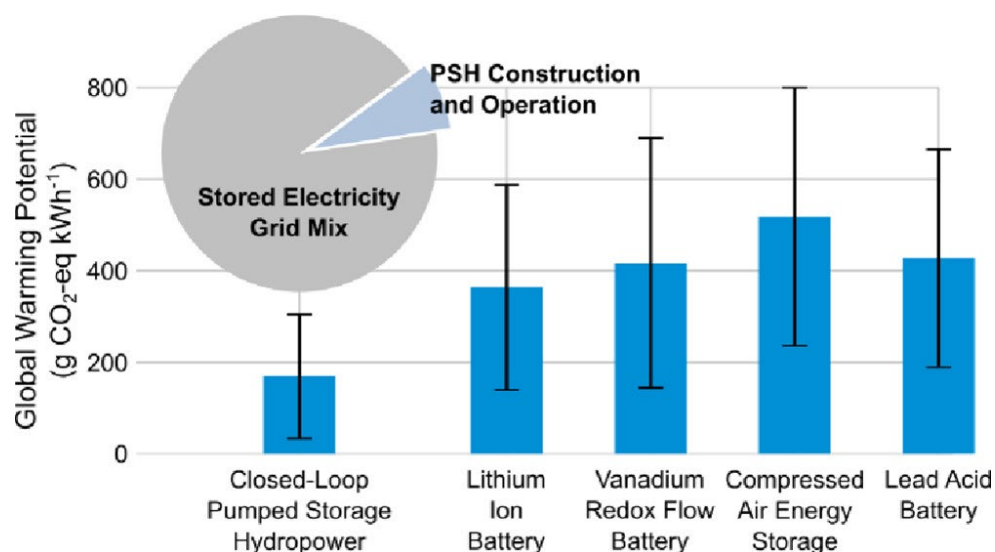


Figure 1 : Global Warming Potential of different kinds of storage solutions [3]

1.1.3. Medium and small pumped hydropower storage (MS PHS) in the world

Developing medium or small PHS using existing reservoirs is one of the strategies to increase low-impact energy storage capacities. In the USA, a PHS production capacity of 22.9 GW is already installed. Recent studies revealed the potential of “closed loop” project based on existing reservoirs such as abandoned mines, caverns, or other storage reservoirs [8]. In this context, NREL has developed an interactive map with geospatial data showing closed-loop pumped storage hydropower [9]. This tool was inspired by a previous study from the Australian National University [10]. They have set up a method to identify potential sites for off-river PHS using GIS algorithms [11] with defined search criteria, allowing to reveal 616 000 potential sites around the world. Of course, this theoretical potential must be refined considering technical, environmental and economic criteria. However, the results of this study must be treated with caution for Europe, particularly given the density of construction in the areas under consideration.

In Europe, a study performed in 2013, also considered connection between existing reservoirs to develop the potential of PHS [12]. They identified a European theoretical potential of 54 TWh (11.4 TWh in the EU) considering a maximum distance of 20 km between existing reservoirs. Considering environmental restrictions, a potential of 29 TWh in Europe (of which 4 TWh in the EU) was assessed. In another study performed in 2024 [13], for EU, the estimated theoretical storage capacity (approximated by the product of storage volume and head) for PHS is 6.3 TWh, while emphasising the cost-effectiveness of interconnecting existing reservoirs, using of abandoned mines, modernising and increasing the storage capacity of existing PHS.



1.1.4. Pumped storage in Switzerland

The world's first pumped storage power plant was built in 1882 in Switzerland (in Zurich) with an installed capacity of 515 kW. Since then, 20 large pumped storage schemes have been built in the country with an installed power capacity of 3 600 MW, among them Nant-de-Drance, the greatest one with 900 MW, commissioned in 2022.

Previous studies on the interest of developing smaller installation have been completed. They are described in chapter 1.2, as most of them were achieved by the same project partners as the present HiDeStor project.

1.2 HiDeStor project partners

The project partners have a wide experience in medium and small hydro power projects and specific knowledge linked to medium and small pumped storage, as described below.

In 2014, HES-SO Valais/Wallis performed a feasibility study on the site of Arbaz (VS), making the demonstration that this storage solution can have a significant impact on the local grid to facilitate the integration of intermittent renewables energies [14].

Between 2013 and 2016, Mhylab was one of the key partners of the SunHydro project, which goal was to improve the integration of intermittent renewable energies at the distribution grid level. To reach this goal, these energies were associated to a pumped storage plant to create a virtual power plant managed by an algorithm in function of the meteorological forecasts, the renewable electricity production and the electricity market prices for the energy and the services. Several potential sites were identified, leading to the feasibility study for two of them. Due to the market condition before 2022, there was unfortunately no further developments.

Thanks to a SIG-COGENER funding (2015-2017) [15], HES-SO Valais/Wallis and Mhylab made a first analysis of decentralized pumped storage possibilities in the range of 1 to 10 MW for 2 to 6 hours at the level of the distribution system operators (DSO) for the Swiss Cantons of Vaud and Valais. Interviews were made with DSO to identify their needs and interests considering the electricity market prevailing in 2016. Technical solutions were assessed to find the most suitable equipment for such applications. About thirty sites allowing storage of minimum 1 MWh were identified, for an installed capacity of minimum 1 MW for the two cantons. The preliminary study of 10 sites had allowed to detail the offered possibilities for a potential storage of about 180 MWh and a capacity of about 35 MW.

Due to the electricity market level before 2022, none of these projects was developed. Considering the market changes, the present HiDeStor project updates this previous study (in the work package WP3).

In the framework of the SCCER Furies, HES-SO Valais/Wallis has developed a tool to size a new small or medium pumped storage power plant and assess a first estimation of the costs based on existing statistics of already built projects.

Finally, Mhylab has led the Small Hydro Mobility project, funded by SFOE, which goal was to link small hydropower plants and e-mobility. After a first phase dedicated to the market conditions and site identification for the whole Switzerland, the second phase focused on three possible pilot sites, while the third one was devoted to dissemination. Even if not directly linked to energy storage, this project gave the opportunity to gather highly useful information regarding the e-mobility market and its important impact on electricity generation and storage, specifically at the DSO level.

The methodologies developed for these five projects and the acquired experience are examples of key factors for the success of the HiDeStor project.

1.3 Project objectives and work packages

HiDeStor project aims at facilitating the development of decentralised pumped storage capacities. The main key lies in the use of existing infrastructures as for instance existing reservoir built for other



purposes than electricity generation (irrigation, artificial snow, etc.). Indeed, this will reduce the investment cost but also improve the acceptance by the population and limit the environmental impact.

HiDeStor project has four main goals:

- **Identify stakeholder needs** — including DSO, local utilities, and public services — in terms of power, energy, pump/turbine cycles, grid constraints, and other relevant factors, to calibrate the site identification process effectively.
- **Update the existing inventories** for the cantons of Vaud and Valais (originally developed between 2015 and 2017 [15]), considering evolving needs and current market conditions.
- **Extend the assessment** to identify similar opportunities in the cantons of Bern, Fribourg, Jura, Neuchâtel, and Ticino, using the updated methodology.
- **Extrapolate the findings** to a national scale, recognizing that the detailed assessment will cover approximately 50% of Switzerland's territory and include all major geographic regions (Jura, Plateau, and Alps).

The project is structured in five WP, as presented in the Figure 2.

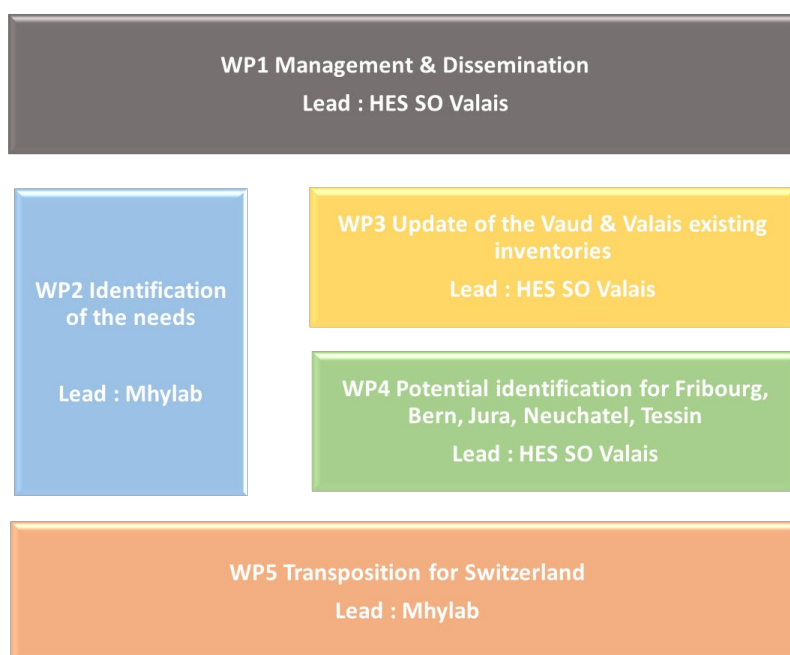


Figure 2 : Structure of the HiDeStor project

WP1 – Management and Dissemination: This work package ensures effective coordination of the project and facilitates the dissemination of results. Regular meetings are organized between the project partners to monitor progress and maintain smooth communication. Dissemination activities include the creation of a new IEA working group on “Hidden Hydro Opportunities,” the publication of a White Paper outlining the main development challenges and recommendations, as well as the submission of articles to scientific and professional journals. The project’s results are also presented at the international Hydro Conferences in 2023, 2024 and 2025 (cf. conference proceeding listed in chapter 5), with support provided for a Swiss exhibition booth (except in 2025), and other event or conferences.

WP2 – Identification of Needs: This work package focuses on identifying the technical and operational needs for small and medium-scale energy storage systems. Key stakeholders across seven cantons are identified, and structured interviews are conducted to understand their expectations in terms of power, storage capacity, operational cycles, grid constraints, and mobility-related demands. The insights gathered allows the revision of the site selection criteria originally used in 2015–2017 [15]. Possible



remuneration mechanisms, such as those linked to ancillary services, are also explored to support future economic evaluations.

WP3 – Update of Inventories for Vaud and Valais: This work package updates the inventories of potential pumped storage sites in Vaud and Valais using revised criteria based on current needs and market conditions. A refined methodology is applied to identify, assess, and rank relevant sites. Technical pre-dimensioning includes estimations of storage capacity, penstock layouts, and equipment specifications. Preliminary economic assessments are performed using key indicators such as capital costs, financial and operational expenses, and applicable remuneration schemes. The updated inventories strengthen the methodology before expanding it to additional cantons.

WP4 – Site Assessment in Five Additional Cantons: The validated methodology is then applied to the cantons of Fribourg, Bern, Jura, Neuchâtel, and Ticino. For each canton, infrastructure inventories are completed, suitable sites are identified and sized, and economic viability is assessed. The results are compiled into detailed maps highlighting the selected sites.

WP5 – National Transposition and Potential Estimation: In the final work package, the results from the seven analysed cantons are used to guide a broader assessment across Switzerland. Instead of extrapolating on general criteria, the method focuses on identifying existing reservoirs in the remaining cantons and pairing them based on defined constraints, such as maximum allowable distance and usable storage volume. This approach allows the identification of potential pumped storage pairs using real infrastructure data. The process provides a consistent and practical estimate of the national potential for MS PHS, while also highlighting the geographical distribution and feasibility of such solutions across the country.

2 Approach, method, results and discussion

2.1 Identification of the needs (WP2)

The increase of electricity production from renewable sources such as solar and wind, makes energy generation forecasts more difficult. At the same time, the global digitalization of society combined with the growing popularity of electric vehicles and heat pumps, lead, not only to a greater demand but also to a shift of peak demands for electricity. In this context, the work of transmission system operators (TSO), who oversee maintaining the electrical grid frequency at a stable level, becomes increasingly challenging. Therefore, new sources to increase flexibility in production and storage are required to ensure and control the grid balance. MS PHS could be part of the solution playing an important role in intraday storage. Of course, its energy capacity is lower than large plants, but MS PHS is easier and quicker to implement (especially for existing infrastructure, such as existing reservoirs) and has less inertia.

To clarify the potential role a MS PHS can play in this context, an identification is carried out to understand the needs of stakeholders acting at transmission grid level. Indeed, this understanding is crucial to find out how a MS PHS can be integrated.

2.1.1. Identification of the stakeholders

2.1.1.1. Swiss electric grid

In order to determine how a MS PHS can be integrated in the present and future electricity context in Switzerland, it is essential to understand the mechanisms that govern the operation and market of the grid. The following analysis is based on references [16], [17], [18], [19], [20] and [21].

In Switzerland, the conditions for a secure energy supply as well as for a competitive electricity market are regulated by the Federal Electricity Supply Act (Stromversorgungsgesetz, “StromVG”) and the Federal Electricity Supply Regulation (Stromversorgungsverordnung, “StromVV”). The StromVV specifies



the technical and economic rules governed by the StromVG for the participants in the Swiss energy markets. Thus, the StromVG and the StromVV form the basis for the market contracts which the transmission system operator (TSO) concludes with other parties.

Switzerland is also part of the European interconnected grid and is connected to neighbouring countries via 41 electrical transmission cross-border lines.

With the Swiss market liberalisation at the beginning of 2009, Swissgrid took the role of Transmission System Operator (TSO) of Switzerland and is therefore the owner of the Swiss transmission grid. It is in charge of maintenance, upgrades and appropriate expansions of the extra-high-voltage grid level (380 and 220 kV), see Figure 3, and for ensuring that the grid is always available.

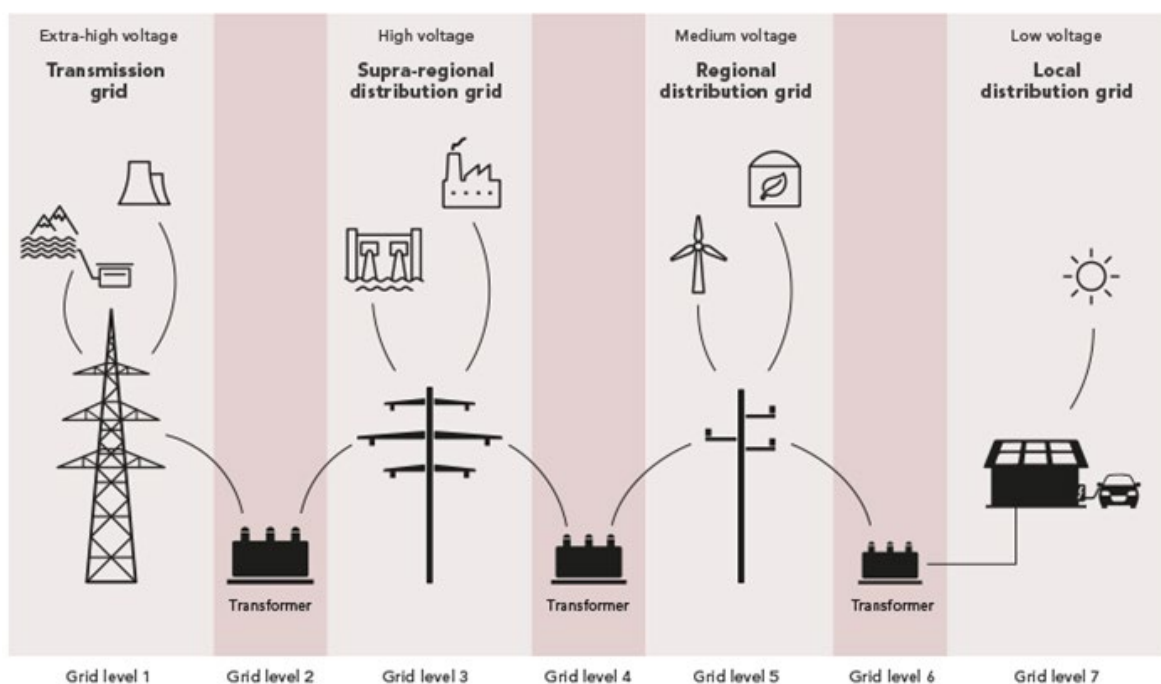


Figure 3 : Grid levels [22]

Moreover, Swissgrid plays the role of Balancing Group Coordinator (BGC) being responsible to ensure a balance between electricity generation and consumption in Switzerland at any times. This equilibrium ensures the secure and stable operation of the grid at a constant frequency of 50 Hz. To this scope, Swissgrid collaborates with other European TSO to ensure that this frequency can be maintained in the entire European interconnected grid.

The Swiss territory consists mainly of one scheduling area equal to the whole Swiss control block. To compensate for unforeseen fluctuations between the injection and withdrawal of electrical energy on the grid, Swissgrid can activate the control energy. This means that power plants prequalified for this service, will increase or reduce the power output at short notice based on a Swissgrid signal.

In the market of energy control, Swissgrid collaborates with other European countries which creates a large market and establishes the conditions to allow power plants operators, including PHS, and aggregators to prequalify for this market.

The control energy is composed of various Ancillary Services (AS) products, defined as services provided by grid operators to customers in addition to the transmission and distribution of electrical energy. To ensure secure operation of the system, Swissgrid organizes the following ancillary services as part of its legal obligations:



- Frequency control (primary, secondary and tertiary control)
- Voltage support
- Compensation for active power losses
- Black start and island operation capability
- System coordination
- Operational measurement

For the purposes of this study, only the first four services are presented below. It should be noted that, due to the massive increase of variable renewable energy production and the consequent rise in the need for flexible and controllable supply from low carbon sources, ancillary services with their remuneration mechanism are constantly evolving, both in Switzerland and in Europe.

2.1.1.2. Frequency control (primary, secondary and tertiary control)

The frequency control is achieved by using a three-stage control procedure as illustrated in the example of Figure 4 : primary control is activated directly after the accident in the entire synchronous area 1 (SA). After 30 seconds, secondary control power is automatically called up, which is replaced by tertiary control after no more than 15 minutes.

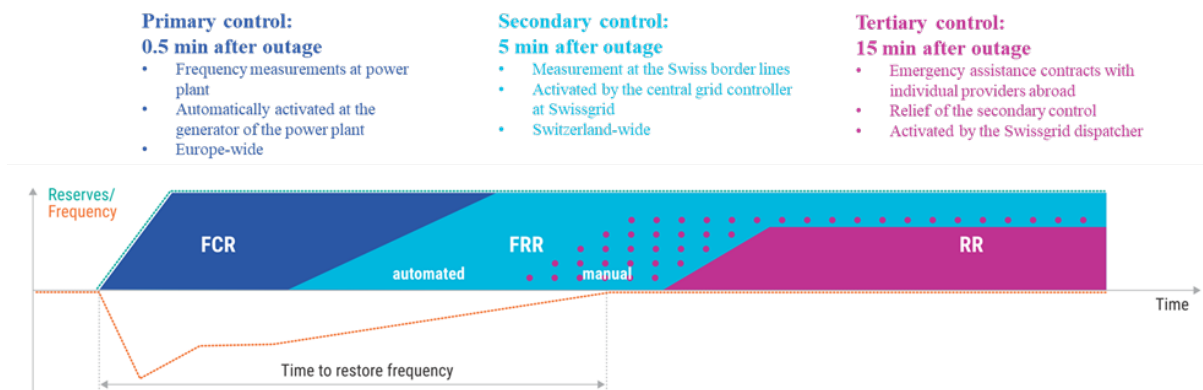


Figure 4 : Example of power plant outage with load-frequency control process [16] [20].

Primary frequency control, also known as Frequency Containment Reserve (FCR), is the first activated reserve. It aims to contain system frequency within permissible limit values after the occurrence of an active power imbalance. The procurement of the primary control power required for Switzerland is achieved by a combined auction between Belgium, Denmark, Germany, France, Netherlands, Austria, and Switzerland. A predefined amount of primary control power capacity must be kept in reserve at any times and is adjusted annually in November in accordance with the requirements of ENTSO-E, the European Network of Transmission System Operators for Electricity - an association representing 40 electricity TSO from 36 countries across Europe - (in Switzerland this is always approximately 70 MW with a frequency deviation of ± 200 mHz).

Secondary frequency control, also known as automatic Frequency Restoration Reserve (aFRR), is an automatic process aiming to restore the system frequency back to its set point value and to maintain the desired energy exchange of a control area with the rest of the SA. A central grid controller automatically activates secondary reserve. As a prerequisite, these power stations must be in operation but must not

¹ In 2019 and 2020, primary control energy was procured in cooperation with the following countries: Austria, Belgium, Germany, France, the Netherlands, Slovenia and Denmark [20].



be generating the maximum or minimum possible nominal capacity to meet the requirements of the central load frequency controller (LFC) at any times. Secondary control is activated after a few seconds and is typically completed after 15 minutes. If the cause of the control deviation is not eliminated after 15 minutes, secondary control gives way to tertiary frequency control.

Tertiary frequency control, in Switzerland, is a combination of manual Frequency Restoration Reserve (mFRR) and Replacement Reserve (RR). It is used to replace the secondary control reserve to restore a sufficient secondary control band. The Swissgrid dispatcher activates this reserve by sending special electronically transmitted messages to the providers, who must then intervene in power plant production to ensure the supply of tertiary control power within a maximum of 30 min, depending on the product.

For all the previous services, every provider who wishes to participate in the tenders must first meet the prequalification criteria. Prequalification consists in an examination of the technical and operational requirements of the supplier and his plants, to ensure his capability to provide the services offered. After the prequalification is accepted, the provider becomes a Balancing Service Provider (BSP) and standard contracts can be concluded for the respective product (ancillary services). After conclusion of the contract, BSP can submit bids in response to Swissgrid invitations to tender.

2.1.1.3. Voltage support

The voltage at a grid node can be affected by the exchange of reactive power. The voltage at a grid node is raised by feeding in reactive power; the intake of reactive power reduces the voltage. Swissgrid specifies reference voltages for the feed-in and withdrawal points for generation units and distribution grid operators in the transmission grid. The controlled exchange of reactive power allows the voltage at the feed-in point to be brought to the specified reference voltage.

Active participation in voltage support is mandatory for all operating power plants directly connected to the transmission grid. Distribution grids and end customers have to participate in the voltage support at a semi-active level. However, they can prequalify for active voltage support. The provision of reactive energy is contractually regulated in the company agreements. For the time being, no invitation to tender is planned. The replaced reactive energy is remunerated via a fixed tariff in addition to a uniform fee for participants. For mandatory voltage support, power plants have the option of participating in the supra-mandatory voltage support. Specific standard contracts regulate the provision of reactive power capacity.

In addition to the remunerated reactive energy, specific remuneration is defined per start and operating hour for each power plant.

2.1.1.4. Compensation of active power losses

For physical reasons, any transport of electricity using a grid leads to losses, i.e. less energy can be withdrawn in comparison to what is injected into the grid. These active power losses are proportional to the transported energy and amount to between 1% and 7% of the transmitted energy. Primary thermal energy is emitted due to resistance in electrical lines or other grid-connected electrical equipment. The longer the transport line and the lower the voltage, the higher the active power losses. The active power losses for the metrologically separate transmission grid can be determined by the difference between all measured feed-ins and withdrawals. Swissgrid is responsible for procuring active energy on the electricity market to compensate for transmission losses on the extra-high voltage grid. The average active power losses in the Swiss transmission grid amount to approx. 110 MW (with a range between approx. 60 and 200 MW). Nevertheless, the TSO (Swissgrid) does not have the infrastructure to supply this active energy. Calls for tenders are scheduled yearly, quarterly, and monthly. Bids are accepted for each 1 MW delivery.



2.1.1.5. Black start and island operation capability

Black-start-enabled power stations ensure the restoration of the grid after major incidents. Special operational sequences and procedures are applied to coordinate the restoration of voltage to the grid. This necessitates a certain number of appropriately equipped power stations with the necessary auxiliary installations, which switch themselves on to the grid in the appropriate operational sequence at the grid operator's request and, in so doing, help to restore the grid. A power plant is capable of black start if it can go from idle to operational without requiring the injection of grid-connected electricity. A power plant can operate in isolation (island operation capability) if it can achieve and maintain a certain operating level without requiring activation of the outgoing lines to the synchronous grid. Four build-up cells have been defined for the «Black Start and Island Operation Capability» ancillary service for Switzerland. Each build-up cell must be able to independently initiate grid restoration measures. The ancillary services are provided by Swissgrid via an invitation to tender.

2.1.1.6. Pricing mechanisms merit order

For some time, energy products for secondary and tertiary control reserve, as well as balance energy, are governed by the pay-as-cleared mechanism (see Figure 5). This means that all proposed offers will be paid at the price of the most expensive one.

This mechanism is also known as "merit order mechanism". Starting with the technologies with the lowest bids or variable costs, higher-cost power plants are activated until demand is met. The last bid to win an auction determines the electricity price (market clearing price) [22].

The merit order curve changes from half an hour to the next. Depending on the level of demand and the availability/production of power plants during that half-hour, or the variable costs of the technologies used, the market clearing price changes.

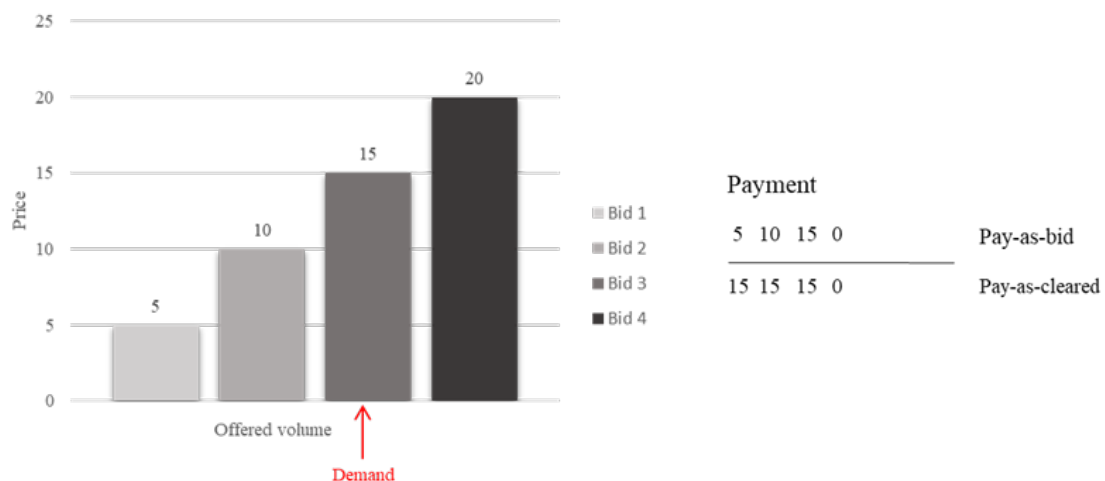


Figure 5 : Pay-as-cleared mechanism [23]

2.1.1.7. Balancing groups concept

The following description is based on reference [17]. As previously mentioned, Swissgrid plays the role of Balancing Group Coordinator, with the important task of providing and operating the grid so that generation and consumption are in equilibrium at any times. This is done using Balance Groups (BG), which must be balanced using a scheduling system also provided for this purpose. All the process of balancing is regulated by the Federal Electricity Supply Act (Stromversorgungsgesetz, StromVG). The relationship and the role of the various stakeholders in the electricity market in Switzerland is shown in Figure 6.

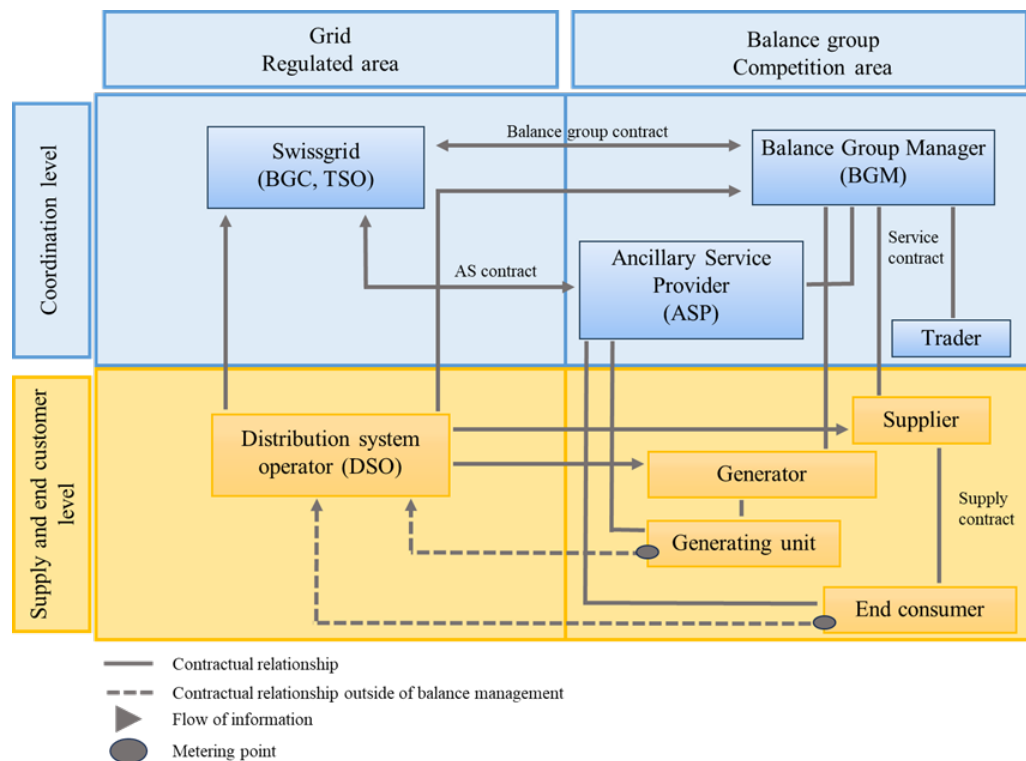


Figure 6 : Key roles and their fundamental contractual relationships within the scope of balance management [17]

The exploitation and maintenance of high, medium and low voltage distribution grid is under the responsibility of the Distribution System Operators (DSO). Within the balance concept, DSO have the responsibility of providing the necessary data for the **Balance Group Manager (BGM)**, Swissgrid, suppliers and generators. In addition, they manage the assignment of the metering points to the balance groups, Ancillary Services Providers (ASP), suppliers and generators. DSO could also act directly via a group as BG.

Balancing groups (BG) are virtual energy volume accounts that allow electricity market stakeholders to balance their actual feed-in and offtake within a control area by means of energy exchanges. The balancing is based on the schedule management that consists of power values per time interval representing the amount of energy to be exchanged between the balance groups within the Swiss scheduling area or with foreign stakeholders. A balance group is managed by a BGM. Switzerland has only one control block, but the number of BG is not limited. The unavoidable differences between forecast and actual consumption within the balance groups with assigned metering points are balanced by Swissgrid (TSO) which charges the BG for the balance energy costs.

To mitigate the risk, BG are interested to contain a diverse portfolio of both volatile and flexibly controllable electricity producers and consumers. However, this is never enough and the use of PHS could balance the energy.

The responsible for ASP, or **Balancing Service Provider (BSP)**, provides ancillary services to the TSO for the imbalance settlement. Ancillary service providers can be generating units or end consumers. A distinction is made between conventional generating units, that refers to bigger power plants connected to the transmission grid found in one location, and virtual generating unit, that refers to groups of smaller power plants of usually different technology types that can also be in different geographical locations. A virtual generating unit with not only power plants belonging to the same balancing group but also with power plants that are part of other balancing groups is called **pooling**.



Traders buy and sell energy from stakeholders. Their energy trading transactions are processed with the help of schedules. Traders are often also BGMs so they can process their business autonomously. Smaller retailers can form balance groups via service contracts to safeguard the processing of their business.

A **Generator** operates one or more generation units and inject energy into the grid via injection points. It must assign each of its injection points to precisely one supplier, which is assigned to a balance group. The responsible DSO performs this assignment based on the information provided by the generator.

If generators operate a larger power plant fleet, they are often also BGMs and traders to ensure they can optimally market the generated energy.

Generating units inject electricity into the grid via injection points. Generating units (injection points) must be assigned to precisely one supplier, which is assigned to a balance group. This is a prerequisite for marketing the generated energy. The responsible DSO performs this assignment based on the information provided by the generator.

Suppliers supply energy to end consumers with which they have concluded an open contract.

2.1.2. Stakeholders' interviews

A MS PHS can theoretically play on all the ancillary services markets mentioned in the previous chapter, but as seen below, some are more interesting and more suitable.

To clarify the interests and opportunities offered by MS PHS within this context, the applied methodology consisted in interviewing stakeholders acting at transmission grid level, especially Distribution System Operators (DSO), balance group managers, and control pool managers, about the following topics:

- Understand the needs of the distribution grid to facilitate and improve the integration of new renewable energies and new consumers with high power demands,
- Identify situations in which small-scale pumped storage may be of interest,
- Define the expected size of small and medium-sized electrical storage (power, energy, cycles) to determine site selection criteria for the HiDeStor project,
- Identify and evaluate possible remuneration mechanisms for such infrastructures and services.

The first approach is to interview in-person (or by conference calls) fourteen stakeholders in the cantons of Vaud, Valais, Fribourg and Ticino. This methodology ensured that the needs of the interviews are properly understood.

Most often, a stakeholder has several roles, which complicates our task of identifying needs. For example, a DSO is generally also a supplier and can own production assets. It is also usually part of a balancing group. Lastly, it is sometimes active on market, with trading activities and providing ancillary services.

It is, therefore, particularly important to consult DSOs to understand their flexibility requirements as a result of present and future developments in the energy market. It is also important to identify the various role of the stakeholder interviewed because these roles drive the need of flexibility. So, in the same company, various people, depending on the department in which they work, may have different needs and therefore different answers to the survey. Insofar as possible, several people were consulted, but they do not always represent all the roles carried out by the company. It is therefore important to have a human rather than a purely statistical analysis of the answers of the survey. We also noted that depending on the function of the people involved they did not necessarily have the same interpretation of certain questions. After a few interviews, we planned an analysis stage to modify and clarify the wording of some questions as well as adding/deleting certain themes to improve the assessment of the need. The final version of the long questionnaire is presented in Appendix 6.2.



Secondly, to increase the number of answers, following these initial interviews, a short online questionnaire (cf. Appendix 6.3) is prepared in 4 languages and submitted to almost all Swiss DSO. Forty-six answers are received in total, covering all regions of Switzerland as shown in Figure 7. In 2024 there were 586 active network operators [23].

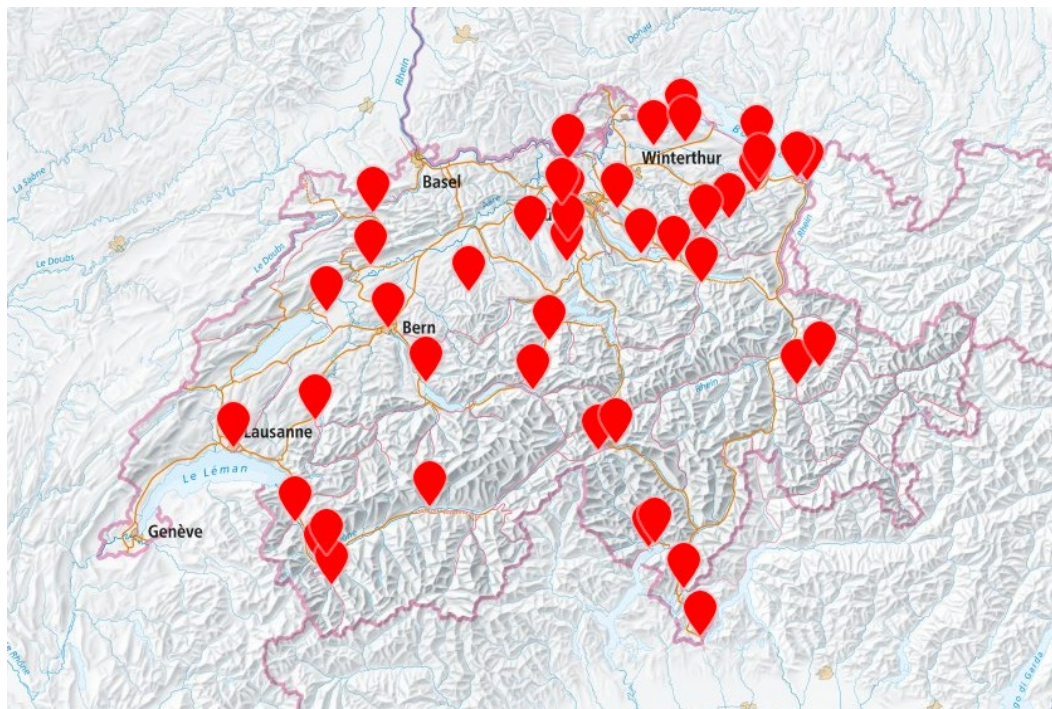


Figure 7 : Breakdown of answers to the short online questionnaire.

Most participants to the short questionnaire (63%) expect a significant change in the load curve of their network in the future, due to the intermittency of new renewable energies and the shift in peak demand (photovoltaic production, mobility electrification and heat pumps), see Figure 8.

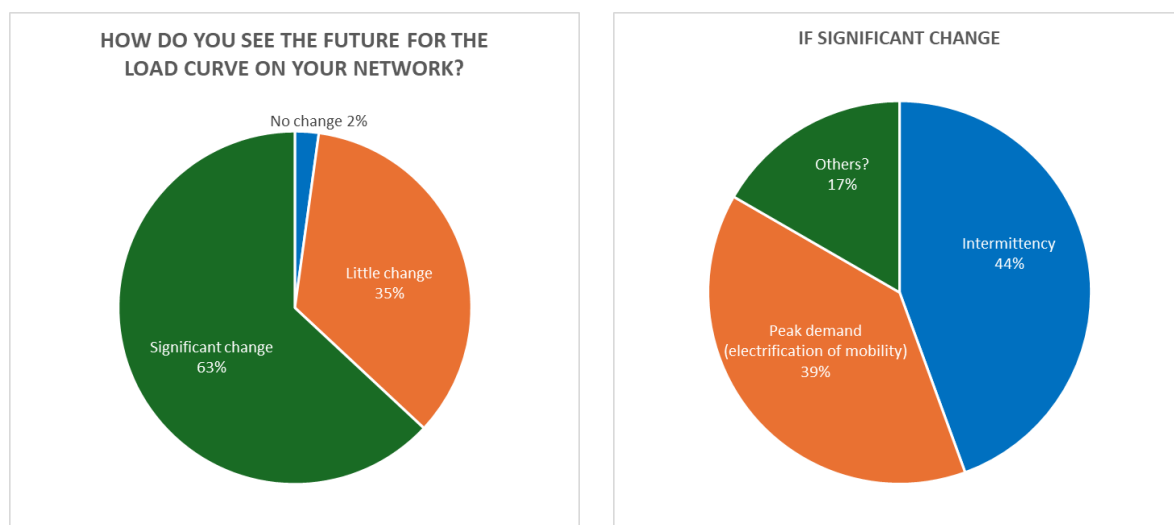


Figure 8 : Future trend of the network load curve revealed by the short online questionnaire.

To cope with these changes, three main solutions are considered: modification of the network, limitation of maximum injectable power and addition of storage resources.



As for the in-person interviews, online answers highlight the interest in the MS PHS technology for short-term energy storage. The merged results of the in-person interviews and online questionnaire are presented in Figure 9.

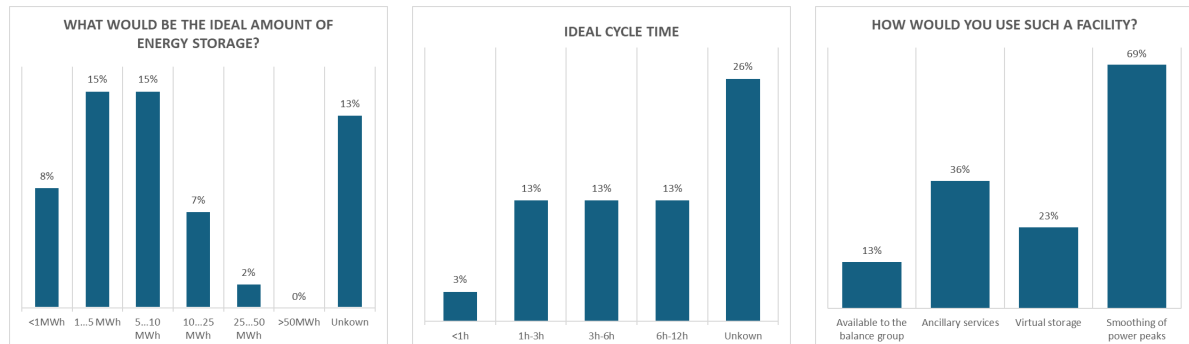


Figure 9 : Overview of the analysis of the interviews²

Finally, based on the different answers, the HiDeStor project sets, a minimal electrical output of 5 MW for both turbine and pump mode, enabling the MS PHS to compete on its own in the SA market, up to 10 MW. **The cycle duration is preferably between 3 and 6 hours, with the possibility of being shorter for 5 MW (for very interesting sites), or longer for 10 MW (for sites with great potential).**

2.1.3.Economic outlook

2.1.3.1. Energy price fluctuations

To evaluate the potential benefits of a MS PHS, an analysis using the Day-Ahead electricity price is performed for two different countries: Switzerland and Spain. Spain was selected as a potential situation for Switzerland in a few years, once the expected energy transition will be implemented with an electricity mix including mainly PV and Hydro. The Day-Ahead electricity price for Switzerland for the last ten years is shown in Figure 10 (left). A yearly variation of the electricity price is visible before the year 2020 and the effect of COVID and more significantly the consequences of the war in Ukraine impacted the electricity price. After 2022, shown in Figure 10 (right), the vertiginous fluctuations stopped but the mean electricity price remained at a higher level compared to the 2010s years. Therefore, to present the most realistic figure, the analysis used exclusively the data for the years 2023 and 2024. The yearly data for Spain showed the same pattern and is thus not shown.

² Note: some totals exceed 100% because some respondents ticked more than one box.

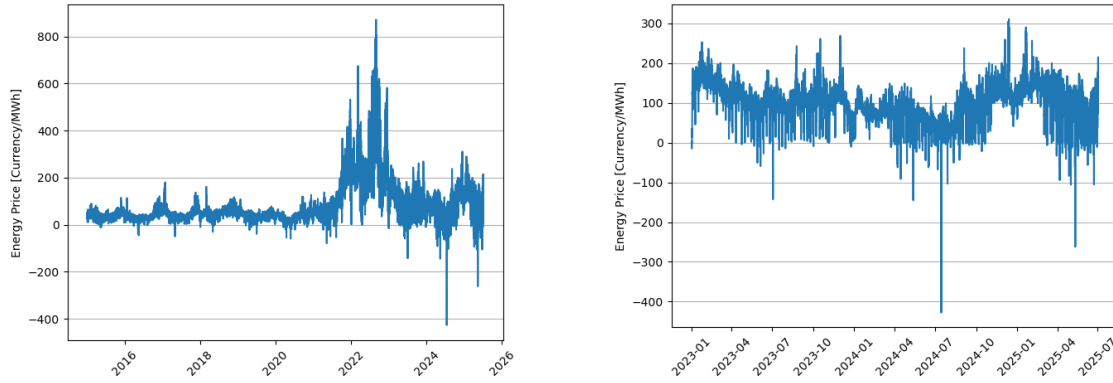


Figure 10 : Day-Ahead electricity price in Switzerland. (left) periods 2015-June 2025. (right) 2023-June 2025.

To establish the typical pattern of the Day-Ahead electricity price, the Swiss and Spanish data were weekly averaged, and the trends are shown in Figure 11 (left). It can easily be seen that there are daily variations but also a difference between the working days and the weekend days. Therefore, a daily trend is extracted for the two different periods and Figure 11 (centre) shows the daily trend obtained from Monday to Friday and Figure 11 (right) the daily trend for Saturday to Sunday. For both periods, we can observe two minimums and two maximums offering the possibility to carry out two cycles per day using a MS PHS. However, the morning cycle during the weekend is ignored as the variation in the electricity price is too low.

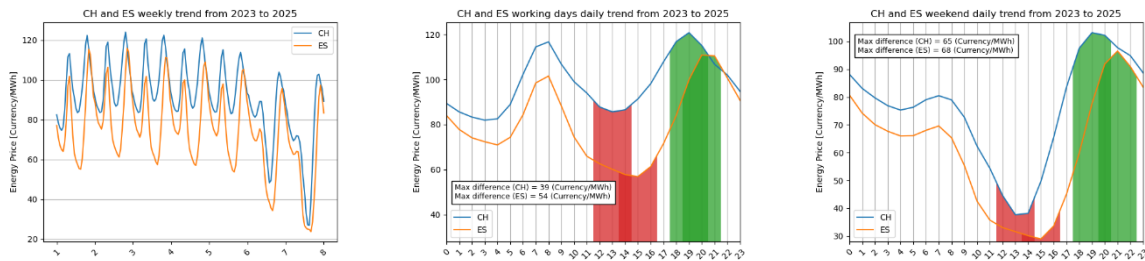


Figure 11 : 2023-2024 Day-Ahead electricity price in Switzerland (CH) and Spain (ES). (left) weekly trend with the number 1 representing Monday. (centre) working days daily trend. (right) weekend daily trend. The red zones show the periods when the MS PHS is in pumping mode and the green zones when it is in generating mode for one cycle.

2.1.3.2. Economic model

To quantify the gain of a MS PHS and to demonstrate if there is an economic potential, a basic model is built using exclusively the Day-Ahead price. The evaluation of a gain based on ancillary services is excluded, as such an evaluation requires a thorough analysis on the future electricity market which is out of the scope of the present research. Following the daily trend of the Day-Ahead electricity price obtained previously (Figure 11), the model used the Day-Head price and blindly turbine and pump water at a given time, see Table 1, independently of the price.

Table 1 : Times expressed in local time when the pump or the turbine is operated. P: pump, T: turbine

Period	Cycles	CH	ES
Working Days	Cycle #1	P: 3h, T: 19h	P: 15h, T: 20h
	Cycle #2	P: 13h, T: 8h	P: 4h, T: 8h
Weekend	Cycle #1	P: 13h, T: 19h	P: 15h, T: 21h



Furthermore, two virtual hydropower plants were defined by identical pump and turbine powers: one hydropower plant with an installed capacity of 5 MW and another one with 10 MW. It is assumed that the reservoirs are sufficiently big to operate the 5 MW hydropower plant for 3 hours and the 10 MW hydropower plant for 2 hours. Finally, an efficiency of 70% for the entire hydropower plant (piping loss, generator heat loss, ...) was selected. At this preliminary stage, this efficiency is applied to the generating mode by reducing the turbine power to 3.5 MW and 7 MW, thus generating less energy.

Table 2 and Table 3 provide the overall results for operating these virtual hydropower plants following the given time of operation listed in Table 1. To explain the role of the row "Loss", Figure 12 and Figure 13 show the monthly distribution of the pump cost, the turbine gain and the resulting revenue during the years of 2023 and 2024. The case of Switzerland, Figure 12, shows that operating the hydropower plant in winter is not lucrative. Therefore, when the row "Loss" has "with" in a column, it means that these not lucrative months are included, whereas in columns "without", negative total revenue is excluded.

Over these two considered years, we can see that only one scenario generated loss, i.e. 2 in Switzerland when operating a hydropower plant with 2 cycles per day, a power 5 MW and a duration of 3 hours. However, these numbers should be taken carefully, because for example, when negative price occurred, these instants were used to pump and, therefore, earn money. However, these results show that taken an efficiency of 70% and the most basic model, it is possible to get a revenue due to the daily fluctuating energy price.

Table 2 : 2023-2024 cost balance in Switzerland

Cycle per day	1				2			
Pump power (MW)	5		10		5		10	
Duration (h)	3		2		3		2	
Loss	with	without	with	without	with	without	with	without
Turbine gain (kEUR)	854	454	1'154	830	1'462	773	1'977	1'048
Pump cost (kEUR)	783	370	1'030	696	1'469	686	1'936	900
Saving (kEUR)	71	84	124	134	-7	86	42	148

Table 3 : 2023-2024 cost balance in Spain

Cycle per day	1				2			
Pump power (MW)	5		10		5		10	
Duration (h)	3		2		3		2	
Loss	with	without	with	without	with	without	with	without
Turbine gain (kEUR)	776	776	1'056	1'056	1'291	1'057	1'759	1'759
Pump cost (kEUR)	569	569	743	743	1'146	912	1'503	1'503
Saving (kEUR)	207	207	312	312	145	145	256	256

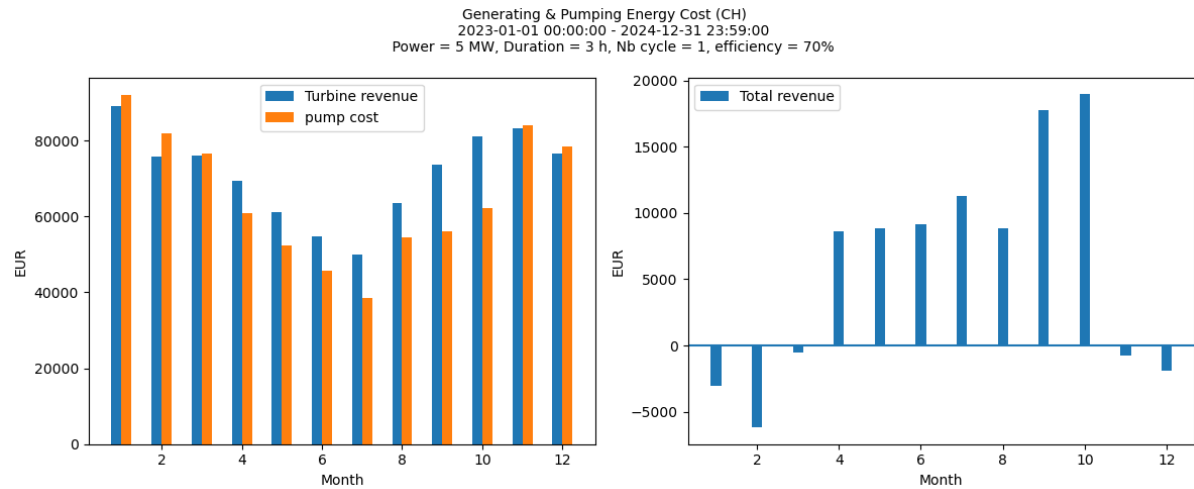


Figure 12 : Monthly distribution of the pump cost and turbine gain in Switzerland during the years 2023 and 2024 (left). Monthly total revenue (right)

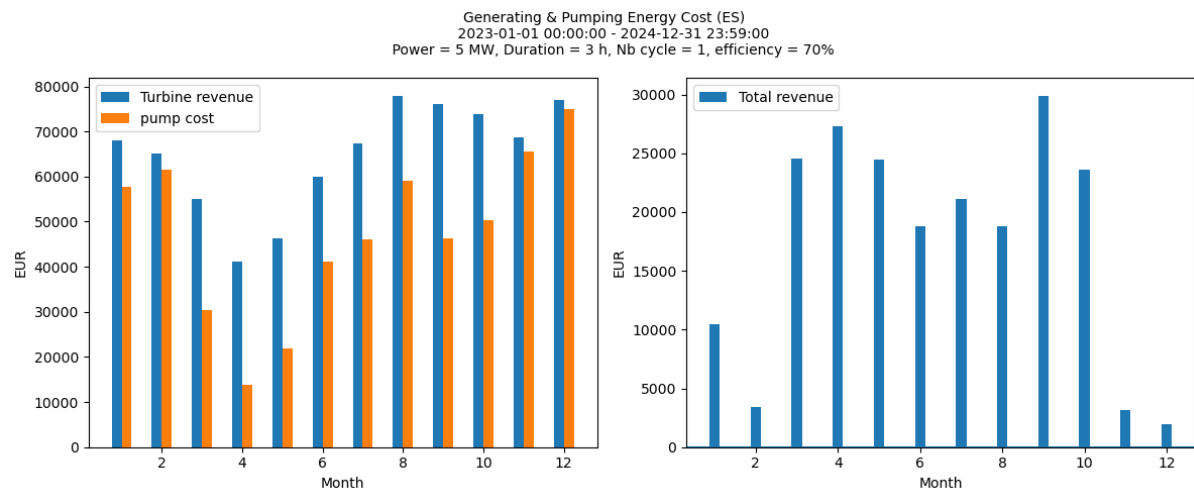


Figure 13 : Monthly distribution of the pump cost and turbine gain in Spain during the years 2023 and 2024 (left). Monthly total revenue (right)

2.1.4. Ancillary systems

Participation in the control energy market must meet the criteria imposed by the national TSO.

Secondary control products are identified as follows:

- $\pm$ SRL: Secondary control power
- $\pm$ SRE: Secondary control energy

To provide secondary control, the minimum output is set to ± 5 MW (asymmetrical bands) for a 15-minute time slot. The tender period is of one week, meaning that, during this period, power stations must be in operation but must not be generating the maximum or minimum possible nominal capacity in order to meet the requirements of the central load frequency controller at all times [34]. The activation delay of the secondary frequency control must not exceed 30 seconds, with full activation in about 5 min.

Tertiary control products are identified as follows:

- mFRR: Standard manual Frequency Restoration Reserve product
- TRE: National tertiary control energy product – local and specific product



- RR: Standard Replacement Reserve product
- RR_TRE_mFRR, RR_TRE, TRE_mFRR: Combination of tertiary energy products

To provide tertiary control reserve, the minimum output is set to ± 5 MW (asymmetrical bands). The tender period is daily.

Within the mFRR products, the full activation time is set to a maximum of 12.5 min and has a minimum delivery period of 15 min. Concerning the RR products, the full activation time is set between 12.5 min and 30 min, and the delivery period varies between 15 min, 30 min and 60 min depending on the products.

Powerplants participating in this market will be paid separately for the procured secondary control power and for the energy supply. Separate tenders are organized for the supply of power and energy.

First of all, power provision is put out to tender on a weekly basis for the secondary control, and weekly and daily basis for the tertiary control. Secondly, control energy is put out to tender. All bidders who receive a contract in the power tendering process, must submit an energy bid.

For the supply of secondary energy, the delivery period is of 15 minutes. The tender procedure closes 25 min before delivery time.

Since some of the above criteria cannot be met by a small power plants or assets, they can be aggregated in a control pool to form a “virtual power plant” and offer their combined power as part of the tendering process [18]. The benefits of participating as an PHS in these control pools would probably be significant under certain specific conditions, notably where infrastructures already exist (reservoirs, turbine powerplant, piping, etc).

The market of the ancillary services is still evolving. New products will probably be introduced in the future and some of the existing ones may be modified.

For example, Swissgrid is already planning to introduce a daily product for daily power provision.

As previously explained, Swissgrid determines the required reserve capacity on aFRR and mFRR based on historical records and dimensioning incidents and procures balancing capacity in an auction mechanism. It is important to notice that not all the available balancing energy is activated.

The trend identified between 2020 and 2022, where an important rise of all the secondary (aFRR) and tertiary (mFRR and RR) products is observed, seems to have stopped, and in 2023 come back down to the level of 2022 (see Figure 14). On average, prices remain relatively high with the upward products of about 160 €/MW, confirming that participating in these markets could be an important source of revenue for a MS PHS. The trend identified before 2021 when upward tertiary reserves were better paid than downward ones, seems to be confirmed in 2022 and 2023, which means a reduction of the pump mode profitably.

Prequalification is usually carried out by means of a real-time test procedure with Swissgrid. For power plants belonging to a control pooling, simplified test procedures are often achieved if the responsible of the control pool has already been prequalified for SDL. The complete procedure is presented in the document [35]. The list of the prequalified bidders for ancillary services in Switzerland is presented in Appendix 6.1.

The analysis of the technical prerequisites of the Swissgrid prequalification procedure does not show any blocking point for the implementation of the various services by a PHS. Small PHS are smaller and have small inertia which allow quick response and power variation, etc.

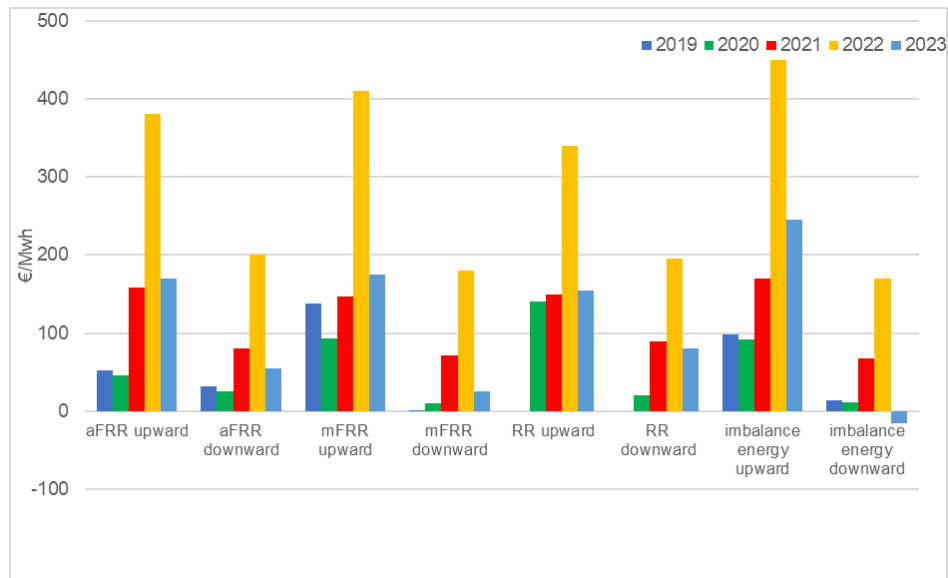


Figure 14 : Balance and imbalance prices (energy and capacity) in Switzerland (EUR/MWh)
(Data from [19], [20], [37] and [38])

2.1.5. Supply of balancing energy

Concerning the energy balance within a balance group, the general and standard process is as follows: schedule management during the day-ahead, possible adjustments during the current day (intraday energy exchanges), and on the working day after the next, energy exchanges in the post scheduling [34]. In this context, it is possible to imagine that a small or medium PHS can help balancing the group schedule in “real time”. The energy delivered by the PHS must be high enough to compensate for the imbalance and the power must be high enough to produce this energy in a small interval before the end of the scheduling. The imbalance depends on the size of the balance group but for larger group several PHS could be aggregated. It is not yet clear how this could be implemented and of course what could be the value for the PHS services, but a study presented in 2021 [36] has shown how this type of balancing could be realized.

As for ancillary service, the price of energy balance for BGM varies widely from day to day and the prices will probably continue to change as the market evolves. So, the PHS must be able to offer several services to the grid and be very flexible to provide and adapt them to the market evolutions.

Technically, the balancing mechanism is activated and controlled by the balance group according to its estimation of the imbalance. For control reserves, the signal is sent from the TSO. In both cases, this requires fast and reliable lines of communication and electro-mechanical equipment capable of quick power variation.

Reference to Figure 14, the cost of energy balancing for Group Balancing is interesting and could be decreased by the integration of a small PHS in the portfolio. Nevertheless, post scheduling adjustment process and trading energy between other groups or inside a subgroup limit the quantity of balancing energy which could be delivered by the PHS. The duration of activation is also reduced unlike, for example, the secondary reserve which is activated and therefore remunerated for an entire week. It is not necessary, but it is better if the turbine or pump is stopped before the balancing mechanism is activated, as this provides more power and capacity, but does not allow acting on ancillary or power market.

2.1.6. Virtual storage power plant

A final interesting application for a MS PHS is its ability to absorb exceeding photovoltaic production (PV), expressed by the concept of virtual storage energy. PV installation produces a much greater amount of electricity during the sunny hours in summer. A MS PHS could therefore be used to store water during peak solar production and produce electricity during evening consumption.



Figure 10 (right) shows the hourly electricity price trend for the period 2023-2025 June in Switzerland. It is important to note how the spot price falls close to 0 €/MWh, or even below, due to the high fed-in from photovoltaic systems. These periods of very low prices or even negative prices could be profitable for pumping. On the other hand, price peaks occur when thermal power plants are required to compensate for the lack of PV production, e.g. before dawn and after sunset.

In addition to an interest in the different uses stakeholders might have in a MS PHS, a correlated objective of the interviews was to define the MS PHS specifications (power, energy, reservoirs size and cycles).

Based on the different answers, the following considerations were made. Energy storage capacity seems to be clearly identified as between 1 to 10 MWh, contrary to cycle time.

The different uses of a MS PHS identified and exposed in this chapter mainly show the importance of having a flexible asset to deal with high price volatility and power demand. Then, it appears that the real interest of stakeholders for a MS PHS will depend on the investment costs and the remuneration provided by various services to the grid. An optimisation could probably be achieved to find the best compromise, but the profitability assessment of a MS PHS is not obvious since the market structure is not yet ready for long-term forecasts, as presented in [21]. Thus, probably the best option for a MS PHS is to be able to provide a large spectrum of services to the grid as the profitability of each one will vary during the depreciation period of the asset, which is long for hydropower and MS PHS projects.



2.2 Methodology to assess the hidden storage potential

The following subsections present the methodology applied to assess the hidden storage potential.

2.2.1. Theoretical, technical and economic potentials

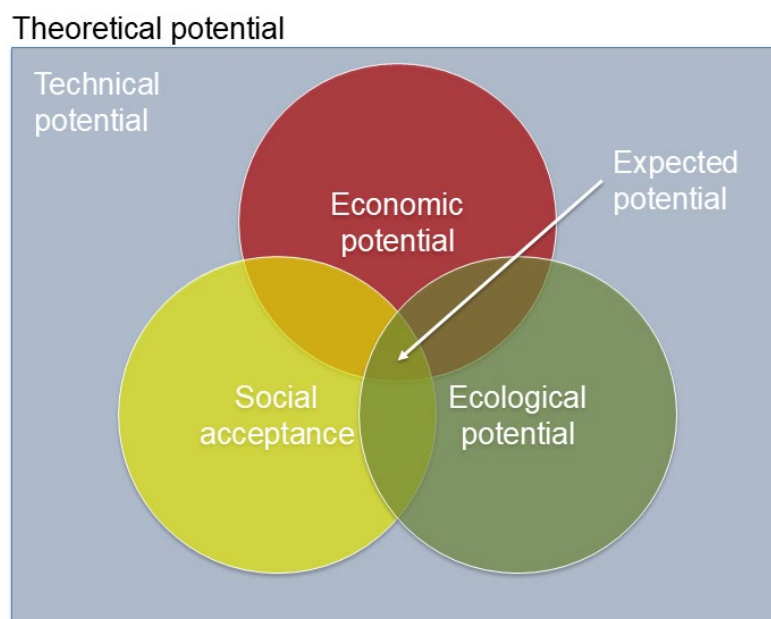


Figure 15 : Different types of potentials (base: [25])

The following definitions are taken from the Energy Outlook 2035 document [25] and used by SFOE in reports in 2012 [26] and 2019 [27] :

1. **Theoretical potential** refers to the total physical supply of an energy agent in the area under study, without considering the actual restrictions involved in its use.
2. **Technical potential** is the proportion of theoretical potential that can be used considering the given technical restrictions. As technical potential depends on technological developments, it changes over time.
3. **Expected potential** is the proportion of technical potential that meets the "ecological", "economic" and "socially accepted" criteria:
 - The potential is **"economic"** if the total costs of converting energy from one source are within the same range as the costs of competing systems. Determining the economic potential depends on assumptions and variable influencing parameters (e.g. interest rates, amortization period, price trends, etc.).
 - The potential is **"ecological"** if its exploitation does not lead to any lasting and irreversible additional damage to biotopes in terms of diversity and interactions between living beings and between living beings and their environment.
 - The **social acceptance** criterion considers the positive or negative attitude, not based on economic or ecological criteria, that individuals or groups have towards a given energy agent (e.g. protection of the landscape).

The **"expected potential"** considers the restrictions and obstacles likely to hinder the development of electricity generation from renewable energy sources. For this reason, in the report on the potential of renewable energies achieved in 2012 by SFOE, the concept of 'expected potential' was used to describe the future potential of electricity generation from renewable energies.



Then, the IEA TCP Hydropower Task XVI on Hidden and Untapped Hydropower Opportunities led by Switzerland defines the concept of Hidden and Untapped Hydropower Opportunities on existing infrastructures (HUHO) with the objective to develop “hidden” or “untapped” hydropower. This involves exploiting existing infrastructures that either do not yet produce and store electricity or those with resources and operations that can be upgraded or modified to increase capacity, generation, and storage.

The HiDeStor project considers these three potential definitions: theoretical potential > technical potential > economic potential, which means that the project does not consider the ecological potential nor the socially expected potential for which conditions can change. Thus, the identified hidden storage potential in this project is not the “expected potential”.

2.2.2.Site selection

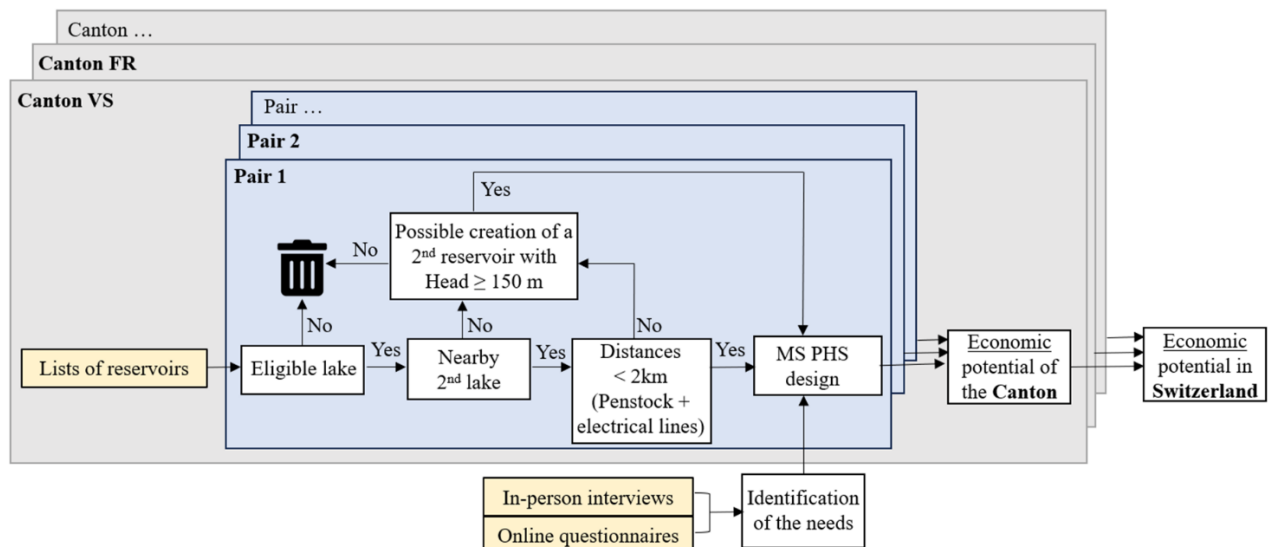


Figure 16 : Methodology for site selection to define the economic potential for a canton and then for Switzerland

To estimate the hidden-storage potential, the HiDeStor project focuses on existing infrastructures, such as reservoirs built for purposes other than power generation, including irrigation, drinking water, artificial snowmaking, flood protection and natural lakes. Thus, this project does not include:

- rivers (white water) as reservoirs, except for Geneva Lake and the Doubs River
- potential from melting glaciers
- the capacity increase of existing pumped storage power plants (e.g. by raising dams or changing equipment).

Therefore, the study focuses first on developments involving two existing reservoirs. It then considers sites where a reservoir could be created.

By cross-referencing data from different lists of structures (list of lakes, list of storage facilities supervised at federal or cantonal levels), an initial list of potential lakes in the various Cantons is drawn up.

The lakes are then paired to create a classic pattern for a pumped storage power plant. Then selection criteria are applied to minimize investment cost:

- Length of the penstock between the two lakes < 2 km (except for important potential, as for sites VS2, BE1, FR2, FR3 and VD1),
- Length between the potential power station and the nearest medium-voltage grid < 2 km (except for huge potential).



If, for a canton, there is only one pair of existing lakes or even no pair at all, the analysis considers the creation of second reservoirs. Two criteria are defined on an iterative process while studying the potential sites:

- a minimal head of 150 m between the existing reservoir and the new one
- a maximal volume of the new reservoir of 50'000 m³.

The volume of the new reservoir cannot, however, be used at 100% and a margin of 10 % is imposed. Indeed, a minimal water level must remain to prevent air to get into the penstock. Therefore, the maximal available storage volume of new reservoirs is 45'000 m³. To set bases to compare the different sites, the new reservoir is defined by a deepness of 10 meters and a square surface. The methodology presented is summarised in Figure 16.

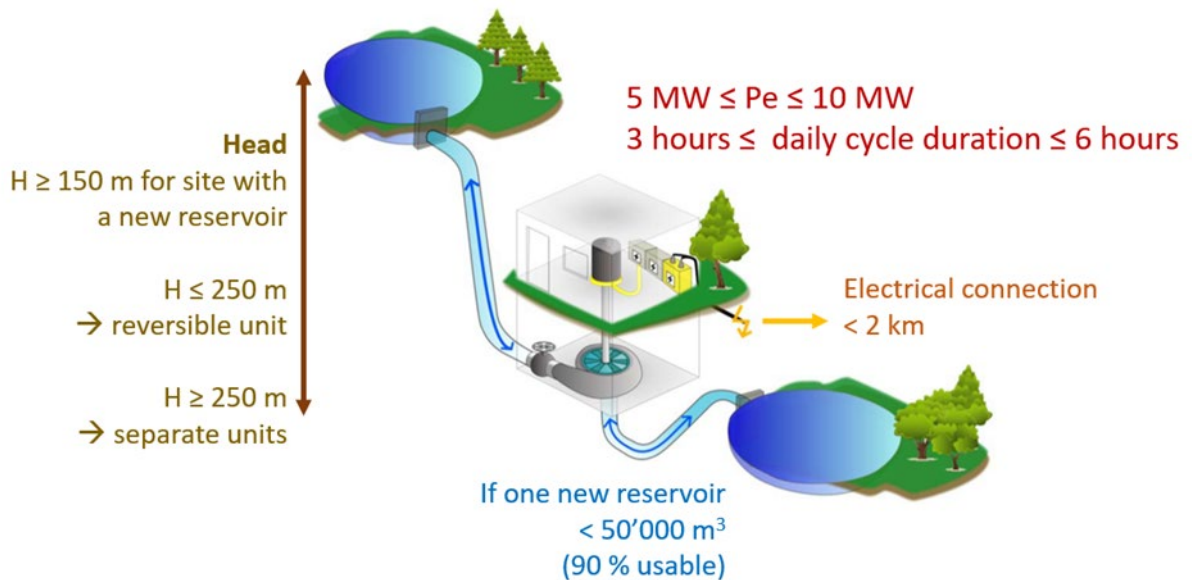


Figure 17 : Summary of the parameters applied for the potential study

2.2.3. Energy definition of the selected sites (theoretical potential)

Once the pairs of reservoirs are selected, the pumped storage station is energetically defined. The design of the MS PHS is based on the definition of electrical output and cycle time.

As a conclusion of the interviews described in chapter 2.1.2, the electrical output has to be between 5 and 10 MW, while the cycle duration is between 3 and 6 hours (the turbine and the pump cycles do not have the same duration). But, for very interesting sites, there is still the possibility:

- of a smaller capacity if the reservoirs already exist and present an economic potential (as for VS4 with an electrical capacity of 2.0 MW – cf. chapter 2.4.4)
- of a shorter cycle for 5 MW sites (as for VS3, VS5 and BE4)
- of a longer cycle for 10 MW sites (as for BE1).

The present methodology considers **the same electrical output for the turbine and the pump**. But as the net heads and the efficiencies are different, the nominal turbine discharge is higher than the pump discharge.

The electrical output of the turbine is calculated using the following expression:

$$P_{eT} = 10^{-6} \rho g Q \eta(Q) H(Q) \quad [\text{MW}]$$



Where	P_{eT} = nominal electrical output of the turbine (between 5 and 10)	[MW]
	ρ = water specific weight, 997	[kg/m ³]
	g = acceleration due to gravity, here 9.804	[m/s ²]
	Q = nominal discharge of the turbine	[m ³ /s]
	η = overall unit efficiency at nominal point of the H&E group for the turbine	[-]
	H = gross head	[m]

The electrical output of the pump is calculated using the following expression:

$$P_{eP} = 10^{-6} \rho g Q H(Q) / \eta(Q) \quad [\text{MW}]$$

Where	P_{eP} = nominal electrical output of the pump (between 5 and 10)	[MW]
	Q = nominal discharge of the pump	[m ³ /s]
	η = overall unit efficiency at nominal point of the H&E group for the pump	[-]

The electrical energy is calculated using the following expression:

$$E_e = P_e \Delta t \quad [\text{MWh/day}]$$

Where	E_e = electrical energy: electricity production or consumption per day	[MWh/day]
	P_e = nominal electrical output of the turbine or the pump	[MW]
	Δt = turbine or pump cycle duration: between 3 and 6	[h/day]

The gross head is estimated from the altitudes of the reservoir indicated, most of the time, on the federal geoportal, geo.admin.ch, or on the different collected lists. No investigations are achieved to detail the definition of these levels.

The unit discharge is defined from an iterative process, starting from the minimal volume of the reservoirs pair and considering the cycle duration and an electrical output between 5 and 10 MW.

The overall unit efficiency of the turbine or the pump at nominal point is calculated with the following definition:

$$\eta = \eta_c \eta_m \eta_e$$

Where	η_c = penstock efficiency at nominal point	[-]
	η_m = mechanical efficiency at nominal point for the turbine or the pump	[-]
	η_e = electrical efficiency at nominal point of the generator or the motor	[-]

Table 4 presents the different efficiencies considered to calculate the electrical output of the turbines and the pumps.



Table 4 : Theoretical efficiencies considered for the HiDeStor project (at nominal point)

Efficiencies	Values
Minimal penstock efficiency, $\eta_{c \min}$	95 %
Mechanical efficiency of the turbine, η_{mT}	90 %
Mechanical efficiency of the pump, η_{mP}	86 %
Generator and motor efficiency, η_e	97 %
Total efficiency of the turbine H&E group, η_T	87.3 %
Total efficiency of the pump H&E group, η_P	83.4 %

The sites which do not respect a cycle variation between 3 and 6 hours are: VS3 (2-3 hours), FR1 (6-9 hours) and BE1 (10 to 15 hours).

To speed up the process and work with a common decision process for all sites, the methodology is based on a decision support shown in Figure 18. The preliminary power plant energy potential is then defined as the intersection between the site potential and the sizing criteria.

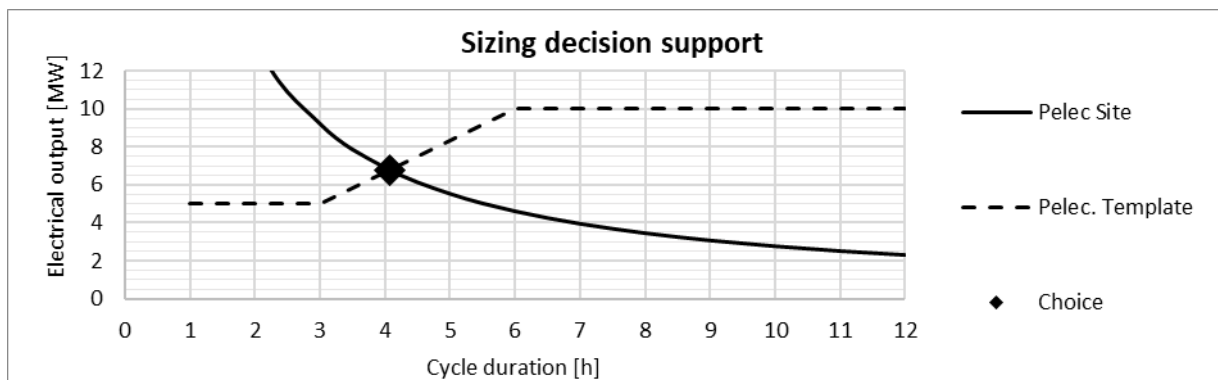


Figure 18 : Example of the decision-making support for defining power and cycle duration of each site

2.2.4. Penstock definition for the selected sites

Regarding the new penstock between the two reservoirs, its route is estimated as realistic as possible following the existing roads. Indeed, its length (measured directly using the tool available on the federal geoportal), thus below 2 km, is considered in the head loss calculation, to define the maximal penstock diameter to respect the minimal penstock efficiency.

Then from the nominal net heads of the turbine and the pump, the characteristics of the turbine and pump processes can be updated.

The length and the diameter of the penstock are then used in the cost estimations.

Each new penstock is equipped with a security valve, as presented in Figure 23, defined as a butterfly valve.

2.2.5. H&E equipment definition of the selected sites (technical potential)

After the definition of the theoretical potential, starts the choice of equipment. As presented on the Figure 19, there are three kinds of pumped storage units if the machines are considered:

- The reversible unit (or binary unit), with only one machine which can work as a turbine and as a pump (while the generator is also a motor)



- The tertiary unit, with a turbine and a pump set on the same shaft, then with only one generator/motor
- The quaternary unit or separate units, with the turbine and its own generator and the pump and its own motor.

For large scale installations, the most compact layout and, therefore, by far the most used, is the binary or reversible unit (currently with variable speed). On the other hand, the quaternary group is generally the most expensive layout in terms of electromechanical equipment and is virtually no longer used in recent large hydropower plants.

Yet, the HiDeStor project, as far as possible, given the needs of the power grid, aims to maximize machines flexibility, while remaining within standard products for the sake of cost-effectiveness.

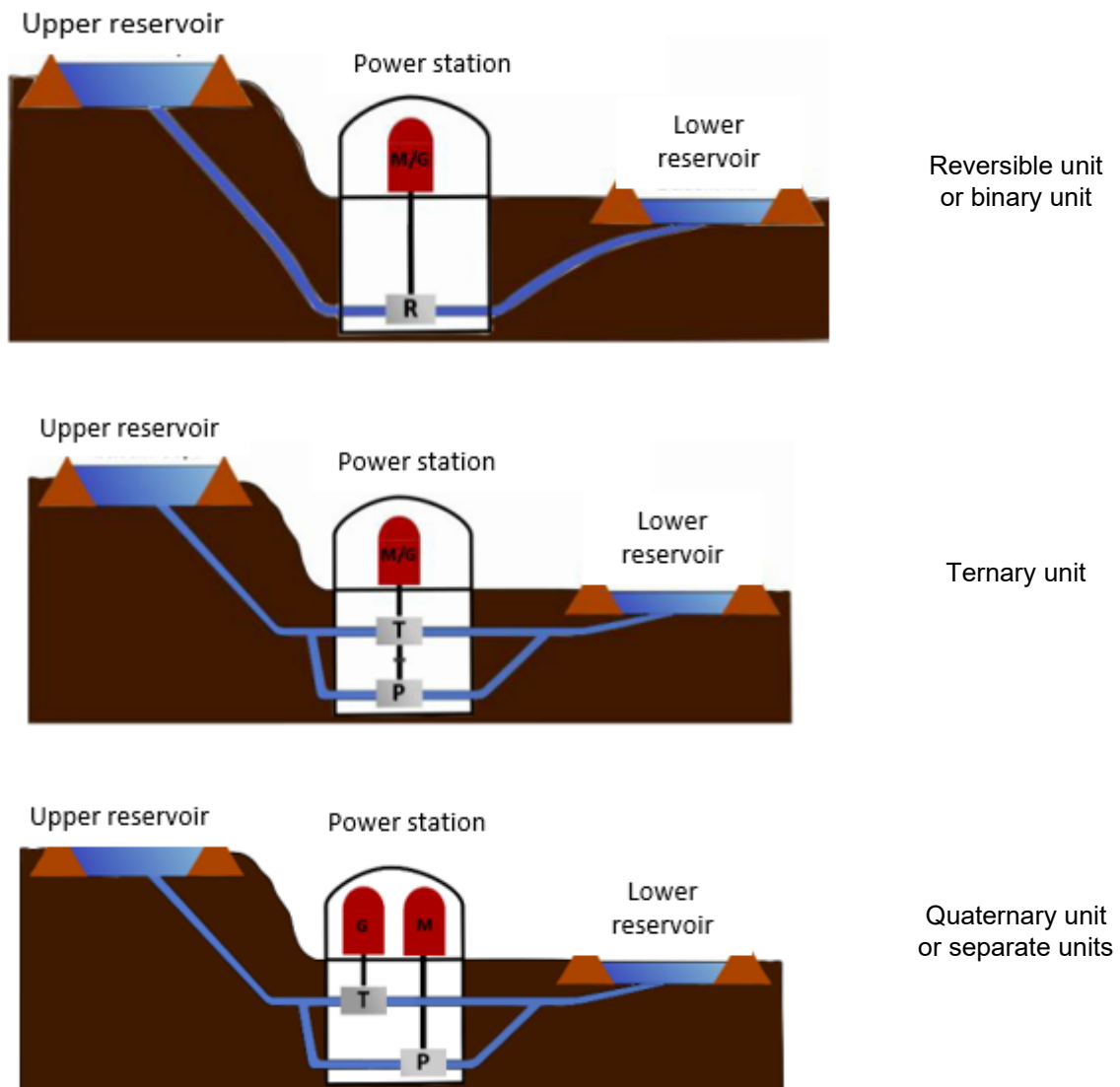


Figure 19 : Schematic diagram of the different types of units
(T = turbine, P = pump, G = generator, M = motor, R = reversible unit) [15]

Given the power range, between 5 and 10 MW, only sites with less than 250 m heads could be equipped with standard reversible machines. Consequently, the priority when sizing pumped storage power plants should be first to try to install a ternary unit, then, if not relevant, a quaternary unit solution (e.g. availability on the market, very high direct and induced costs on civil engineering, etc.).



However, in the HiDeStor project, no sites are designed with a ternary unit in front of the constraints and the machines available on the market.

For pairs requiring the creation of a new reservoir, as already mentioned, the process of locating sites for its creation leads us to choose only those with heads over 150 m, to limit the volumes of the reservoir for the turbine to reach the power objectives.

Among turbines, along with Francis, Pelton turbines are particularly suitable for ternary and quaternary groups. For a ternary unit, a horizontal axis layout is preferred, with the number of nozzles limited to three. The pump dictates the rotation speed, even if the turbine imposes a maximum standard speed of 1000 rpm. For separate units, the Pelton turbine can also be set on a vertical axis, with up to six nozzles (cf. Figure 20).

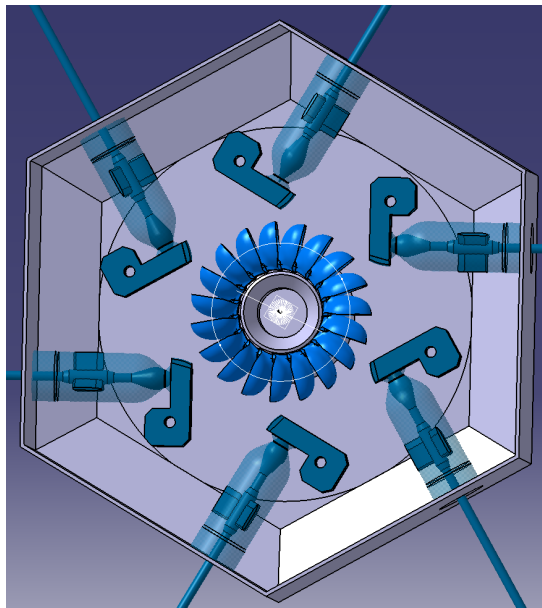


Figure 20 : Hydraulic profile of a 6-nozzle Pelton turbine, inside the casing, from underneath, a design chosen for the site VD2 [Mhylab]

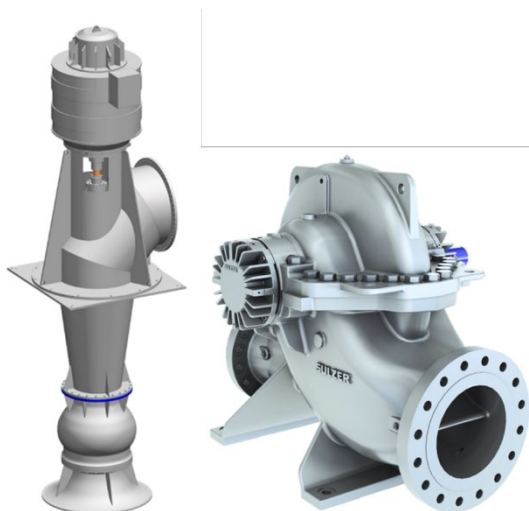


Figure 21 : Example of pumps used as booster [Sulzer]

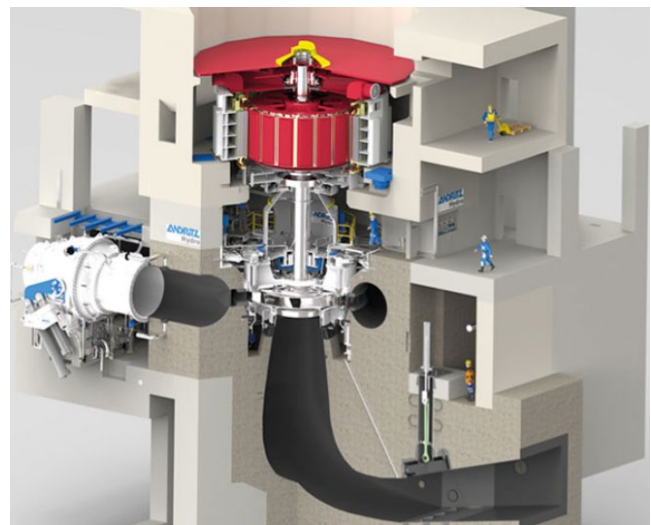


Figure 22 : Example of a reversible group of a large power plant. The principle is the same for small hydro [Andritz]



The design of the Pelton unit tends to maximise the number of nozzles to maximise the flexibility of the turbine, and the (fixed) rotation speed (limited to 1000 rpm), thus, to minimise the turbine size and its cost. Each turbine design is realistic (regarding specific speed for example – it might be recalled here that one of the partners' main activities is to design turbines).

Finally, within the HiDeStor project, each site is defined as equipped with:

- if the head is lower than 250 m: one standard reversible unit (binary unit)
- if the head is higher than 250 m: one turbine unit and one or several standard pumps (quaternary unit).

However, the present market shows that for the considered output range of the HiDeStor project, standard pumps are not common.

Table 5 presents the selected sites of the seven cantons which are equipped with a reversible unit.

Table 5 : The 9 selected sites equipped with a reversible unit (head < 250 m)

Site	Elevation difference	Energy storage potential	Total dynamic head (TDH)	Q	Electrical output
	m	MWh	m	m ³ /s	kW
VS3	55	11	56	7.4	5 000
VS5	141	6	144	2.9	5 000
BE3	70	16	72	5.8	5 000
BE4	100	11	102	4.1	5 000
JU2	146	18	148	2.9	5 000
JU3	206	25	209	2.4	5 900
NE1	183	22	191	2.5	5 500
NE2	147	18	155	2.9	5 000
NE3	173	21	182	2.6	5 400

To reduce the pump cost, it is necessary to limit the impeller size, which means maximizing the rotation speed. But the higher the speed, the higher the NPSH (net positive suction head), thus the risk of cavitation (which implies the reduction of performances and of the operation lifetime of the machine). To reduce the cavitation risk, the pump has to be set as low as possible from the downstream water level.

For heads higher than 200 meters, booster pumps, centrifugal pumps used to increase the pressure of water, can be considered to reduce the excavation. In other words, using a booster pump leads to decrease the net head of the main pump, allowing a higher setting and reducing the excavation needs.

The maximal rotation speed considered for separate units is 3000 rpm.



Turbines and pumps are not the only components of the electromechanical equipment. Valves have also to be considered, especially as their costs are not negligible. Table 6 and Table 7 present how valves are considered for each type of hydro schemes.

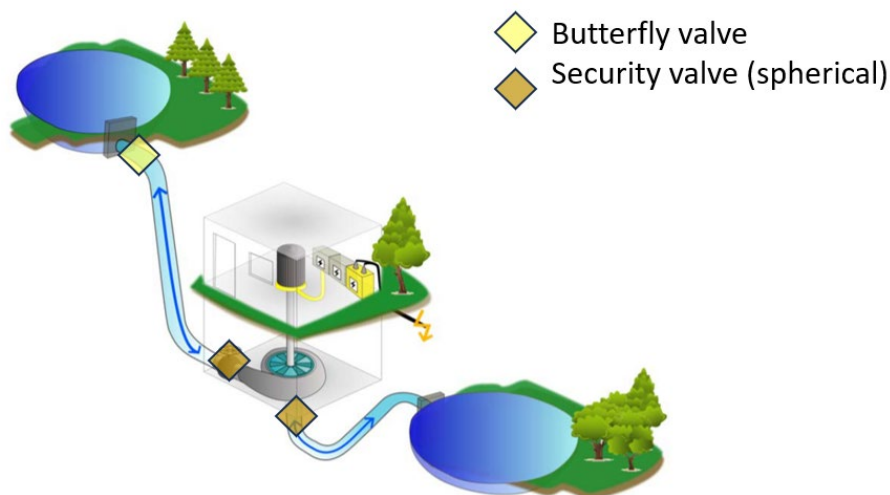


Figure 23 : Three different valves for a reversible unit, not equipped with a booster pump

Table 6 : Equipment for separate units: booster pump and valves
(if disproportionately expensive: * butterfly valve / ** slide gate valve)

Booster pump?	Pump under the downstream water level?	per turbine	Per pump (Booster excluded)		Total valves number	
		Security valve	Security valve	Inspection valve	Butterfly	spherical
No	Yes	Spherical (*)	Spherical (*)	Spherical (**)	1	3
No	No	Spherical (*)	Spherical (*)	0	1	2
Yes	No	Spherical (*)	Spherical (*)	0	1	2

Table 7 : Equipment for reversible units: valves
(if disproportionately expensive: *: butterfly valve / **: slide gate valve)

Pump under the downstream water level?	on the upper reservoir side	on the lower reservoir side		Total valves number	
	Security valve	Security valve	Inspection valve	Butterfly	spherical
Yes	Spherical (*)	Spherical (*)	Spherical (**)	1	3

2.2.6. Definition of the electrical connection

The connection to the grid is defined by:

- its length, directly measured from the downstream reservoir to the closest electrical line appearing on the map,
- its voltage, of 16'000 V in general, but also depending on each canton (a voltage of 13'800 V is also possible).



Then, a transformer is considered as needed for each site.

2.2.7. Definition of civil engineering and civil works

The definition of civil engineering and civil works deals mainly in the sizing of the possible new reservoir and the powerhouse.

2.2.8. Evaluation of the investments (economic potential)

Investments are grouped into four main categories, defining the total cost:

- Piping: the new penstock
- H&E equipment (hydro, mechanical and electrical equipment): turbine, pumps, valves (including the penstock one), the automation
- Electrical connection
- Civil engineering: possible new reservoir, intake, forebay, trash rack, powerhouse, possible excavation for the pumps, construction site installation and other civil works

In each category, common technical characteristics and parameters are gathered as bases for the cost estimation, as described below.

For piping, the investment of the penstock considers its length and diameter, but also the size of the trench.

For H&E equipment:

- the cost of each valve considers its type, diameter and nominal pressure.
- the price of the (Pelton) turbine considers its rotation speed and capacity.
- the price of the pump (and the booster pump) considers its rotation speed, runner diameter and capacity.

For civil engineering:

- The height of the new powerhouse is set at 10 meters.
- The surface of the new powerhouse considers the number of machines.
- For separate units, the need for significant back pressure at the reversible unit outlet requires the construction of underground power plants. The required excavation volume is determined based on the power output (machine size). The required volume of concrete and prices are estimated from internal data.

For electrical connection, the investment calculation considers the voltage, the length of the cables, the civil works to bury these cables, the capacity of the transformer.

The evaluation of the total cost for each site is based on statistics, adapted considering:

- The impact of inflation
- The Swiss Construction Price Index
- The Swiss materials price index

To strengthen these bases, offers have been collected for pumps and reversible machines in 2025 from specific suppliers; and an expert in civil engineering for power plants set in caverns has been consulted.

From this investment evaluation, for each equipment, the following costs are then added:

- The transport as 3 % of the investment
- The installation and commissioning as 5 % of the investment



At this step of the investment estimation, for each site, the prices are adapted by so called difficulty coefficients, varying between 1.0 and 1.5, depending on the implementation or the access. These coefficients are described in devoted tables, as presented below in the description of each site.

Then, the following costs are considered:

- Studies: 10% of the total cost
- Miscellaneous (and unforeseen expenses): 15% of the total cost

For each case study presented per canton in the following chapters, the economic data are described in the appendices (chapter 6.4).

2.2.9.LCOS - Levelized Cost of Storage

The definition used in this study to calculate the LCOS is based on the previous work of Jülch (2016) [28] and on the recent work developed by the Pacific Northwest National Laboratory [29].

The equation used is the following one:

$$LCOS(CHF/kWh) = \left(\frac{\sum_0^N \text{Revenue requirements (CHF)}}{(1+WACC)^n} - \frac{RV_N(CHF)}{(1+WACC)^N} \right) \cdot \left(\frac{\sum_0^N \text{Annual Energy Output (kWh)}}{(1+WACC)^n} \right)^{-1}$$

With:

- N: the analysis period,
- WACC: the Weighted Average Cost of Capital,
- RV_N : the residual value at N.

The following assumptions are considered for this study:

- No inflation.
- No taxes.
- Electricity cost: 0.04 CHF/kWh.
- Analysis period: 20 years.
- Project lifetime: 40 years.
- Calendar life: 40 years.
- Operating costs: 2% of CAPEX of Electromechanical components.
- A fixed operating cost.
- No insurance cost (included in OPEX at 2% of CAPEX).
- WACC: 5.11%, according to SFOE guidelines.

The LCOS for the seven analysed cantons are presented in chapter 2.12.



2.2.10. Environmental approach (ecological potential)

To reach the definition of the “expected potential” as defined in chapter 2.2.1 from the evaluation of the economic potential, criteria dealing with environmental and social aspects should be considered.

One possibility to approach the ecological criteria is to use the habitat map defined by the SFOEN, available on the federal geoportal (geo.admin.ch).

The dataset relies on the existing Switzerland-wide land cover mapping from the Swisstopo Topographic Landscape Model (TLM). The coarse habitat classes are recorded at level 1 of the TypoCH classification. The second level allows identifying different habitat classes such as class 1. water bodies, 3. glaciers, rock, debris and scree, 9. buildings. Habitat types were then mapped at a finer level of detail (TypoCH 3rd level where possible) using a combination of different methods, in particular distribution models based on machine learning and complex rule sets both of which rely heavily on Earth observation data. In total, 84 habitat types or groups are mapped.

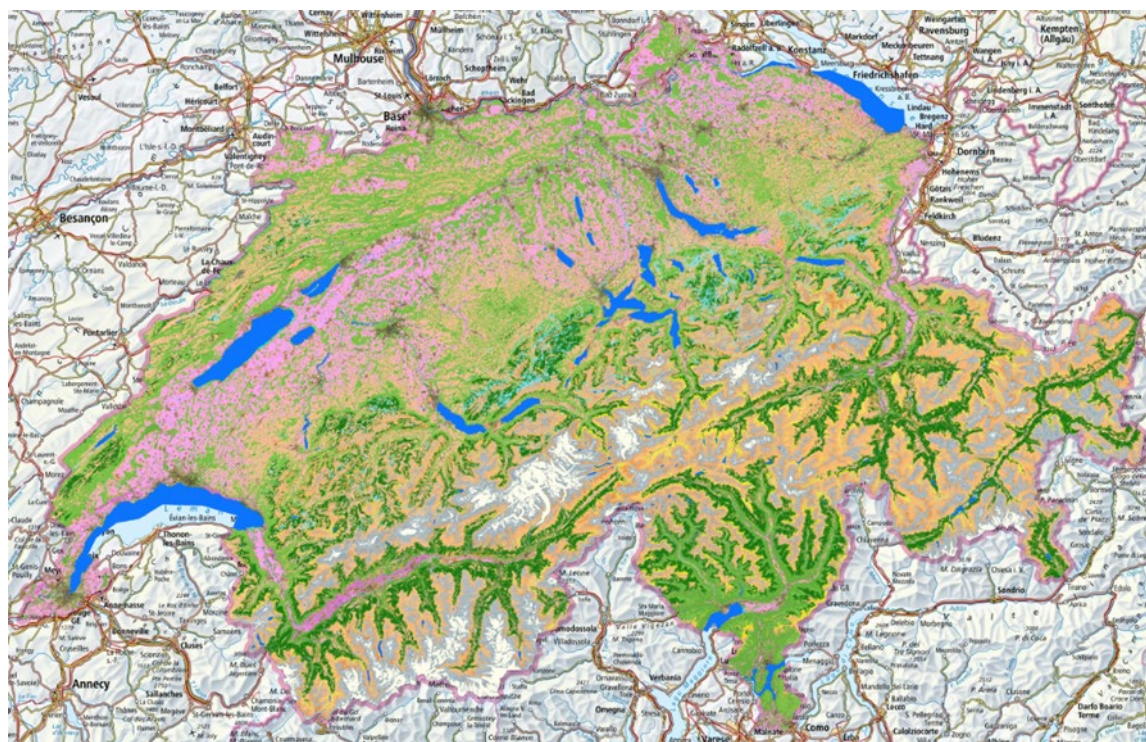


Figure 24 : The habitat map (from SFOEN) of Switzerland, from the federal geoportal (geo.admin.ch), which legend is defined in Figure 25

As shown in Figure 25, the map considers the 9 main habitats:

- | | |
|--|---|
| 1. Open waters | 6. Forests |
| 2. Shores and wetlands | 7. Pioneer vegetation in areas disturbed by man |
| 3. Glaciers, rocks, scree and moraines | 8. Plantations, fields and crops |
| 4. Grasslands and meadows | 9. Built-up areas |
| 5. Heaths, edges and bushes | |

Some examples applied on selected sites are given in the appendices (chapter 6.5). This approach is not sufficient to reach the ecological potential for each site. This objective is beyond the scope of the project. To deal with environment issues, another partner would have been needed, expert in this field.



Légende

- 1 Eaux libres
- 1.1 Eaux calmes
- 1.2 Eaux courantes
- 2 Rivaux et lieux humides
- 2.1.x Rivaux avec végétation
- 2.2.x Bas marais
- 2.3.x Prairies humides
- 2.4.x Tourbières bombées
- 3 Glaciers, rochers, éboulis et moraines
- 3.1 Glaciers, névés
- 3.2.x Alluvions et moraines
- 3.3 Eboulis
- 3.4 Parois rocheuses
- 4 Pelouses et prairies
- 4.0 Gazons et prairies artificiels
- 4.1 Dalles rocheuses et lapiez
- 4.2.x Pelouses sèches thermophiles
- 4.3.x Pelouses et pâturages maigres d'altitude
- 4.4 Combes à neige
- 4.5.x Prairies et pâturages gras
- 5 Landes, lisières et mégaphorbiaies
- 5.2 Mégaphorbiaies, coupes forestières
- 5.3.x Formations buissonnantes
- 5.4 Landes
- 6 Forêts
- 6.0 Plantations/Arbre isolé
- 6.1.x Forêts inondables
- 6.2.x Hêtraies
- 6.3.x Autres forêts de feuillus
- 6.4.x Pinèdes thermophiles
- 6.5.x Forêts de tourbières
- 6.6.x Forêts de conifères d'altitude
- 7 Végétation pionnière des endroits perturbés par l'homme
- 7.1 Terrains piétinés et rudéraux
- 8 Plantations, champs et cultures
- 8.1.x Cultures de plantes ligneuses
- 8.2.x Cultures de plantes herbacées
- 9 Milieux construits
- 9.2 Bâtiment
- 9.3.x Voies de communication
- 9.4 Terrain de sport revêtu, place de parc

Legende

- 1 Gewässer
- 1.1 Stehende Gewässer
- 1.2 Fließgewässer
- 2 Ufer und Feuchtgebiete
- 2.1.x Ufer mit Vegetation
- 2.2.x Flachmoore
- 2.3.x Feuchtwiesen
- 2.4.x Hochmoore
- 3 Gletscher, Fels, Schutt und Geröll
- 3.1 Gletscher, Firn- und Schneefelder
- 3.2.x Alluvionen und Moränen
- 3.3 Steinschutt- und Geröllfluren
- 3.4 Felsen
- 4 Grünland (Naturrasen, Wiesen und Weiden)
- 4.0 Kunstrasen
- 4.1 Pionierfluren auf Felsböden
- 4.2.x Wärmeliebende Trockenrasen
- 4.3.x Gebirgs-Magerrasen
- 4.4 Schneetälchen
- 4.5.x Fettwiesen und -weiden
- 5 Krautsäume, Hochstaudenfluren und Gebüsche
- 5.2 Hochstauden- und Schlagfluren
- 5.3.x Gebüsche
- 5.4 Zwergstrauchheiden
- 6 Wälder
- 6.0 Forstpflanzungen/Einzelbäume
- 6.1.x Bruch- und Auenwälder
- 6.2.x Buchenwälder
- 6.3.x Andere Laubwälder
- 6.4.x Wärmeliebende Föhrenwälder
- 6.5.x Hochmoorwälder
- 6.6.x Gebirgs-Nadelwälder
- 7 Pioniervegetation gestörter Plätze (Ruderalstandorte)
- 7.1 Trittrasen und Ruderalfluren
- 8 Pflanzungen, Äcker und Kulturen
- 8.1.x Baumschulen, Obstgärten, Rebberge
- 8.2.x Feldkulturen
- 9 Bauten, Anlagen
- 9.2 Bauten
- 9.3.x Verkehrswege
- 9.4 Versiegelte Sportplatz, Parkplatz usw

Figure 25 : The main habitats, legend of Figure 24



2.3 Overview of the selected sites

As already mentioned, the first objective is to analyse the MS PHS of seven cantons, which can be considered as representative for the whole Switzerland: Valais, Vaud, Fribourg, Bern, Neuchâtel, Jura and Ticino. In the scope of HiDeStor, 27 sites have been selected and studied, from three to four per canton. Among those 27 sites, three have not been considered as relevant as economic potentials in the scope of HiDeStor: TI3, TI4 and TI 5, all included in the Canton of Ticino. Indeed, the storage hydropower potential of each of these sites is over the threshold of 10 MW and are already considered in specific studies. Finally, the economic potential estimated by the HiDeStor project is composed of 24 sites.

Each of the 27 sites is presented in the following chapters regarding the main characteristics, while the economic details are described in the appendices (chapter 6.4). A synthesis of the economic results can be found in chapter 2.12, dealing with LCOS.

2.4 Potential sites in the canton of Valais

The location of the reservoirs in the Valais canton is given in Figure 26. Among the 281 reservoirs, the volume is known for 133 (47.3%). The unknown volumes are mainly small lakes in mountainous areas, i.e. high altitude. Where the volume is known, the total volume is represented by a blue disc.

Among those known volumes, a first investigation was carried out to sort out the usable ones. The criteria were to have two existing reservoirs with a minimum of 1 MWh of energy storage. This site identification gave the theoretical potential in the Valais canton, shown in Figure 27.

Finally, the first five sites having the highest energy storage are selected for the technical potential analysis in the Valais canton. The site's locations are shown in Figure 28.

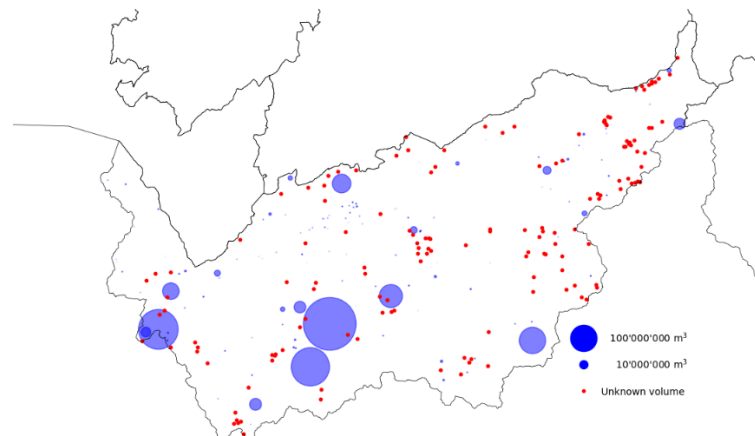


Figure 26 : Locations of the natural and artificial reservoirs in the Valais canton. The disc size represents the water volume of the reservoirs if known. Otherwise, the location is marked by a red point.

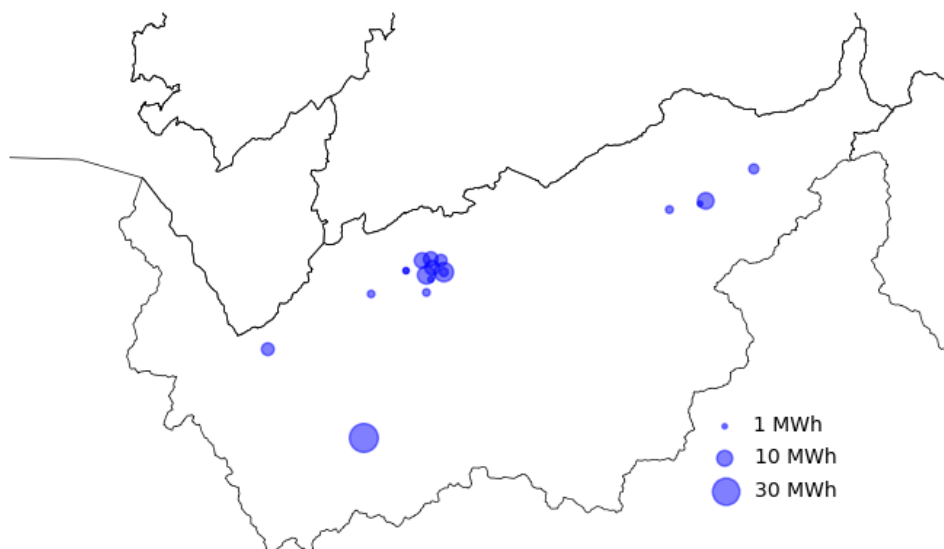


Figure 27 : Locations of the theoretical potential sites in the Valais canton. The disc size represents the potential energy storage

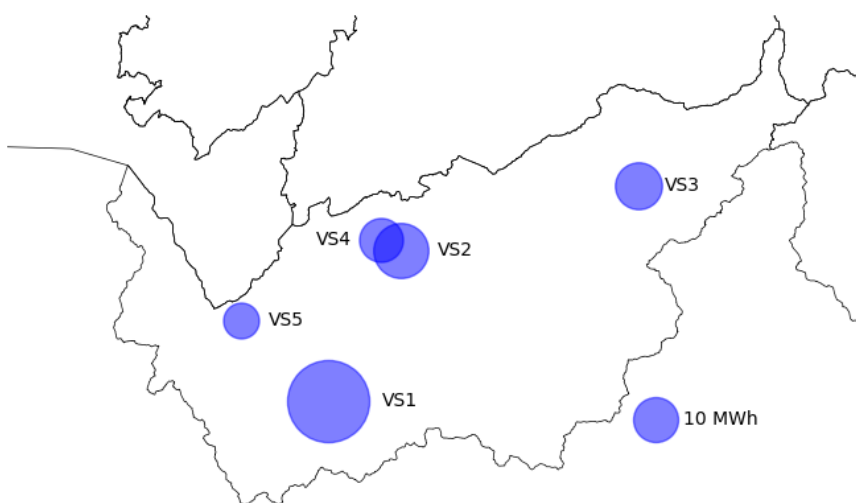


Figure 28 : Locations of the economic potential sites in the Valais canton. The disc size represents the potential energy storage.

The description of the sites identified in the canton of Valais is presented in the following subsections. Additional information on the sites can be found in the appendices (cf. chapter 6.4.1).



2.4.1.Site VS1: Fionnay FMM – Louvie

Context

The objective of this site is to exploit the storage potential between the Fionnay FMM compensation basin and Lake Louvie, located in the Val de Bagnes, with an altitude difference of 722 m. The usable storage volume is 17'000 m³, providing a theoretical storage potential of 33.3 MWh. The corresponding electrical power output of this site is 6.8 MW.

Site plan and longitudinal profile

Figure 29 shows the location of the existing reservoirs (Fionnay FMM and Lake Louvie) as well as the path of the penstock in red.

The longitudinal profile of the penstock's route is shown in Figure 30 with an approximate straight-line length of 1'500 m.

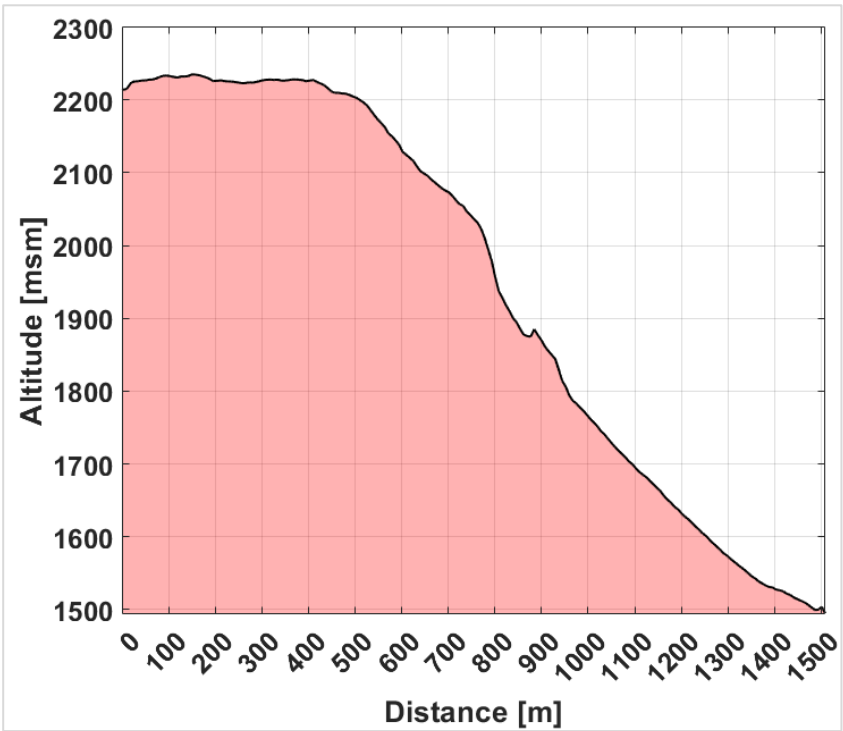


Figure 30 : Longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir



Figure 29 : Location map of the Fionnay FMM and Lake Louvie reservoirs with the route of the penstock

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant.

Table 8 : Difficulty coefficients for site VS1

Components	Difficulty coefficients	Comments
Powerhouse	1.2	Requires a deep excavation for the booster pumps.
Penstock	1.5	Mountainous area with steep slopes



Table 9 : Reservoirs characteristics of site VS1

Reservoirs characteristics	Values
Upstream reservoir altitude	2'214 m
Upstream reservoir volume	400'000 m ³
Downstream reservoir altitude	1'492 m
Downstream reservoir volume	170'000 m ³
Elevation difference	722 m
Available storage volume	17'000 m ³
Energy storage potential	33.3 MWh

Table 10 : Penstock characteristics of site VS1

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	700 mm
Length	1'800 m

Table 11 : Powerhouse equipment characteristics of site VS1

Characteristics	Turbine	Pump
Type of machine [-]	Pelton with vertical axis	Multi-stage vertical axis pump + booster pump
Number of machine(s) [-]	1	2
Net head [m]	701.5	731.6
Operating time [h]	4.1	6.2
Discharge [m ³ /s]	1.16	2 · 0.40
Rotation speed [rpm]	1'000	3'000
Hydraulic power [MW]	8.0	2 · 2.9
Electrical power [MW]	6.8	2 · 3.4

Economic analysis

For this site, which requires separate equipment for the pump and turbine cycles, the electromechanical investment component, including the pump, turbine, motors, and control-command system, represents the largest share, accounting for more than 49% of the total investment cost. The penstock is the second-largest expense, representing just over 23% of the total cost, which amounts to slightly over 18 million Swiss Francs.



2.4.2.Site VS2: Combuissan – Miriougues

Context

The objective of this site is to exploit the storage potential between Lake of Combuissan and Miriougues Pond, located in the Crans-Montana region, with a height difference of 367 m. The usable storage volume is 15'000 m³, giving a theoretical storage potential of 15.0 MWh. The corresponding electrical power output of this site is 5 MW.

Site plan and longitudinal profile

Figure 31 shows the location of the existing reservoirs (Lake of Combuissan and Miriougues pond) and the path of the penstock in red.

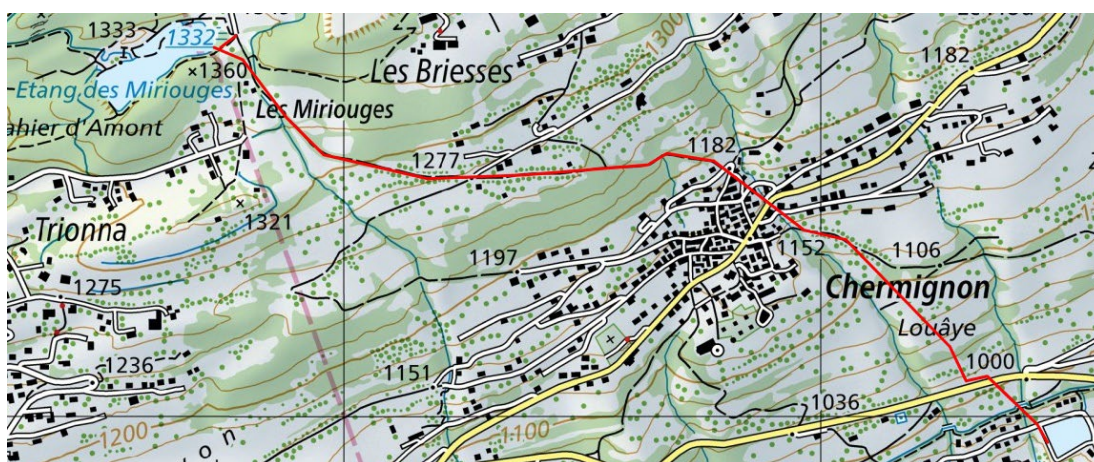


Figure 31 : Location map of the Lake of Combuissan and Miriougues pond with the path of the penstock

The longitudinal profile of the penstock route is shown in the Figure 32 , with an approximate straight-line length of 2'100 m.

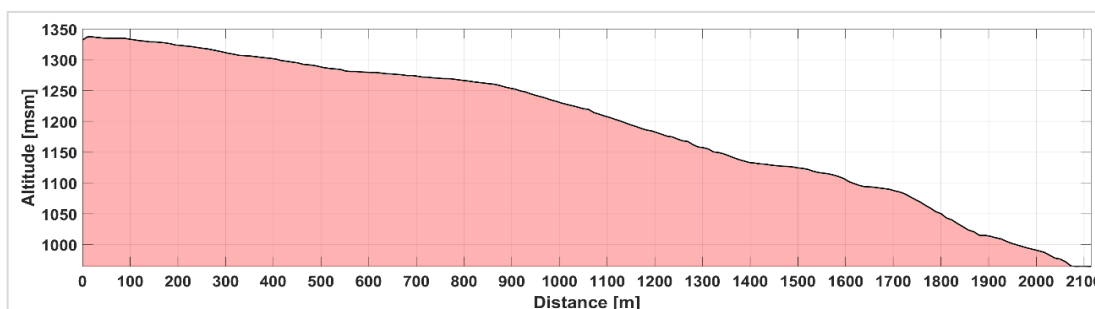


Figure 32 : Longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant. Table 12 provides the difficulty coefficients, Table 13 the reservoirs characteristics, Table 14 the penstock characteristics and Table 15 the powerhouse characteristics.

Table 12 : Difficulty coefficients for site VS2

Components	Difficulty coefficients	Comments
Powerhouse	1.1	Located in a residential area
Penstock	1.2	Path crossing main road and residential area



Table 13 : Reservoirs characteristics of site VS2

Reservoirs characteristics	Values
Upstream reservoir altitude	1'330 m
Upstream reservoir volume	70'000 m ³
Downstream reservoir altitude	963 m
Downstream reservoir volume	30'000 m ³
Elevation difference	367 m
Available storage volume	15'000 m ³
Energy storage potential	15.0 MWh

Table 14 : Penstock characteristics of site VS2

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	900 mm
Length	2'160 m

Table 15 : Powerhouse equipment characteristics of site VS2

Characteristics	Turbine	Pump
Type of machine [-]	Pelton with vertical axis	Multi-stage horizontal axis pump + booster pump
Number of machine(s) [-]	1	2
Net head [m]	353.1	373.4
Operating time [h]	2.5	3.8
Discharge [m ³ /s]	1.68	2 · 0.57
Rotation speed [rpm]	1'000	2'960
Hydraulic power [MW]	5.8	2 · 2.1
Electrical power [MW]	5	2 · 2.5

Economic analysis

For this site, whose total investment cost amounts to just over CHF 21.8 million, electromechanical equipment, including the pump, turbine, motors and command and control system, accounts for the largest share, representing just over 39% of the total cost. The penstock is the second largest expense item, accounting for just under 34% of the investment cost.



2.4.3.Site VS3: Bettmersee – Scheene Bodu

Context

The objective of this site is to exploit the storage potential between Bettmersee and Scheene Bodu reservoir, located in the Bettmeralp region, with a difference in altitude of 55 m. The usable storage volume is 72'785 m³ (1 meter of water level), giving a theoretical storage potential of 10.9 MWh. The corresponding electrical power output of this site is 5.0 MW.

Site plan and longitudinal profile

Figure 33 shows the location of the existing reservoirs (Bettmersee and Scheene Bodu reservoir) and the path of the penstock in red.

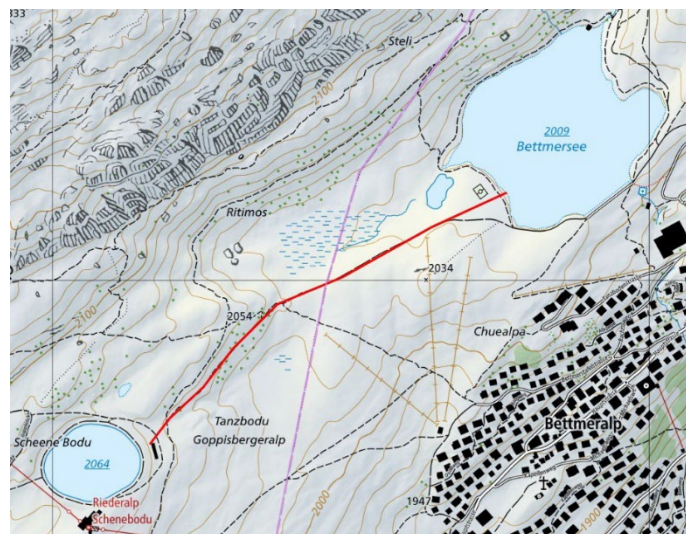


Figure 33 : Location map of the Bettmersee and Scheene Bodu reservoir with the route of the penstock

The longitudinal profile of the penstock route is shown in the Figure 34 , with an approximate straight-line length of 745 m.

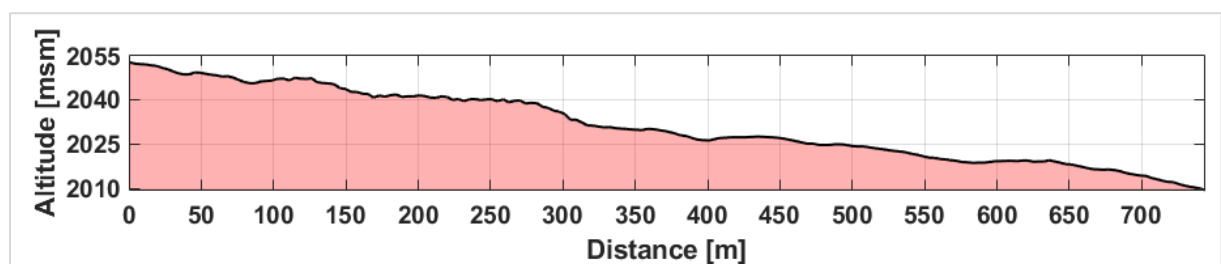


Figure 34 : Longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant. Table 16 provides the difficulty coefficients, Table 17 the reservoirs characteristics, Table 18 the penstock characteristics and Table 19 the powerhouse characteristics.

Table 16 : Difficulty coefficients for site VS3

Components	Difficulty coefficients	Comments
Powerhouse	1.3	Mountainous area
Penstock	1.3	Mountainous area



Table 17 : Reservoirs characteristics of site VS3

Reservoirs characteristics	Values
Upstream reservoir altitude	2'064 m
Upstream reservoir volume	95'000 m ³
Downstream reservoir altitude	2'009 m
Downstream reservoir volume	560'000 m ³
Elevation difference	55 m
Available storage volume	72'785 m ³
Energy storage potential	10.9 MWh

Table 18 : Penstock characteristics of site VS3

Penstock characteristics	Sizing
Material	Burried PVC
Diameter	2'200 mm
Length	750 m

Table 19 : Powerhouse equipment characteristics of site VS3

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis turbine	
Number of machine(s) [-]	1	
Net head [m]	53.0	55.9
Operating time [h]	1.8	2.7
Discharge [m ³ /s]	11.2	7.6
Rotation speed [rpm]	500	
Hydraulic power [MW]	5.8	4.2
Electrical power [MW]	5.0	

Economic analysis

For this site, with a total investment of just over 21 million Swiss Francs and where the penstock diameter is large, the cost of the penstock represents the largest share of the total investment, at 38%. In second place, the investment in electromechanical equipment accounts for more than 20% of the total cost.



2.4.4.Site VS4: Croix – Icogne

Context

The objective of this site is to exploit the storage potential between the Croix compensation basin and the Lake of Icogne, located in the commune of Icogne, with an altitude difference of 499 m. The usable storage volume is 7'000 m³, giving a theoretical storage potential of 9.5 MWh. The turbine and penstock already exist. The potential of this site has already been studied as part of the COGENER project, and a comparison is made in the observation below. The corresponding electrical power output of this site is 2.0 MW.

Site plan and longitudinal profile

Figure 35 shows the location of the existing reservoirs (Croix compensation basin and Lake of Icogne) and the approximated path of the existing penstock in red.



Figure 35 : Location map of the Croix compensation basin and the Lake of Icogne with the approximated path of the existing penstock

The approximated longitudinal profile of the existing penstock path is shown in the Figure 36 , with an approximate straight-line length of 1'550 m.

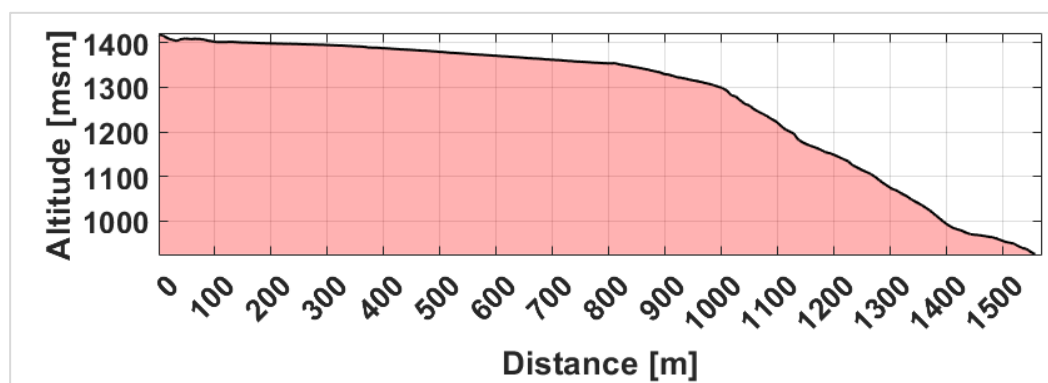


Figure 36 : Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant. Table 20 provides the difficulty coefficients, Table 21 the reservoirs characteristics, Table 22 the penstock characteristics and Table 23 the powerhouse characteristics.

Table 20 : Difficulty coefficients for site VS4

Components	Difficulty coefficients	Comments
Powerhouse	1.1	Residential area
Penstock	1.3	Residential area with steep portion on the path



Table 21 : Reservoirs characteristics of site VS4

Reservoirs characteristics	Values
Upstream reservoir altitude	1'417 m
Upstream reservoir volume	40'000 m ³
Downstream reservoir altitude	918 m
Downstream reservoir volume	90'000 m ³
Elevation difference	499 m
Available storage volume	7'000 m ³
Energy storage potential	9.5 MWh

Table 22 : Penstock characteristics of site VS4

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	500 mm
Length	1'700 m

Table 23 : Powerhouse equipment characteristics of site VS4

Characteristics	Turbine	Pump
Type of machine [-]	Pelton with vertical axis (existing)	Multi-stage horizontal axis pump + booster pump
Number of machine(s) [-]	1	1
Net head [m]	478.5	508.4
Operating time [h]	3.9	6.0
Discharge [m ³ /s]	0.49	0.34
Rotation speed [rpm]	1'000	3'584
Hydraulic power [MW]	2.3	1.7
Electrical power [MW]	2.0	

Economic analysis

For this site, where the penstock and turbine are already in place, the total cost is significantly lower than that of the other sites in Valais, representing less than 10% of their costs, or just 1.9 million Swiss Francs. The cost of hydromechanical and electromechanical equipment accounts for the largest share of the total investment, at over 41%. This is followed by civil engineering works, which account for more than 28% of the investment cost.

Observation

The main difference with the former COGENER study is that presently, the electrical power is identical for the turbine and the pump. As a turbine of 2 MW already exist, the pump was designed consequently.

2.4.5.Site VS5: Lower Fully – Higher Fully

Context



The objective of this site is to exploit the storage potential between the downstream and upper Fully lakes, located in the municipality of Fully, with a height difference of 141 m. The usable storage volume is 16'500 m³, giving a theoretical storage potential of 6.3 MWh. The potential of this site has already been studied as part of the COGENER project, and a comparison is made in the observation below. The corresponding electrical power output of this site is 5.0 MW.

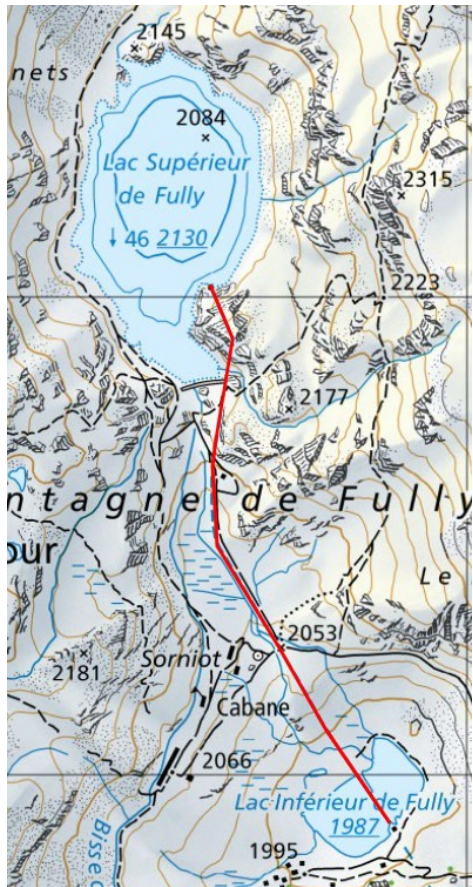


Figure 37. Location map of the Fully downstream and upper lakes with the route of the penstock

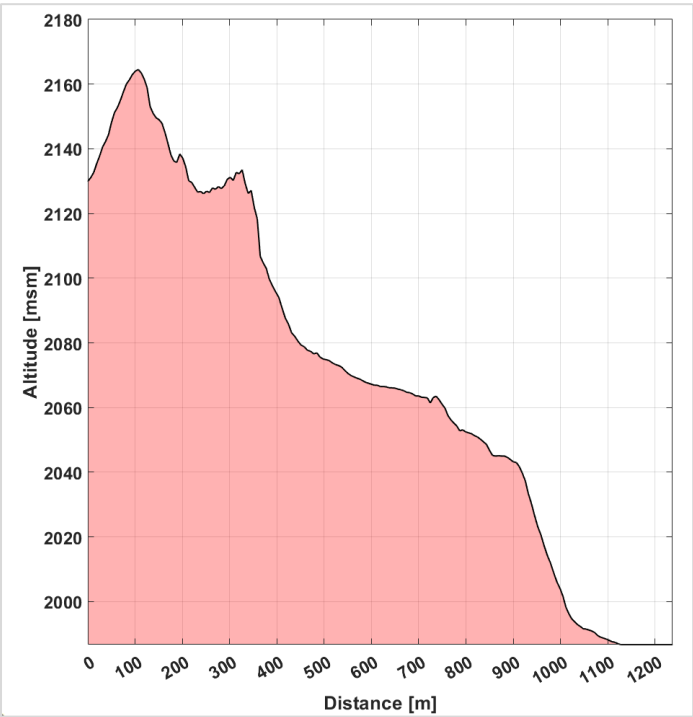


Figure 38. Elevations of the natural terrain along the planned route of the pipeline

Site plan and longitudinal profile

Figure 37 shows the location of the existing reservoirs (Fully downstream and upper lakes) and the penstock path in red. The elevations of the natural terrain along the planned route of the pipeline are shown in Figure 38, with an approximate straight-line length of 1'280 m

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant.

Table 24 : Difficulty coefficients for site VS5

Components	Difficulty coefficients	Comments
Powerhouse	1.5	Mountainous area
Penstock	1.5	Mountainous area



Table 25 : Reservoirs characteristics of site VS5

Reservoirs characteristics	Values
Upstream reservoir altitude	2'128 m
Upstream reservoir volume	5'200'000 m ³
Downstream reservoir altitude	1'987 m
Downstream reservoir volume	35'000 m ³
Elevation difference	141 m
Available storage volume	16'500 m ³
Energy storage potential	6.3 MWh

Table 26 : Penstock characteristics of site VS5

Penstock characteristics	Sizing
Material	Burried Polyvinyl chloride (PVC)
Diameter	1'400 mm
Length	1'350 m

Table 27 : Powerhouse equipment characteristics of site VS5

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis turbine	
Number of machine(s) [-]	1	
Net head [m]	135.1	143.7
Operating time [h]	1.0	1.6
Discharge [m ³ /s]	4.37	2.97
Rotation speed [rpm]	1'000	
Hydraulic power [MW]	5.8	4.2
Electrical power [MW]	5.0	

Economic analysis

For this site, where the total investment cost amounts to more than 16.9 million Swiss francs and the diameter of the penstock is relatively large, the cost of the penstock represents the largest share of the total investment, at just under 40% of the investment cost. In second place are civil engineering costs, which account for more than 20% of the total cost.

Observation

In the COGENER document, the site is studied as a small-scale pumped storage system (STEPPE) of around 1.7 MW, limited by the reservoir level variation and the protection of the drinking water resource, whereas within the HiDeStor project the same site is sized at around 5 MW, by mobilising a significantly larger usable storage volume.



2.4.6. Summary

Table 28 summarises the hydraulic pumping capacity and the energy storage potential of each Valais site.

Table 28 : Summary of the potential of each Valais site

Sites	P_e [MW]	Energy storage potential [MWh]
VS1	6.8	33.3
VS2	5.0	15.0
VS3	5.0	10.9
VS4	2.0	9.5
VS5	5.0	6.3
Total	23.8	75.0

Figure 39 shows the distribution of investment costs for all Valais sites.

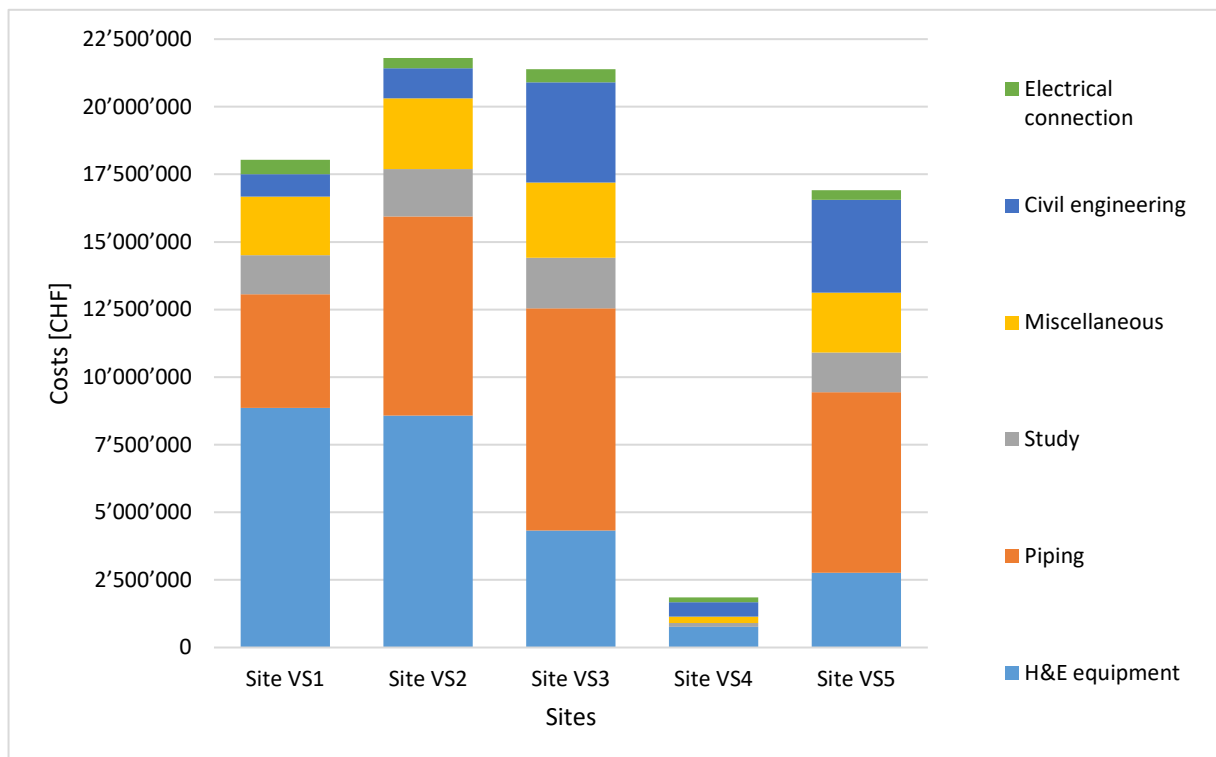


Figure 39 : Distribution of investment costs for each Valais site



2.5 Potential sites in the canton of Bern

Bern canton is composed of approximately 160 lakes. The analysis of the characteristics of each lake showed that 4 pairs having at least a storage of 15 MWh except for the fourth site which has a potential of 9.5 MWh. The locations of these sites are shown in Figure 40.

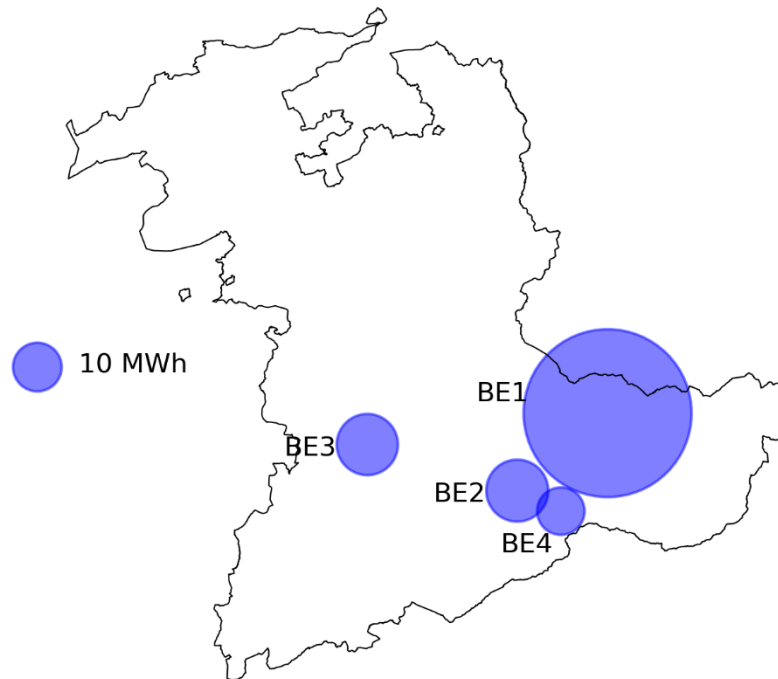


Figure 40: Locations of the economical potential sites in the Bern canton. The disc size represents the potential energy storage.

2.5.1. Site BE1: Brienzersee – Hinterburgseeli

The aim of this site is to exploit the storage potential between Brienzer Lake and Lake Hinterburgseeli, located in the North of the Swiss Alps, with an altitude difference of 951 m. The usable storage volume is 46'000 m³, giving a theoretical storage potential of 118.8 MWh. The corresponding electrical power output of this site is 10.0 MW.



Figure 41: Location map of Lake Brienzsee and Lake Hinterburgseeli with the approximate route of the penstock.

The Figure 41 shows the location of the existing reservoirs (Lake Brienzsee and Lake Hinterburgseeli) and the approximate route of the penstock in red.

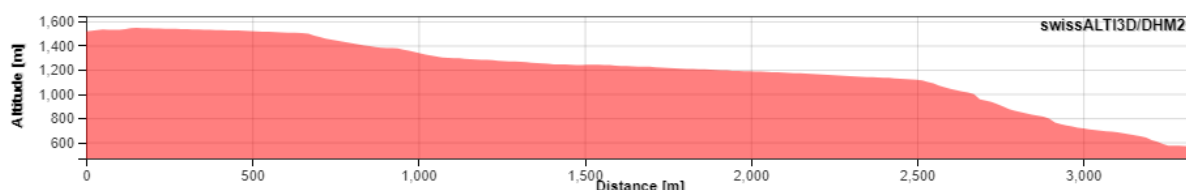


Figure 42: Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

The longitudinal profile of the penstock route is shown in Figure 42, with an approximate length of 3300 m.

Hydropower plant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 29 provides the difficulty coefficients, Table 30 the reservoirs characteristics, Table 31 the penstock characteristics and Table 32 the powerhouse characteristics.

Table 29 : Difficulty coefficients for site BE1

Components	Difficulty coefficients	Comments
Powerhouse	1.2	Lakeshore area with restricted access
Penstock	1.4	Residential area

Table 30 : Reservoirs characteristics of site BE1

Reservoirs characteristics	Values
Upstream reservoir altitude	1'515 m
Upstream reservoir volume	69'000 m ³
Downstream reservoir altitude	564 m



Downstream reservoir volume	5'170'000'000 m ³
Elevation difference	951 m
Available storage volume	46'000 m ³
Energy storage potential	118.8 MWh

Table 31 : Penstock characteristics of site BE1

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	800 mm
Length	3'600 m

Table 32 : Powerhouse equipment characteristics of site BE1

Characteristics	Turbine	Pump
Type of machine [-]	Pelton	Multi-stage horizontal axis pump
Number of machine(s) [-]	1	1
Net head [m]	925.5	962.9
Operating time [h]	9.9	15.0
Discharge [m ³ /s]	1.30	0.89
Rotation speed [rpm]	750	3'000
Hydraulic power [MW]	11.8	8.5
Mechanical power [MW]	10.6	9.9
Electrical power [MW]		10.0

Economic analysis

For this site, whose total investment cost amounts to just over 30 million Swiss francs, electromechanical equipment, including the pump, turbine, motors and command and control system, accounts for the largest share, at just under 40% of the total cost. The penstock is the second largest expense item, accounting for just over 34% of the investment cost.



2.5.2.Site BE2: Sulsseeli – Obers Sulsseeli

The objective of this site is to exploit the storage potential between Lake Sulsseeli and Lake Obers Sulsseeli, located in the Bernese Oberland, with a height difference of 271 m. The usable storage volume is 22'000 m³, which corresponds to a theoretical storage potential of 16.2 MWh. The corresponding electrical power output of this site is 5.0 MW.

The Figure 43 shows the location of the existing reservoirs (Lake Sulsseeli and Lake Obers Sulsseeli) and the approximate route of the penstock in red.

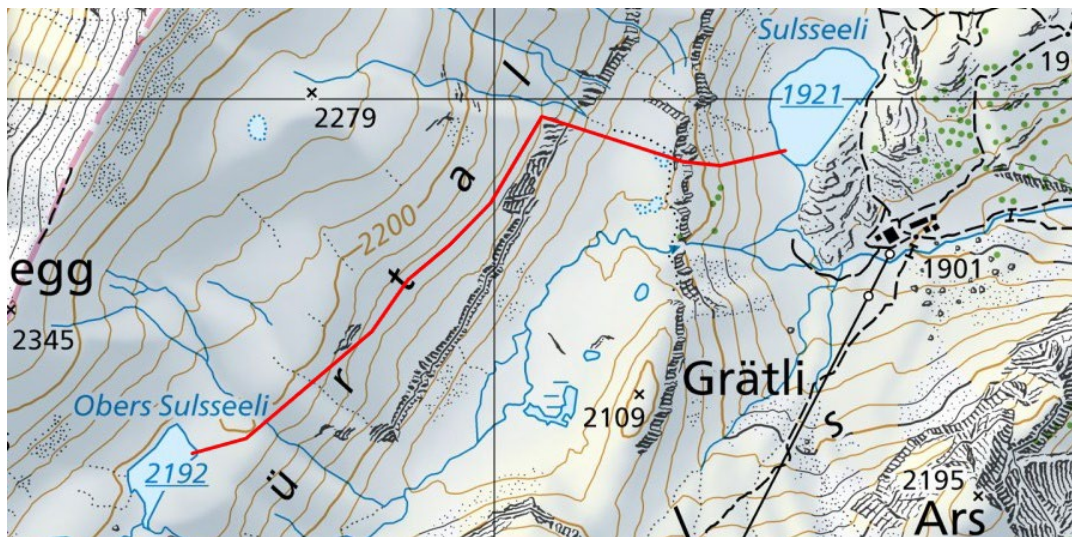


Figure 43 : Location map of Lake Sulsseeli and Lake Obers Sulsseeli with the approximate route of the penstock

The longitudinal profile of the penstock route is shown in the Figure 44, with an approximate straight-line length of 1250 m.

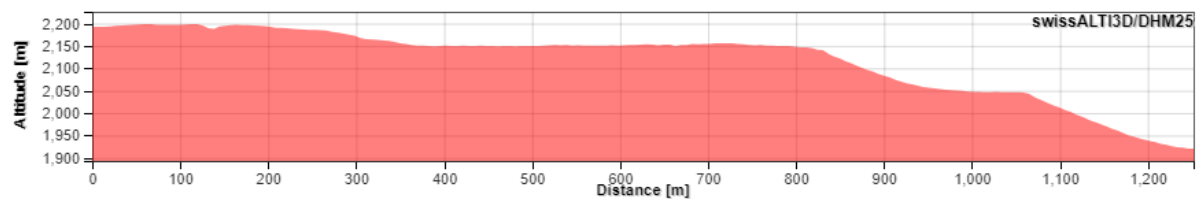


Figure 44 : Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 33 provides the difficulty coefficients, Table 34 the reservoirs characteristics, Table 35 the penstock characteristics and Table 36 the powerhouse characteristics.

Table 33 : Difficulty coefficients for site BE2

Components	Difficulty coefficients	Comments
Powerhouse	1.5	Mountainous area
Penstock	1.5	Mountainous area



Table 34 : Reservoirs characteristics of site BE2

Reservoirs characteristics	Values
Upstream reservoir altitude	2'192 m
Upstream reservoir volume	121'500 m ³
Downstream reservoir altitude	1'921 m
Downstream reservoir volume	33'000 m ³
Elevation difference	271 m
Available storage volume	22'000 m ³
Energy storage potential	16.2 MWh

Table 35 : Penstock characteristics of site BE2

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	1'000 m
Length	1'350 m

Table 36 : Powerhouse equipment characteristics of site BE2

Characteristics	Turbine	Pump
Type of machine [-]	Pelton	High pressure double-casing multi-stage pump
Number of machine(s) [-]	1	1
Net head [m]	261.8	275.3
Operating time [h]	2.7	4.0
Discharge [m ³ /s]	2.28	1.55
Rotation speed [rpm]	600	3'000
Hydraulic power [MW]	5.8	4.2
Mechanical power [MW]	5.3	4.9
Electrical power [MW]		5.0

Economic analysis

For this site, whose total investment cost amounts to just under 20 million Swiss francs, electromechanical equipment, including the pump, turbine, motors and command and control system, accounts for the largest share, representing just over 41% of the total cost. The penstock is the second largest expense item, accounting for just under 29% of the investment cost.



2.5.3.Site BE3: Hinderstockesee – Oberstockesee

The aim of this site is to exploit the storage potential between Lake Hinderstockesee and Lake Oberstockesee, located in the Simmental region, with a height difference of 70 m. The usable storage volume is 83'000 m³, which corresponds to a theoretical storage potential of 15.8 MWh. The corresponding electrical power output of this site is 5.0 MW.

The Figure 45 shows the location of the existing reservoirs (Hinderstockesee and Oberstockesee lakes) and the approximate route of the penstock in red.

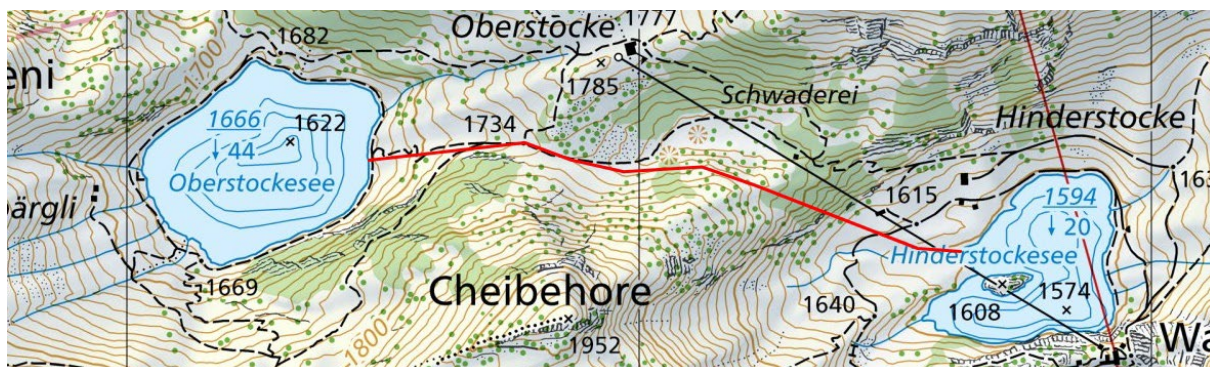


Figure 45 : Location map of Lake Hinderstockesee and Lake Oberstockesee with the approximate route of the penstock

The longitudinal profile of the penstock route is shown in the Figure 46, with an approximate straight-line length of 1190 m.

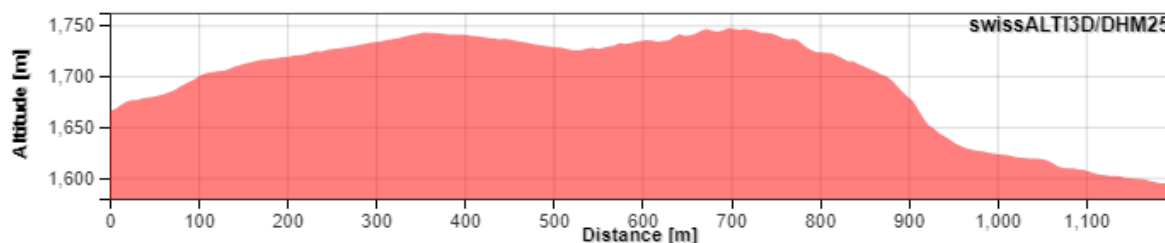


Figure 46 : Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 37 provides the difficulty coefficients, Table 38 the reservoirs characteristics, Table 39 the penstock characteristics and Table 40 the powerhouse characteristics.

Table 37 : Difficulty coefficients for site BE3

Components	Difficulty coefficients	Comments
Powerhouse	1.5	Remote alpine site with limited vehicle access
Penstock	1.5	Steep alpine terrain and difficult construction logistics



Table 38 : Reservoirs characteristics of site BE3

Reservoirs characteristics	Values
Upstream reservoir altitude	1'665 m
Upstream reservoir volume	2'684'000 m ³
Downstream reservoir altitude	1'595 m
Downstream reservoir volume	830'000 m ³
Elevation difference	70 m
Available storage volume	83'000 m ³
Energy storage potential	15.8 MWh

Table 39 : Penstock characteristics of site BE3

Penstock characteristics	Sizing
Material	Steel
Diameter	2'000 mm
Length	1'250 m

Table 40 : Powerhouse equipment characteristics of site BE3

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis turbine	
Number of machine(s) [-]	1	
Net head [m]	66.6	71.6
Operating time [h]	2.6	4.0
Discharge [m ³ /s]	8.81	5.96
Rotation speed [rpm]	500	
Hydraulic power [MW]	5.7	4.2
Mechanical power [MW]	5.2	4.9
Electrical power [MW]	5.0	

Economic analysis

For this site, where the total investment cost amounts to more than 24.2 million Swiss francs and the diameter of the penstock is large, the cost of the penstock represents the largest share of the total investment, at just over 48%. In second place, investment in electromechanical equipment accounts for more than 17% of the total cost.



2.5.4.Site BE4: Scheidegg - Wengernalp Lauberhorn

The aim of this site is to exploit the storage potential between the Scheidegg reservoir and the Wengernalp Lauberhorn reservoir, located in the Wengen region, with a height difference of 100 m. The usable storage volume is 39'230 m³, which corresponds to a theoretical storage potential of 9.5 MWh. The corresponding electrical power output of this site is 5.0 MW.

The Figure 47 shows the location of the existing reservoirs (Scheidegg and Wengernalp Lauberhorn) and the approximate route of the penstock in red.



Figure 47 : Location map of Scheidegg reservoir and the Wengernalp Lauberhorn reservoir with the approximate route of the penstock

The longitudinal profile of the penstock route is shown in the Figure 48, with an approximate straight-line length of 1450 m.

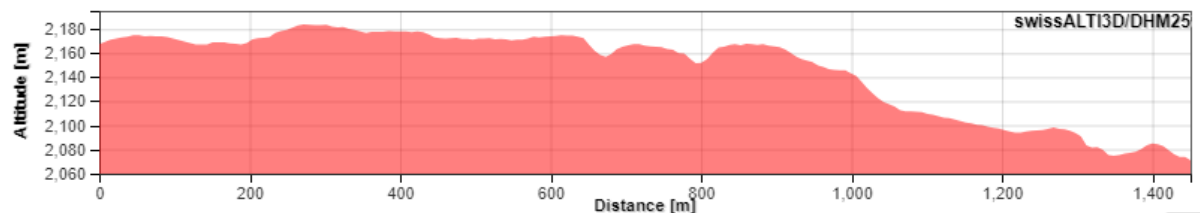


Figure 48 : Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Hydropower plant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 41 provides the difficulty coefficients, Table 42 the reservoirs characteristics, Table 43 the penstock characteristics and Table 44 the powerhouse characteristics.

Table 41 : Difficulty coefficients for site BE4

Components	Difficulty coefficients	Comments
Powerhouse	1.3	Alpine area with seasonal access constraints
Penstock	1.4	Steep alpine slopes and coordination with tourist infrastructure



Table 42 : Reservoirs characteristics of site BE4

Reservoirs characteristics	Values
Upstream reservoir altitude	2'167 m
Upstream reservoir volume	39'770 m ³
Downstream reservoir altitude	2'067 m
Downstream reservoir volume	39'230 m ³
Elevation difference	100 m
Available storage volume	35'000 m ³
Energy storage potential	9.5 MWh

Table 43 : Penstock characteristics of site BE4

Penstock characteristics	Sizing
Material	Steel
Diameter	1'700 mm
Length	1'500 m

Table 44 : Powerhouse equipment characteristics of site BE4

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis	
Number of machine(s) [-]	1	
Net head [m]	95.3	102.2
Operating time [h]	1.6	2.4
Discharge [m ³ /s]	6.17	4.18
Rotation speed [rpm]	750	
Hydraulic power [MW]	5.8	4.2
Mechanical power [MW]	5.2	4.9
Electrical power [MW]	5.0	

Economic analysis

For this site, with a total investment cost of over 21.6 million Swiss francs, and where the penstock diameter is large, the cost of the penstock represents the largest share of the total investment, at just under 48%. In second place, the investment in electromechanical equipment accounts for more than 17% of the total cost.



2.5.5. Summary

Table 45 summarises the hydraulic pumping capacity and the energy storage potential of each Bern site.

Table 45 : Summary of the potential of each Berne site

Sites	P _e [MW]	Energy storage potential [MWh]
BE1	10	118.8
BE2	5	16.2
BE3	5	15.8
BE4	5	9.5
Total	25	160.3

Figure 49 shows the distribution of investment costs for all Berne sites.

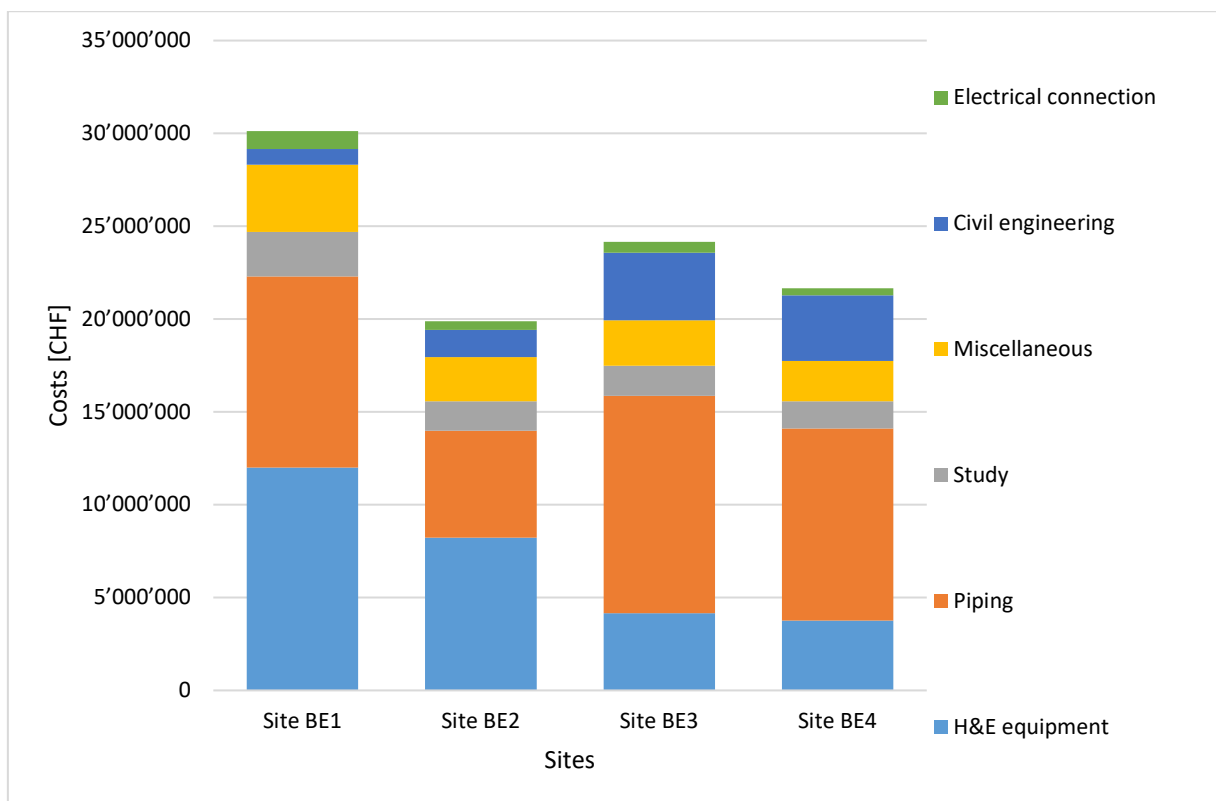


Figure 49: Distribution of investment costs for each Berne site



2.6 Potential sites in the canton of Fribourg

Fribourg canton is composed of approximately 20 lakes. The analysis of the characteristics of each lake showed that 2 pairs having at least a storage of 15 MWh. To have at least 3 sites a third site was added, which requires the building of a new reservoir (FR3). The locations of these sites are shown in Figure 50

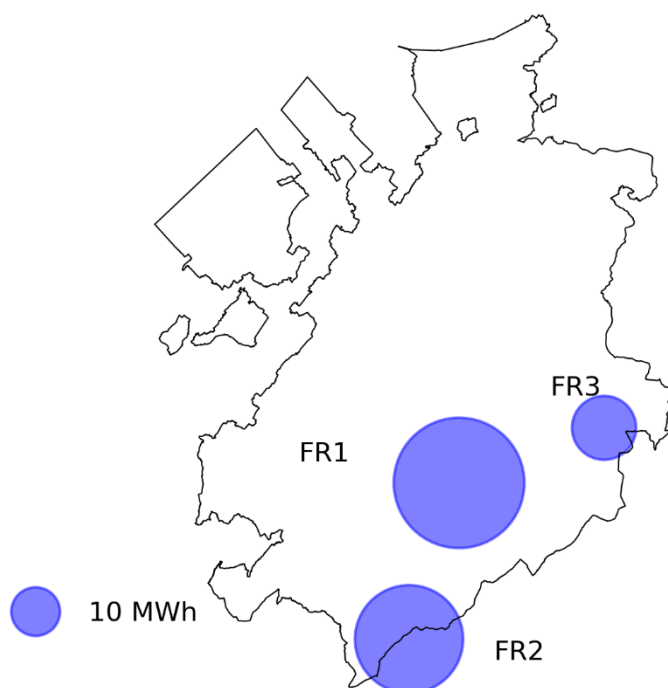


Figure 50: Locations of the economical potential sites in the Fribourg canton. The disc size represents the potential energy storage.

2.6.1.Site FR1: Gruyère – Montsalvens

Context

The aim of this site is to use the storage potential between Gruyère Lake and Montsalvens Lake, located in the Gruyère region, with a difference in levels of 120 m. The usable storage volume is 612'000 m³, which corresponds to a theoretical storage potential of 199 MWh. In the scope of the HiDeStor project, the electrical pump storage output of this site is limited to 10 MW and 71.7 MWh. This site is also present in the E-cube report [40], which focused on large hydropower plant (>60 MW).



Figure 51 shows the location of the existing lakes (Gruyère and Montsalvens) and the approximate route of the penstock in red. The section of the penstock located in the south, which is connected to Montsalvens Lake, is already existing, while the northern section, leading to Gruyère Lake, is a planned segment still to be built.

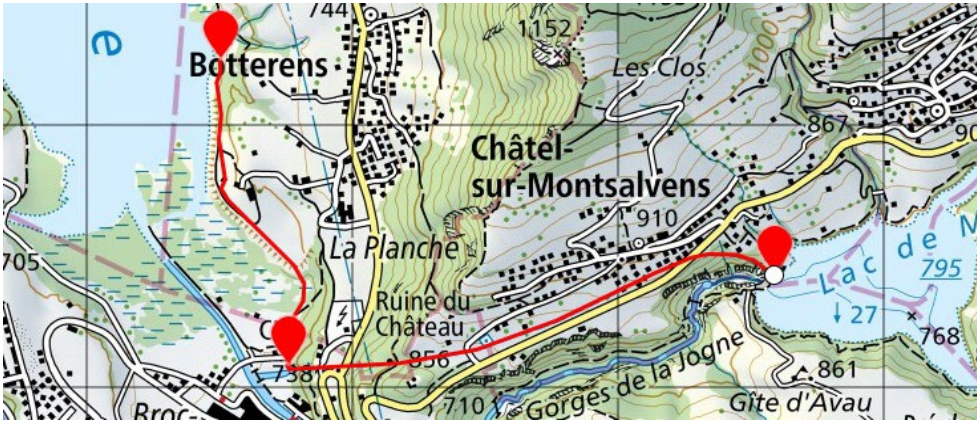


Figure 51 : Location map of Gruyère Lake and Montsalvens Lake with the approximate route of the penstock

The length of the penstock route to be built is estimated at 1305 m.

Hydropower plant characteristics

The following tables summarise the main characteristics of the hydropower plant.

Table 46 : Difficulty coefficients for site FR1

Components	Difficulty coefficients	Comments
Powerhouse	1.2	Semi-urban area with limited construction space
Penstock	1.2	Routing close to housing and transport corridor



Table 47 : Reservoirs characteristics of site FR1

Reservoirs characteristics	Values
Upstream reservoir altitude	797 m
Upstream reservoir volume	12'600'000 m ³
Downstream reservoir altitude	677 m
Downstream reservoir volume	200'000'000 m ³
Elevation difference	120 m
Available storage volume	220'000 m ³
Energy storage potential	71.7 MWh

Table 48 : Penstock characteristics of site FR1 (new section to be constructed)

Penstock characteristics	Sizing
Material	Steel
Diameter	2'000 mm
Length	1'400 m

Table 49 : Powerhouse equipment characteristics of site FR1

Characteristics	Turbine ³	Pump ⁴
Type of machine [-]	Francis (existing)	Multi-stage horizontal axis pump
Number of machines [-]	5	2
Net head [m]	114.8	127.4
Operating time [h]	5.9	9.0
Discharge [m ³ /s]	5x 5.2	2x 3.49
Rotation speed [rpm]	500	750
Hydraulic power [MW]	5x 5.8	2x 4.0
Electrical power [MW]	5x 5.0	2x 5.0

Economic analysis

For this site, which total investment cost amounts to just under 26.8 million Swiss francs, the penstock, with its large diameter, constitutes the main expense item, accounting for nearly 48% of the total. The electromechanical equipment comes second, representing just over 24% of the investment.

³ Source : <https://www.electrobroc.ch/sites/default/files/inline-files/Panneau%20Montsalvens%20-%20Broc.pdf>

⁴ In this case the sizing of the new pump station is limited to 10 MW based on the DSO interviews even though the existing turbine power is higher.



2.6.2.Site FR2: Montbovon – Vernex

The objective of this site is to harness the storage potential created by the elevation difference between Lake Montbovon and Lake Vernex, located in the Intyamon valley, which amounts to 85 m.⁵ The usable storage volume is 213'000 m³, corresponding to a theoretical storage capacity of approximately 49.2 MWh. The corresponding electrical power output of this site is 8.2 MW.

The Figure 52 shows the location of the two lakes as well as the existing penstock route, shown in red. Only a short additional section needs to be built between the current turbine location and Lake Montbovon.



Figure 52 : Location map of Lake Montbovon and Lake Vernex, with the existing route of the penstock

The length of the penstock route to be constructed is estimated 2'975 m, of which only the final 200 m remain to be constructed.

Hydropower plant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 50 provides the difficulty coefficients, Table 51 the reservoirs characteristics, Table 52 the penstock characteristics and Table 53 the powerhouse characteristics.

Table 50 : Difficulty coefficients for site FR2

Components	Difficulty coefficients	Comments
Powerhouse	1.2	Rural site with moderate access constraints
Penstock	1.2	Sloping terrain across agricultural parcels

Table 51 : Reservoirs characteristics of site FR2

Reservoirs characteristics	Values
Upstream reservoir altitude	859 m
Upstream reservoir volume	1'310'000 m ³
Downstream reservoir altitude	774 m
Downstream reservoir volume	1'300'000 m ³

⁵ The natural inflows feeding Lake Vernex are currently such that the Montbovon power plant operates almost entirely in run-of-river mode, without interrupting turbine operation. According to a report published in April 2024 by E-CUBE Strategy Consultants [40], the lake could lose its storage capacity by 2039 if no action is taken. A study has therefore been carried out to assess the feasibility of raising the dam, with three variants under consideration: +1 m, +2 m and +3 m. The viability of pumping into this lake is therefore being questioned.



Elevation difference	85 m
Available storage volume	213'000 m ³
Energy storage potential	49.2

Table 52 : Penstock characteristics of site FR2 (new section to be constructed)

Penstock characteristics	Sizing
Material	Steel
Diameter	1'800 mm
Length	200 m

Table 53 : Powerhouse equipment characteristics of site FR2

Characteristics	Turbine ⁶	Pump ⁷
Type of machine [-]	Francis (existing)	Multi-stage horizontal axis pump
Number of machine(s) [-]	2	2
Net head [m]	80.0	85.8
Operating time [h]	5.0	7.6
Discharge [m ³ /s]	2 · 20.0	2 · 4.08
Rotation speed [rpm]	375	740
Hydraulic power [MW]	2 · 15.5	2 · 3.4
Electrical power [MW]	2 · 13.9	2 · 4.1

Economic analysis

For this site, whose total investment cost amounts to just under 10 million Swiss francs, electromechanical equipment, including the pump, motors and command and control system, accounts for the largest share, representing just under 60% of the total cost. The small section of the penstock to be constructed is the second largest item of expenditure, accounting for just under 15% of the investment cost.

⁶ Source : <https://www.e-periodica.ch/digbib/view?pid=bts-002%3A1977%3A103%3A%3A521>

⁷ In this case the sizing of the new pump is limited to 10MW based on the DSO interviews even though the existing turbine power is higher.



2.6.3.Site FR3: Schwarzsee – New reservoir

The objective of this site is to harness the elevation difference between Lake Schwarzsee, which serves as the downstream reservoir, and a new reservoir that would be located on the Ober Weid alpine pasture, approximately 454 m above it. The usable storage volume is 14'000 m³, which corresponds to a theoretical storage capacity of about 17.3 MWh. The corresponding electrical power output of this site is 5.0 MW.

The Figure 53 illustrates the location of the two reservoirs as well as the approximate route of the penstock in red.



Figure 53 : Location map of Lake Schwarzsee and the new reservoir with the approximate route of the penstock

The longitudinal profile of the penstock route to be constructed is shown in the Figure 54, with an approximate straight-line length of 2'300 metres.

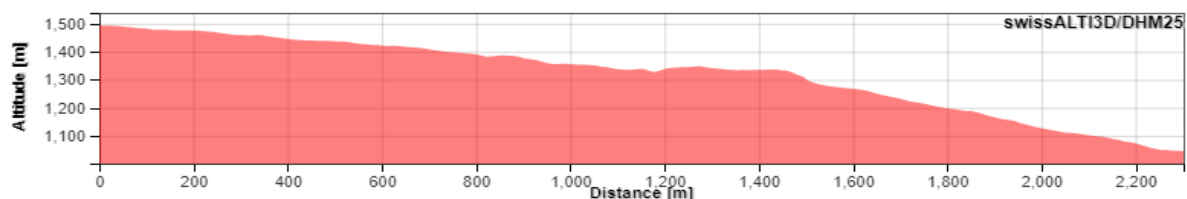


Figure 54 : Approximated longitudinal profile of the penstock from the upstream reservoir to the downstream reservoir

Powerplant characteristics

The following tables summarises the main characteristics of the hydropower plant. Table 54 provides the difficulty coefficients, Table 55 the reservoirs characteristics, Table 56 the penstock characteristics and Table 57 the powerhouse characteristics.

Table 54 : Difficulty coefficients for site FR3

Components	Difficulty coefficients	Comments
Powerhouse	1.2	Lakeside site with direct road access
Penstock	1.4	Steep alpine slope with coactivity from tourist infrastructure



Table 55 : Reservoirs characteristics of site FR3

Reservoirs characteristics	Values
Upstream reservoir altitude	1'500 m
Upstream reservoir volume	15'000 m ³
Downstream reservoir altitude	1'046 m
Downstream reservoir volume	30'000'000 m ³
Elevation difference	454 m
Available storage volume	14'000 m ³
Energy storage potential	17.3

Table 56 : Penstock characteristics of site FR3

Penstock characteristics	Sizing
Material	Ductile iron
Diameter	800 mm
Length	2'400 m

Table 57 : Powerhouse equipment characteristics of site FR3

Characteristics	Turbine	Pump
Type of machine [-]	Pelton	Multi-stage horizontal axis pump
Number of machine(s) [-]	1	1
Net head [m]	435.3	462.6
Operating time [h]	2.9	4.4
Discharge [m ³ /s]	1.36	0.92
Rotation speed [rpm]	1'000	2'980
Hydraulic power [MW]	5.8	4.2
Electrical power [MW]	5.0	

Economic analysis

For this site, whose total investment cost amounts to just under 20 million Swiss francs, electromechanical equipment, including the turbine, pump, motors and command and control system, accounts for the largest share, representing just over 36% of the total cost. The penstock is the second largest expense item, accounting for just under 35% of the investment cost.



2.6.4. Summary

Table 58 summarises the hydraulic pumping capacity, hydraulic turbine capacity and energy storage potential of each Fribourg site. Figure 55 shows the distribution of the investment costs for the different sites in Fribourg canton.

Table 58: Summary of the potential of each site of the canton of Fribourg

Sites	P_e [MW]	Energy storage potential [MWh]
FR1	10.0	71.7
FR2	8.2	49.2
FR3	5.0	17.3
Total	23.2	138.2

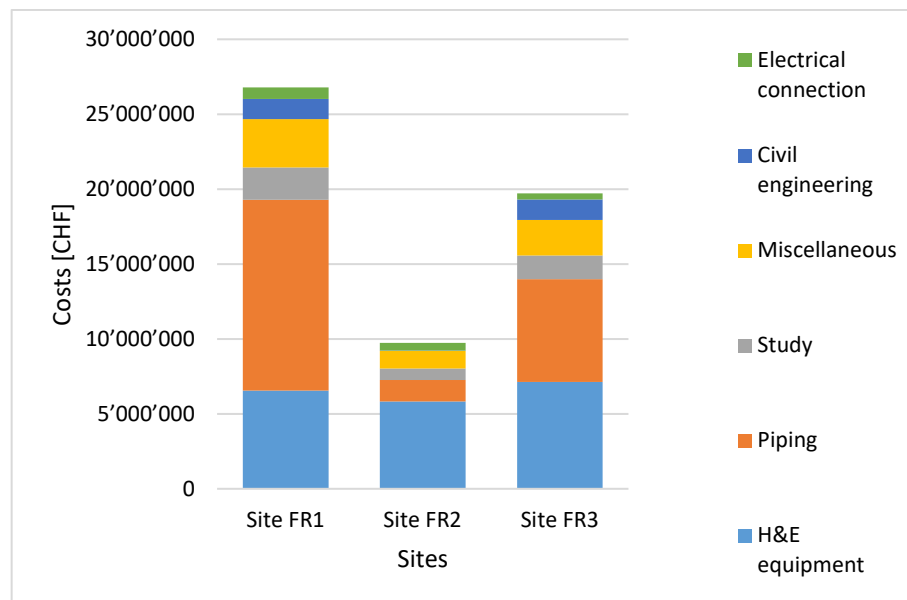


Figure 55: Distribution of investment costs for all Fribourg sites.



2.7 Potential sites in the canton of Vaud

The analysis of potential sites for the canton of Vaud is based on the COGENER project results [15].

Vaud Canton has three main lakes: Lake Léman is by far the largest, followed by Neuchâtel Lake, shared with cantons of Neuchâtel, Fribourg and Bern, and finally Joux Lake.

Potential sites were identified based on the federal geoportal⁸ and the Guichet cartographies cantonal vaudois⁹. Different types of reservoirs (artificial lakes, existing dams, irrigation and snowmaking basins, etc..) were identified and analysed. A total of 94 potential water reservoirs were identified (cf. Figure 56).

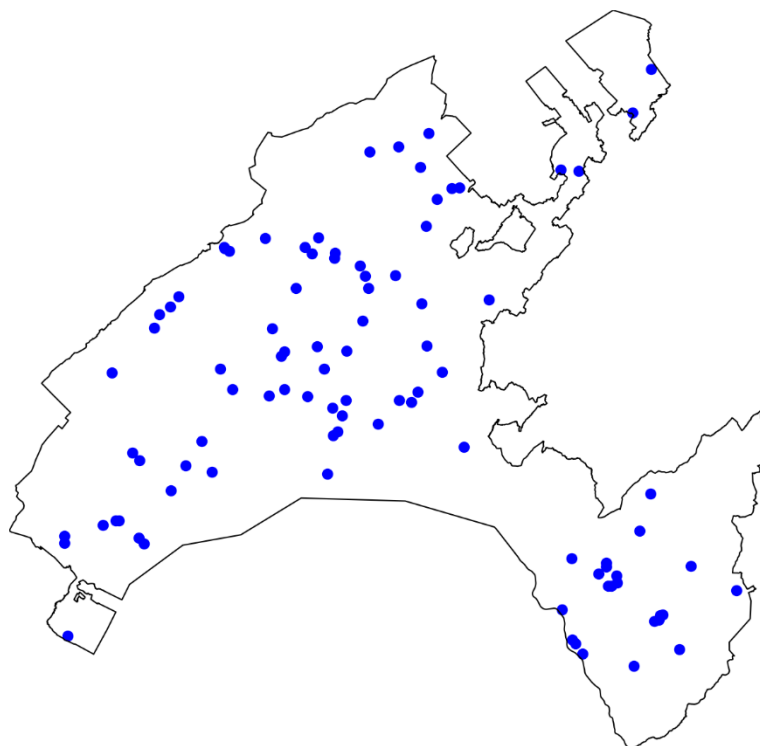


Figure 56 : Locations of potential reservoir in the canton Vaud

The analysis of the 94 potential reservoirs led to the elimination of:

- 9 reservoirs flood control basins as they are not suitable for pumped storage.
- 30 reservoirs for topographical reasons, as the difference in levels was too small.
- 7 reservoirs as the drive were too long (>2km) for moderate gradients (100 or 150m).
- 2 reservoirs as the use of the reservoirs were incompatible with an MS PHS.
- 36 reservoirs for technical reasons (too small capacity).

After applying the first eliminatory criteria, only 10 reservoirs remain eligible.

Between these 10 reservoirs, except for the pair represented by Léman and Bret lakes, no other identified site can be coupled to form a pair of reservoirs. For this reason, it has been chosen to consider only the 5 reservoirs having the greatest potential (see the blue symbols in Figure 57).

⁸ <https://www.geo.admin.ch/en>

⁹ <https://www.geo.vd.ch/themes.htm>

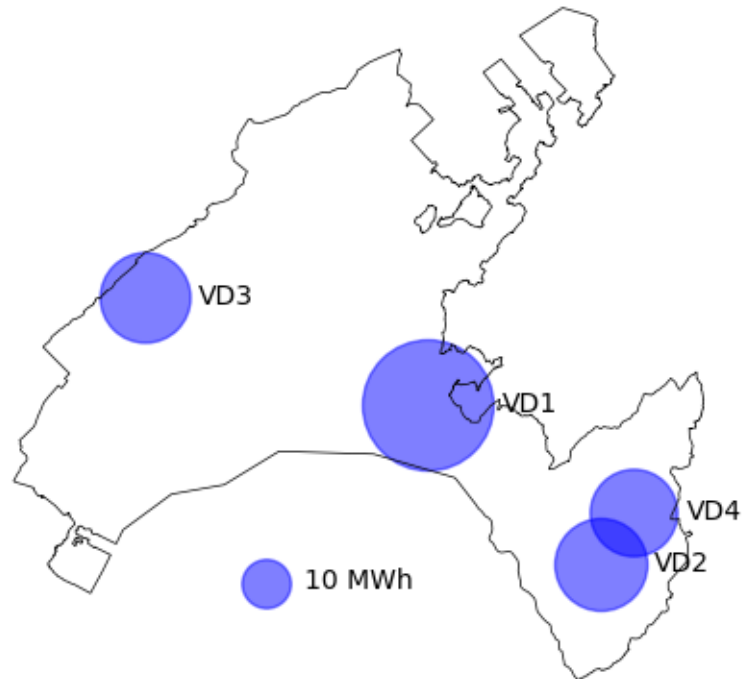


Figure 57 : Locations of the economical potential sites in the Vaud canton.
The disc size represents the potential energy storage.

The description of the sites identified in the canton of Vaud is presented in the following subsections.
Additional information on the sites can be found in the appendices.



2.7.1.Site VD1: Léman Lake – Bret Lake

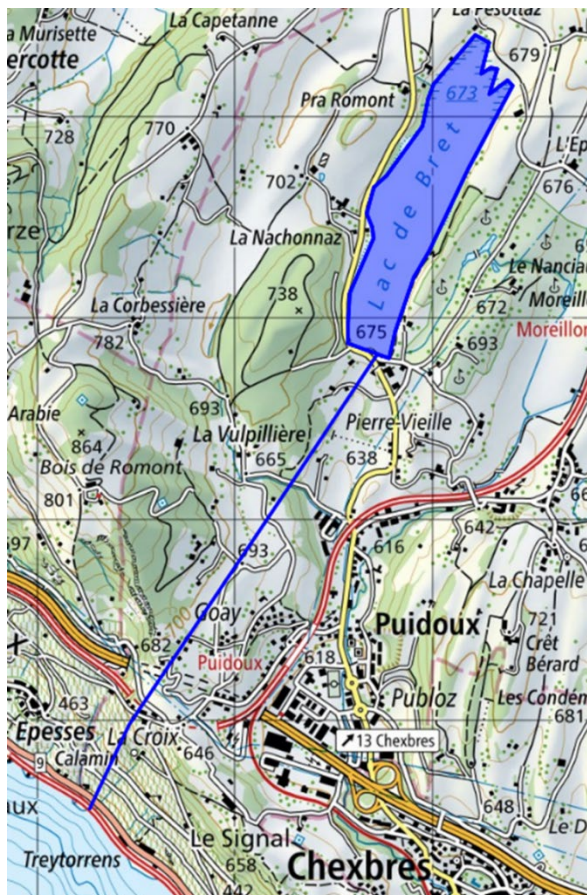


Figure 58 : Location map of the new penstock route linking the two lakes Bret-Geneva.

Context

The objective of this variant is to take advantage from the huge storage potential of Léman Lake (downstream reservoir), by linking it to the Bret Lake (upstream reservoir), see Figure 58. The resulting difference in levels is about 300 m, and the size of the Bret Lake allows a potential storage capacity of 72.0 MWh.

The Bret Lake is used to stock water to produce drinking water. Particular attention must therefore be paid to the multiple uses of this resource. The presence of a particular snail, *Gyraulus crista*, and mussel, the *Anodonta anatina*, both of which have an "endangered" status on the Swiss Red List of Threatened Species, could be a major obstacle to the development of this site for the creation of an MS PHS.

Site plan and longitudinal profile

Given the environmental constraints (UNESCO listed site), the station and the penstock, with a first route of 2.8 km defined straight between the two reservoirs, have to be built underground. As described in the methodology, this pair is considered even though the length of the penstock exceeds the defined limit of 2 km, thanks to its huge potential.

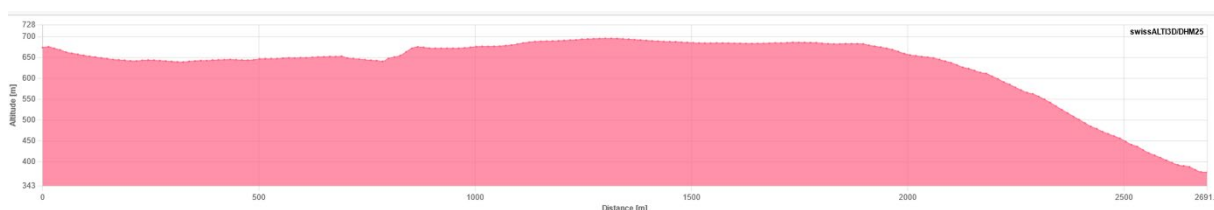


Figure 59 : Longitudinal profile of the penstock's route between the two lakes Bret and Geneva.

Hydropower plant characteristics

Table 59 : Difficulty coefficients for site VD1

Components	Difficulty coefficients	Comments
Powerhouse	1.5	Located in the UNESCO World Cultural heritage.
Penstock	1.5	The penstock is quite long. Its route crosses a motorway tunnel and a railways tunnel. High density area regarding existing infrastructures. It also passes through the UNESCO World Cultural heritage



Table 60 : Reservoirs characteristics of site VD1.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	673
Upstream reservoir volume	m ³	4 300 000
Downstream reservoir altitude	m	370
Downstream reservoir volume	m ³	80 910 000 000
Elevation difference	m	303
Available storage volume	m ³	87 500
Energy storage potential	MWh	72.0

Table 61 : Penstock characteristics of site VD1.

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1 500
Length	m	2 800

Table 62 : Powerhouse equipment characteristics of site VD1.

Characteristics	Turbine	Pump
Type of machine [-]	6-nozzle Pelton turbine	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	2	2
Total nominal discharge [m ³ /s]	4.07	2.78
Net head [m]	295.6	261.5
Operating time [h]	6.0	9.1
Rotation speed [rpm]	750	990
Hydraulic power [MW]	12.1	7.9
Electrical power [MW]	10.0	

Economic analysis (cf. chapter 6.4.4.1)

The distribution of the investment cost is given in Appendix 6.4.4.1 Table 126. The total investment reaches approximately 44 million Swiss Francs which is by far the highest investment of the 26 identified sites. VD1 corresponds to 4'281 CHF/kW, which is very high.



2.7.2.Site VD2: New reservoir - Chavonnes

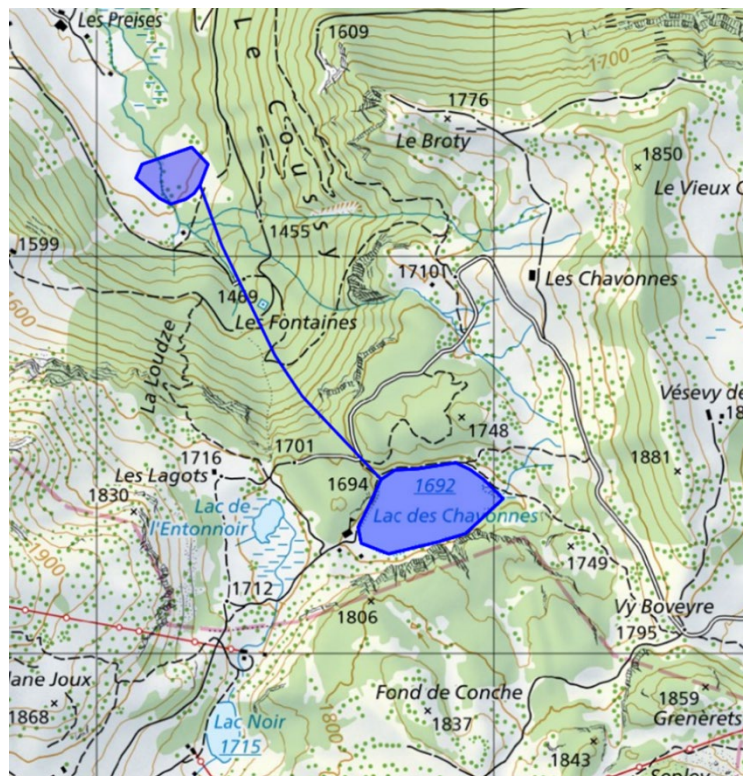


Figure 60 : Situation of the site VD2.

Context

This site uses Chavonnes Lake as the upper reservoir. The estimated volume is sufficient to create a storage capacity of about 35.9 MWh. An artificial reservoir can be built nearby with a resulting differential head of 290m. The situation is presented in Figure 60.

Chavonnes Lake is protected by a classification decree issued by the canton of Vaud in September 1971. This could represent a major problem for the development of this MS PHS site.

Site plan and longitudinal profile

The preliminary route of the pipeline was established based on topographical data, avoiding rocky bars and existing streams. The longitudinal profile is shown in Figure 61, with an approximate length of 980 m.

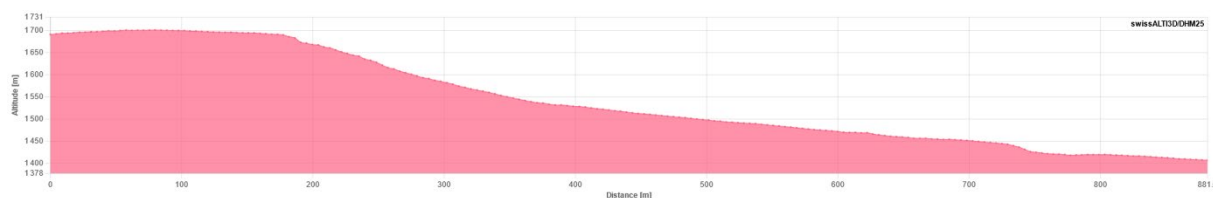


Figure 61 : Longitudinal profile of the penstock's route for site VD2.

Powerplant characteristics

Table 63 : Difficulty coefficients for site VD2.

Components	Difficulty coefficients	Comments
New reservoir	1.5	The access by road is difficult for large machinery.
Powerhouse	1.0	To be built near the new reservoir.
Penstock	1.4	The penstock route runs through a steep area and the access via the existing road is difficult for large machinery.



Table 64 : Reservoirs characteristics of site VD2.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1692
Upstream reservoir volume	m ³	519 000
Downstream reservoir altitude	m	1402
Downstream reservoir volume	m ³	45 655
Elevation difference	m	290
Available storage volume	m ³	45 600
Energy storage potential	MWh	35.9

Table 65 : Penstock characteristics of the site VD2.

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1 100
Length	m	980

Table 66 : Powerhouse equipment characteristics of site VD2.

Characteristics	Turbine	Pump
Type of machine [-]	6-nozzle Pelton turbine with a vertical axis	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	1	2
Nominal discharge [m ³ /s]	2.98	2.04
Net head at nominal discharge [m]	283.1	293.2
Operating time [h]	4.3	6.5
Rotation speed [rpm]	750	980
Hydraulic power [MW]	8.4	5.5
Electrical power [MW]	7.0	

Economic analysis (cf. chapter 6.4.4.2)

The total investment reached approximately to 24.3 million Swiss Francs, i.e. 3'379 CHF/kW. The main investment is in H&E equipment, which accounts for 43% of the total price.



2.7.3.Site VD3: Joux - New reservoir



Figure 62 : Situation of the site VD3.

Context

This case uses Joux Lake as the lower natural reservoir. Given its volume, the effect on the tidal is negligible. The capacity is more than sufficient to create an MS PHS with a capacity of 34.3 MWh.

An artificial reservoir can be built nearby with a resulting differential head of 316 m. Its layout is based on topology and takes account of access roads and wooded areas.

Joux Lake and the new reservoir are located within the area of the “Regional Nature Park”, which is protected in accordance with the Federal Act on the Protection of Nature and Cultural Heritage, 1st July 1966)¹⁰. This could represent a major problem for the development of this MS PHS site.

Site plan and longitudinal profile

The preliminary route of the pipeline was established based on topographical data. The longitudinal profile is shown in Figure 63, with an approximate length of 1'100 m.

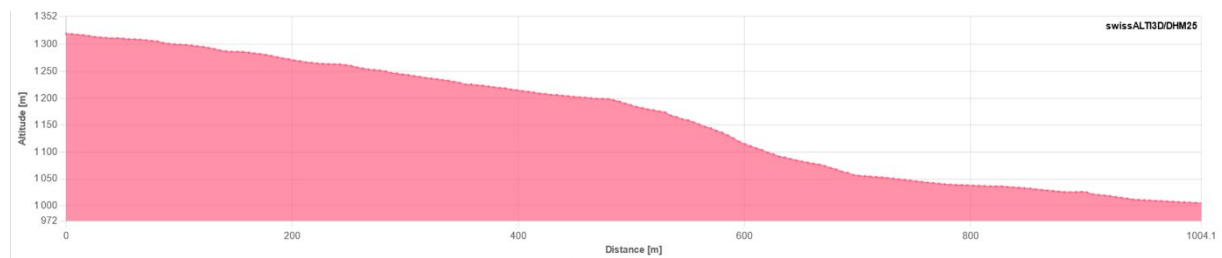


Figure 63 : Longitudinal profile of the penstock's route for site VD3.

Hydropower plant characteristics

The following tables summarise the main characteristics of the site.

Table 67 : Difficulty coefficients for site VD3

Components	Difficulty coefficients	Comments
New reservoir	1.0	The access road to La Coche provides access to the upper reservoir.
Powerhouse	1.0	The powerhouse is accessible via the cantonal road.
Penstock	1.5	The penstock route crosses a wooded area and two roads.

¹⁰ <https://map.geo.admin.ch>.



Table 68 : Reservoirs characteristics of site VD3.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1320
Upstream reservoir volume	m ³	43 900
Downstream reservoir altitude	m	1004
Downstream reservoir volume	m ³	43 900
Elevation difference	m	316
Available storage volume	m ³	40 000
Energy storage potential	MWh	34.3

Table 69 : Penstock characteristics of the site VD3.

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1 000
Length	m	1 100

Table 70 : Powerhouse equipment characteristics of site VD3.

Characteristics	Turbine	Pump
Type of machine [-]	6-nozzle Pelton turbine with a vertical axis	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	1	2
Nominal discharge [m ³ /s]	2.73	1.86
Net head at nominal discharge [m]	305.2	321.0
Operating time [h]	4.1	6.2
Rotation speed [rpm]	750	980
Hydraulic power [MW]	8.4	5.5
Electrical power [MW]	7.0	

Economic analysis (cf. chapter 6.4.4.3)

The total investment reached approximately to 23.8 million Swiss Francs, i.e. 3'348 CHF/kW. The main investment is in H&E equipment, which accounts for 43% of the total price.



2.7.4.Site VD4: New reservoir – Lioson



Figure 64 : Situation of the site VD4.

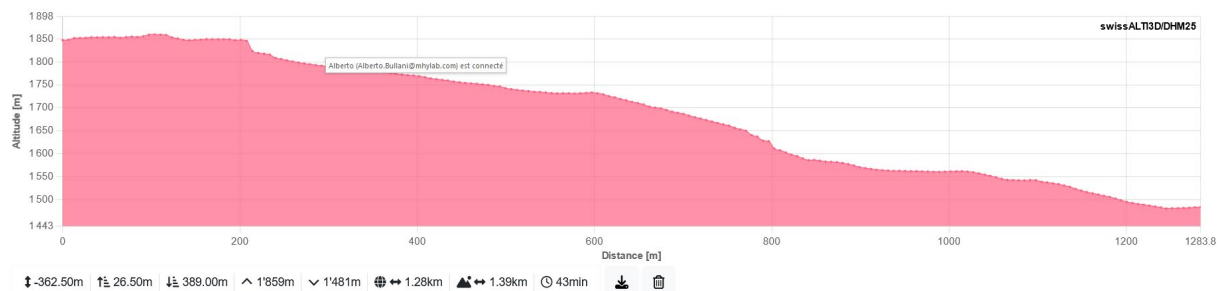


Figure 65 : Longitudinal profile of the penstock's route for site VD4.

Hydropower plant characteristics

The following tables summarises the main characteristics of the site.

Table 71 : Difficulty coefficients for site VD4.

Components	Difficulty coefficients	Comments
New reservoir	1.0	The reservoir is reached from the Ch. de Praz Cornet road.
Powerhouse	1.1	To be built near the new reservoir.
Penstock	1.3	The penstock route runs through a wooded area.

Context

This case uses Lioson Lake as the upper reservoir. The estimated volume is sufficient to create a storage capacity of about 31.9 MWh.

An artificial reservoir can be built nearby with a resulting differential head of 367 m. The situation is presented in Figure 64.

Lioson Lake borders a large mire area. The penstock and the new reservoirs are located in the marshland. The fact that this is a natural protected area could represent a major obstacle to the development of an MS PHS.

Site plan and longitudinal profile

The preliminary route of the pipeline was established based on topographical data. It runs along the road leading to the upper lake for half its length. The longitudinal profile is shown on the Figure 65, with an approximate length of 1'350 m.



Table 72 : Reservoirs characteristics of site VD4.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1848
Upstream reservoir volume	m ³	846 000
Downstream reservoir altitude	m	1481
Downstream reservoir volume	m ³	36 000
Elevation difference	m	367
Available storage volume	m ³	32 000
Energy storage potential	MWh	31.9

Table 73 : Penstock characteristics of the site VD4

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	900
Length	m	1 350

Table 74 : Powerhouse equipment characteristics of site VD4.

Characteristics	Turbine	Pump
Type of machine [-]	6-nozzle Pelton turbine with a vertical axis	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	1	2
Nominal discharge [m ³ /s]	2.35	1.59
Net head at nominal discharge [m]	350.9	374.8
Operating time [h]	3.8	5.7
Rotation speed [rpm]	1 000	1716
Hydraulic power [MW]	8.4	5.5
Electrical power [MW]	7.0	

Economic analysis (cf. chapter 6.4.4.4)

The total investment reached approximately to 21.8 million Swiss Francs, i.e. 3'103 CHF/kW. The main investment is in H&E equipment, which accounts for almost 50% of the total price.



2.7.5. Summary

The following table presents the electrical capacity and energy storage potential of each site of the canton of Vaud.

Table 75 : Summary of the potential of each site of the canton of Vaud

Sites	P_e [MW]	Energy storage potential [MWh]
VD1	10.0	72.0
VD2	7.0	35.9
VD3	7.0	34.3
VD4	7.0	31.9
Total	31.0	174.1

The following figure shows the distribution of investment costs for each site of the canton of Vaud.

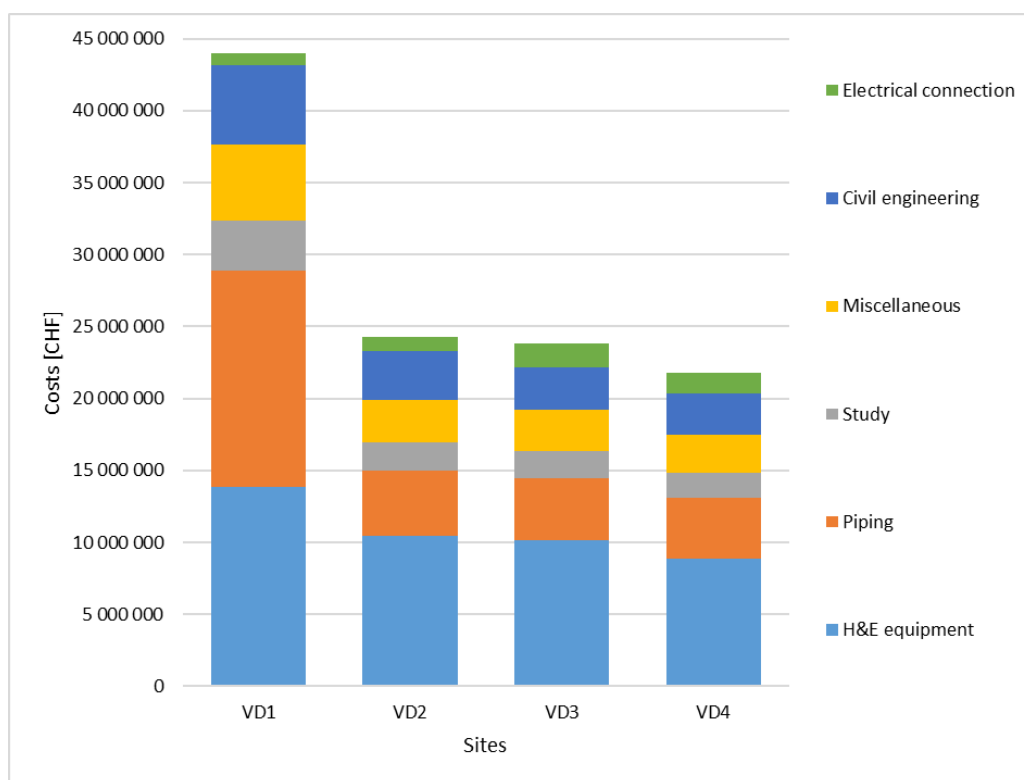


Figure 66 : Distribution of investment costs for each site of the canton of Vaud



2.8 Potential sites in the canton of Jura

Jura canton presents no important lakes, but several small ones. There are no pairs of reservoirs (which means the necessity to create new reservoirs).

Figure 67 summarises the economic potentials of the identified sites for Jura canton.

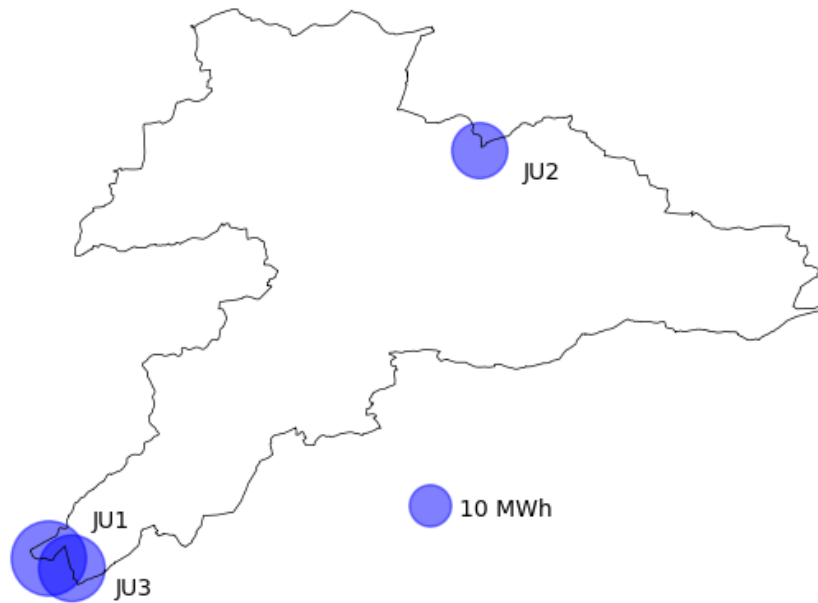


Figure 67 : Locations of the economic potential sites in the Jura canton. The disc size represents the potential energy storage

The description of the sites identified in the canton of Jura is presented in the following subsections. Additional information on the sites can be found in the appendices.



2.8.1.Site JU1: Biaufond

Context

The objective of this site is to use the storage potential of Biaufond Lake. As shown in Figure 68, Biaufond Lake is created by the Refrain dam set on Doubs River, a cross-border water stream between Switzerland and France. This water stream can be considered as under surveillance on different environmental, economic and political aspects, such as fish migration, sediment transport, and electricity production.

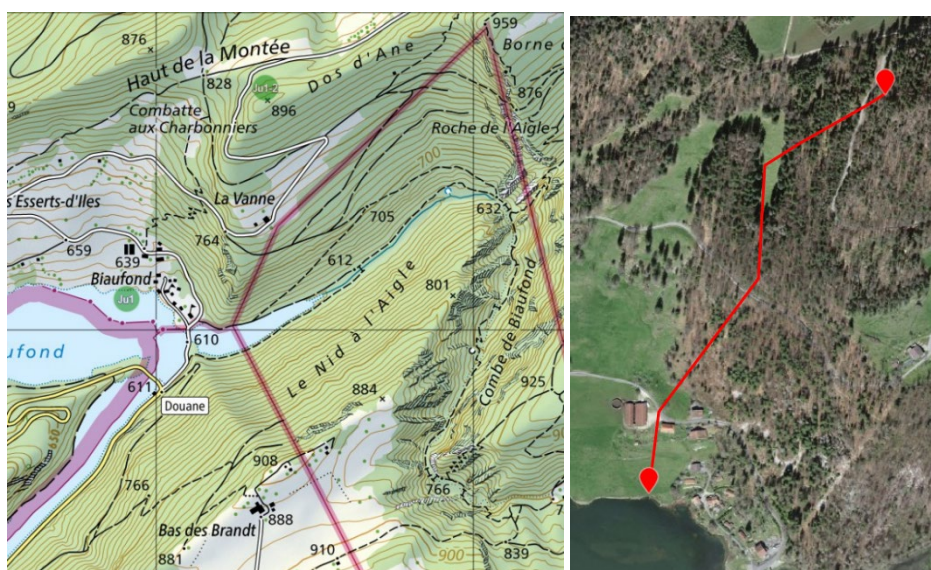


Figure 68 : Global view of Biaufond Lake / Figure 69 Location map of the new upstream reservoir with the route of the penstock from this reservoir to Biaufond Lake

Site plan

The new reservoir would be built at the highest area in the surroundings of Biaufond lake, close to a road. A first penstock route of about 0.8 km has been mainly defined by following the existing roads and paths.

Hydropower plant characteristics

Table 76 : Difficulty coefficients of site JU1

Components	Difficulty coefficients	Comments
New reservoir	1.3	Steep area
Powerhouse	1.1	No technical difficulties in front of the social and ecological acceptance feasibility
Penstock	1.3	Steep area - but the main difficulty concerns the project acceptance



Table 77 : Reservoirs characteristics for the site JU1

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	873.0
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	610.0
Downstream reservoir volume	m ³	2'350'000
Elevation difference	m	263
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	32.1
Electrical power	MW	7.1

Table 78 : Penstock characteristics for the site JU1

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1000
Length	m	830

Table 79 : Powerhouse equipment characteristics for the site JU1

Characteristics	Turbine	Pump
Type of machine [-]	Pelton	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	1	2
Total nominal discharge [m ³ /s]	3.33	2.26
Nominal discharge per machine [m ³ /s]	3.33	1.13
Net head at nominal discharge [m]	251.0	268.5
Operating time [h]	3.8	5.7
Rotation speed [rpm]	750	980
Hydraulic power [MW]	8.6	5.6
Electrical power [MW]	7.1	
Electricity production / consumption [MWh/cycle]	26.8	40.6

Economic analysis (cf. appendix 6.4.5.1)

For this site, which requires separate equipment for pump and turbine cycles, the electromechanical investment component, including the pump, turbine, motors, and control-command system, represents the largest share, amounting to over 50% of the total investment cost (54%). Then the piping, the miscellaneous and the civil engineering share approximatively the second major expense.

This site is close to VD2 characteristics.



2.8.2.Site JU2: Etang de Lucelle

Context

The objective of this site is to use the storage potential of the natural pond of Lucelle situated in the commune of Pleigne, on the Lucelle water stream. This small lake is also close to the French border. This pond is surrounded by slopes. At this step of the project, the chosen site considers the highest slope so as to reduce the length of the penstock. The project would consist then in creating a new reservoir at the highest and closest point in the surroundings. The main difficulty for this site is the fact that in this area there are almost no infrastructures, nor buildings, nor farms.

Site plan



Figure 70 : Location map of the new upstream reservoir with the route of the penstock from this reservoir to Etang de Lucelle

A first penstock route has been defined by following the existing paths and roads. Its longitudinal profile is shown in Figure 71 with an approximate length of 0.7 km.



Figure 71 : Longitudinal profile of the penstock's route from the new upstream reservoir to Etang de Lucelle

Hydropower plant characteristics

The following tables summarise the main characteristics of the site: difficulty coefficients, reservoirs and penstock characteristics.

Table 80 : Difficulty coefficients of the site JU2

Components	Difficulty coefficients	Comments
New reservoir	1.3	Steep area
Powerhouse	1.1	No technical difficulties in front of the social and ecological acceptance feasibility
Penstock	1.3	Steep area - but the main difficulty concerns the project acceptance



Table 81 : Reservoirs characteristics of the site JU2

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	745.6
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	600.0
Downstream reservoir volume	m ³	210'000
Elevation difference	m	145.6
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	17.8

Table 82 : Penstock characteristics of the site JU2

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1200
Length	m	660

Table 83 : Powerhouse equipment characteristics the site JU2

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis turbine	
Number of machines [-]	1	
Nominal discharge per machine [m ³ /s]	4.24	2.88
Net head at nominal discharge [m]	139.6	148.4
Operating time [h]	3.0	4.5
Rotation speed [rpm]	1 000	
Hydraulic power [MW]	6.0	4.0
Electrical power [MW]	5.0	
Electricity production / consumption [MWh/cycle]	14.9	22.5

Economic analysis (cf. chapter 6.4.5.2)

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (21%). Civil engineering and piping represent more than half of the cost (55 %).

JU2 is close to VS 5 and NE2 (cf. chapter 2.4.5).



2.8.3.Site JU3: Cul des Prés

Context

The objective of this variant is to use the storage potential of the natural lake of Cul des Prés situated in the commune of Les Bois in the Jura canton and in the commune of La Ferrière in the Bern canton. This lake is close to a pond situated within a golf club. At this step of the project, this pond has not been selected as an interesting reservoir, in front of its situation and size and the length of the new penstock, as the area around the golf is quite flat.

A new reservoir would be built at the highest point in the surroundings of Cul des Prés Lake.

Site plan

The site is set within a natural area with almost no infrastructure and a few roads.

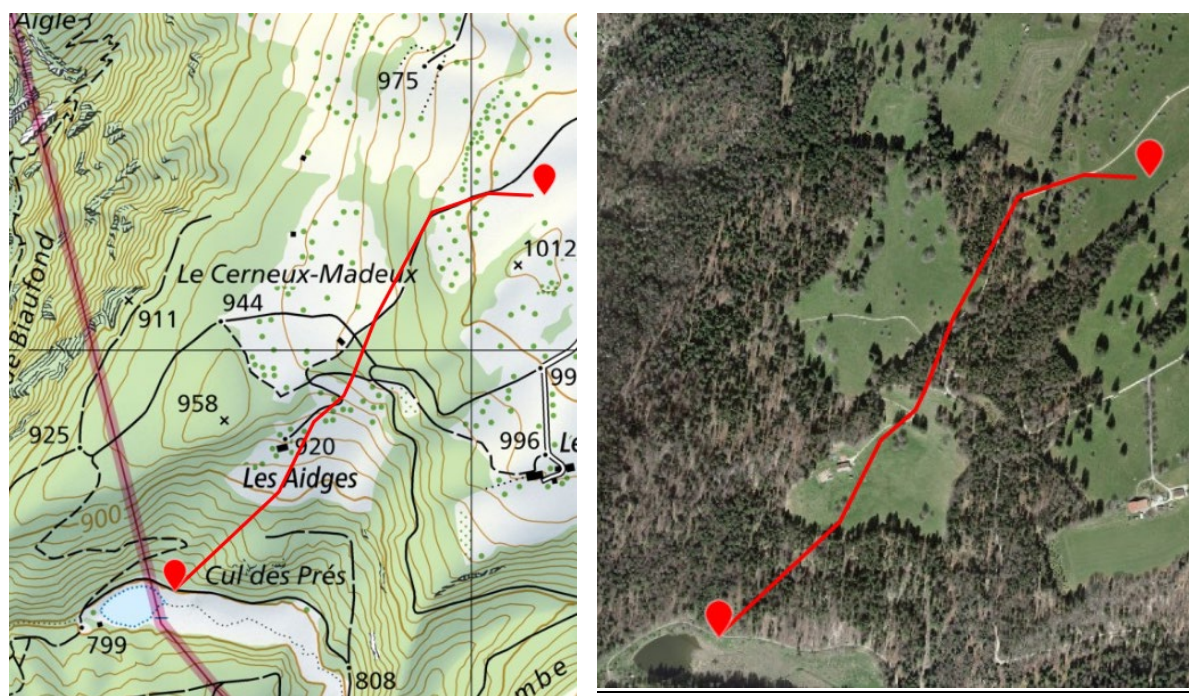


Figure 72 : Location map of the new upstream reservoir with the route of the penstock from this reservoir to le Cul-des-Prés Lake

A first penstock route has been defined by following the existing paths and roads.

Hydropower plant characteristics

The following tables summarise the main characteristics of the site.

Table 84 : Difficulty coefficients for the site JU3

Components	Difficulty coefficients	Comments
New reservoir	1.1	Accessible and flat area
Powerhouse	1.2	Accessible area
Penstock	1.3	Steep area



Table 85 : Reservoirs characteristics of the site JU3

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1004.0
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	798.0
Downstream reservoir volume	m ³	125'000
Elevation difference	m	206
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	25.2

Table 86 : Penstock characteristics of the site JU3

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1200
Length	m	1130

Table 87 : Powerhouse equipment characteristics of the site JU3

Characteristics	Turbine	Pump
Type of machine [-]	Reversible Francis turbine	
Number of machines [-]	1	
Nominal discharge per machine [m ³ /s]	3.53	2.41
Net head at nominal discharge [m]	198.8	209.3
Operating time [h]	3.5	5.4
Rotation speed [rpm]	1 000	
Hydraulic power [MW]	7.1	4.7
Electrical power [MW]	6.0	
Electricity production / consumption [MWh/cycle]	21.2	31.8

Economic analysis (cf. chapter 6.4.5.3)

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (14%). Civil engineering and piping represent more than half of the cost (57 %).



2.8.4. Summary

The following table presents the electrical capacity and energy storage potential of each site of the canton of Jura.

Table 88 : Summary of the potential of each site of the canton of Jura

Sites	P _e [MW]	Energy storage potential [MWh]
JU1	7.1	32.1
JU2	5.0	17.8
JU3	6.0	25.2
Total	18.2	75.1

The following figure shows the distribution of investment costs for each site of the canton of Jura.

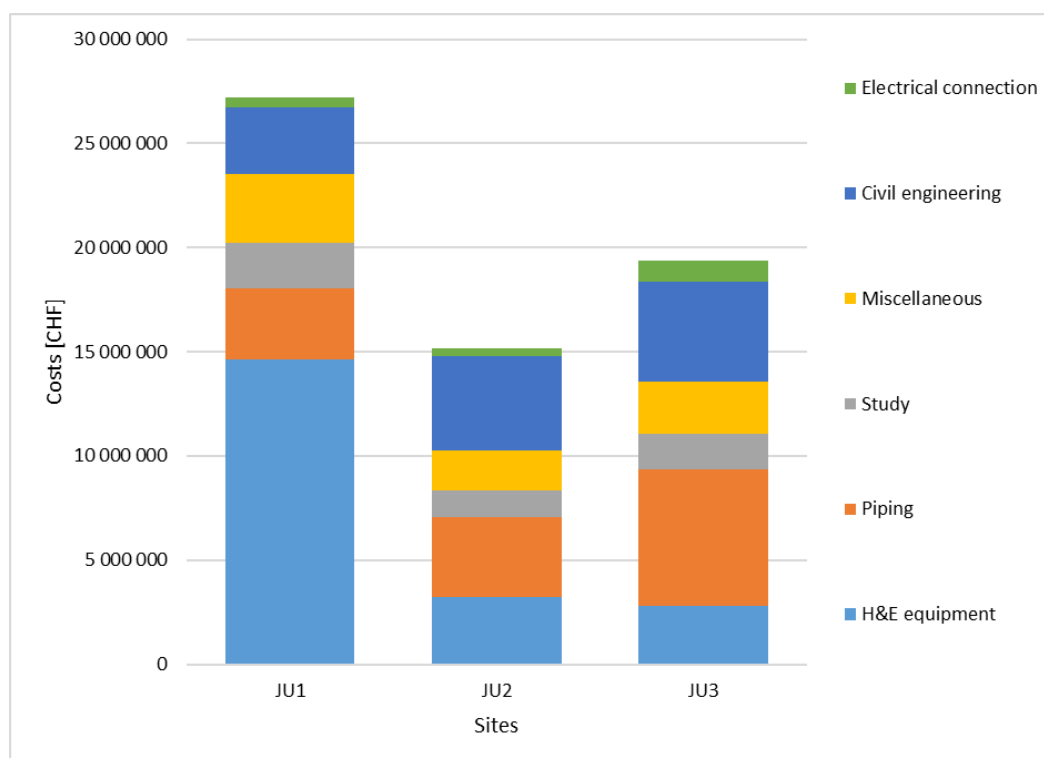


Figure 73 : Distribution of investment costs for each site of the canton of Jura



2.9 Potential sites in the canton of Neuchâtel

Neuchâtel canton presents several lakes, Neuchâtel Lake being by far the biggest, shared with Vaud, Fribourg and Bern cantons. But there are no pairs of reservoirs.

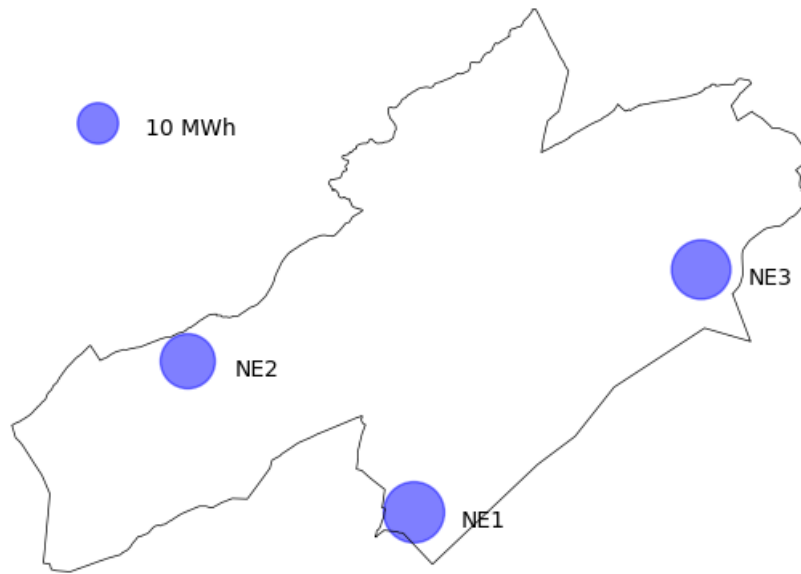


Figure 74 : Locations of the technical potential sites in Neuchâtel canton. The disc size represents the potential energy storage



2.9.1.Site NE1: Neuchâtel

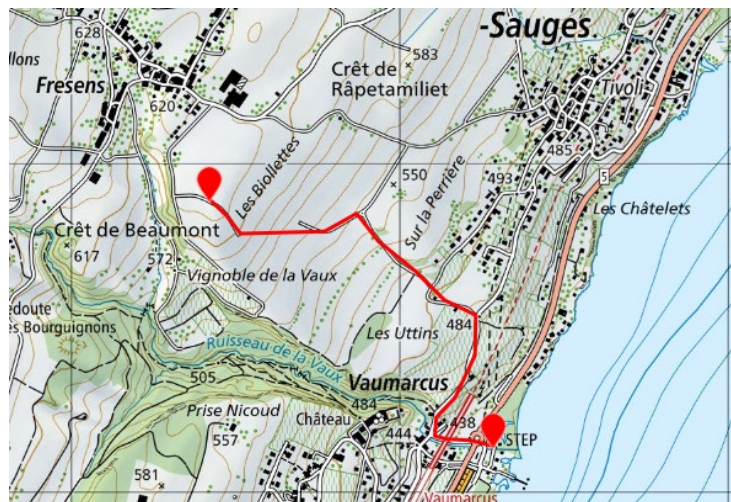


Figure 75 : Location map of the new upstream reservoir with the route of the penstock from this reservoir to Neuchâtel Lake

This site is here considered by supposing that:

- This area could also be crossed by a penstock.
- Sufficient space would remain on the border of the lake to set up a station.
- A reservoir could be created respecting the criteria listed in the chapter describing the methodology.

The station would be close to the existing wastewater treatment plant (referred to STEP for station d'épuration in Figure 75). The upstream reservoir would be created close to the centre of Fresens, in an agricultural area. A first penstock route has been defined by following the existing roads. The site of the powerhouse has been especially chosen as it is already used for technical purposes and by the fact that a road crosses the railway lines under a bridge.

Hydropower plant characteristics

The following tables summarise the main characteristics of the site.

Table 89 : Difficulty coefficients for the site

Components	Difficulty coefficients	Comments
New reservoir	1.0	Built in an accessible area, used nowadays for agriculture purposes. No vineyards should be impacted.
Powerhouse	1.4	Limited space between a main road, the wastewater treatment plant and the lake
Penstock	1.5	The penstock stock route depends on the possibility to follow the present roads which cross the motorway and the railways under a bridge. High density area regarding existing infrastructures.

Context

The objective of this site is to use the huge storage potential of Neuchâtel Lake.

In the canton of Neuchâtel, the lake is bordered by major roads, railway tracks and residential areas. The most suitable area to plan a storage station could be in Vaumarcus locality (La Grande Béroche commune).



Table 90 : Reservoirs characteristics of the site NE1

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	615.0
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	432.5
Downstream reservoir volume	m ³	14.10 ⁹
Elevation difference	m	182.5
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	22.3

Table 91 : Penstock characteristics of the site NE1

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1300
Length	m	1600

Table 92 : Powerhouse equipment characteristics of the site NE1

Characteristics	Turbine	Pump
Type of machine [-]	one reversible Francis turbine	
Nominal discharge per machine [m ³ /s]	3.72	2.52
Net head at nominal discharge [m]	175.1	190.9
Operating time [h]	3.4	5.1
Rotation speed [rpm]	1 000	
Hydraulic power [MW]	6.6	4.4
Electrical power [MW]	5.6	
Electricity production / consumption [MWh/cycle]	18.7	28.1

Economic analysis (cf. chapter 6.4.6.1)

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (14%). Civil engineering and piping represent more than half of the cost (57 %).

NE1 is close to NE3.



2.9.2.Site NE2: Taillères

Context

The objective of this variant is to use the storage potential of natural lake of Taillères situated in the commune of La Brévine, a lake close to the French border. This side of the lake is quite flat compared to the other one. The project would consist in creating a new reservoir at the highest point in the surroundings considering the parameters of the methodology. The main difficulty for this site is the fact that in this area there are almost no infrastructure, nor buildings, nor farms.

Site plan



Figure 76 : Location map of the new upstream reservoir with the route of the penstock from this reservoir to Taillères Lake

A first penstock route has been defined by following the existing paths and roads.

Hydropower plant characteristics

The following tables summarise the main characteristics of the site.

Table 93 : Difficulty coefficients for the site

Components	Difficulty coefficients	Comments
New reservoir	1.1	In an accessible area, but within a natural landscape
Powerhouse		
Penstock		



Table 94 : Reservoirs characteristics of the site

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1185.0
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	1038.0
Downstream reservoir volume	m ³	2'250'000
Elevation difference	m	147
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	18.0

Table 95 : Penstock characteristics of the site

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1400
Length	m	1600

Table 96 : Powerhouse equipment characteristics of the site

Characteristics	Turbine	Pump
Type of machine [-]	one reversible Francis turbine	
Nominal discharge per machine [m ³ /s]	4.19	2.85
Net head at nominal discharge [m]	140.6	154.9
Operating time [h]	3.4	5.1
Rotation speed [rpm]	1 000	
Hydraulic power [MW]	6.0	4.0
Electrical power [MW]	5.0	
Electricity production / consumption [MWh/cycle]	15.0	22.7

Economic analysis (cf. chapter 6.4.6.2)

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (13%). Piping costs represents almost half of the cost (48 %).

NE2 is close to JU2 and VS 5 (cf. chapter 2.4.5).



2.9.3.Site NE3: Le Loclat

Context

The objective of this variant is to use the storage potential of natural lake of Le Loclat situated in the commune of Cornaux, close to Neuchâtel Lake. These lakes cannot be considered as a pair for the HiDeStor project as the difference in water levels between them is around 10 meters.

A new reservoir would be created at the highest point in the surroundings of Le Loclat Lake.

Site plan

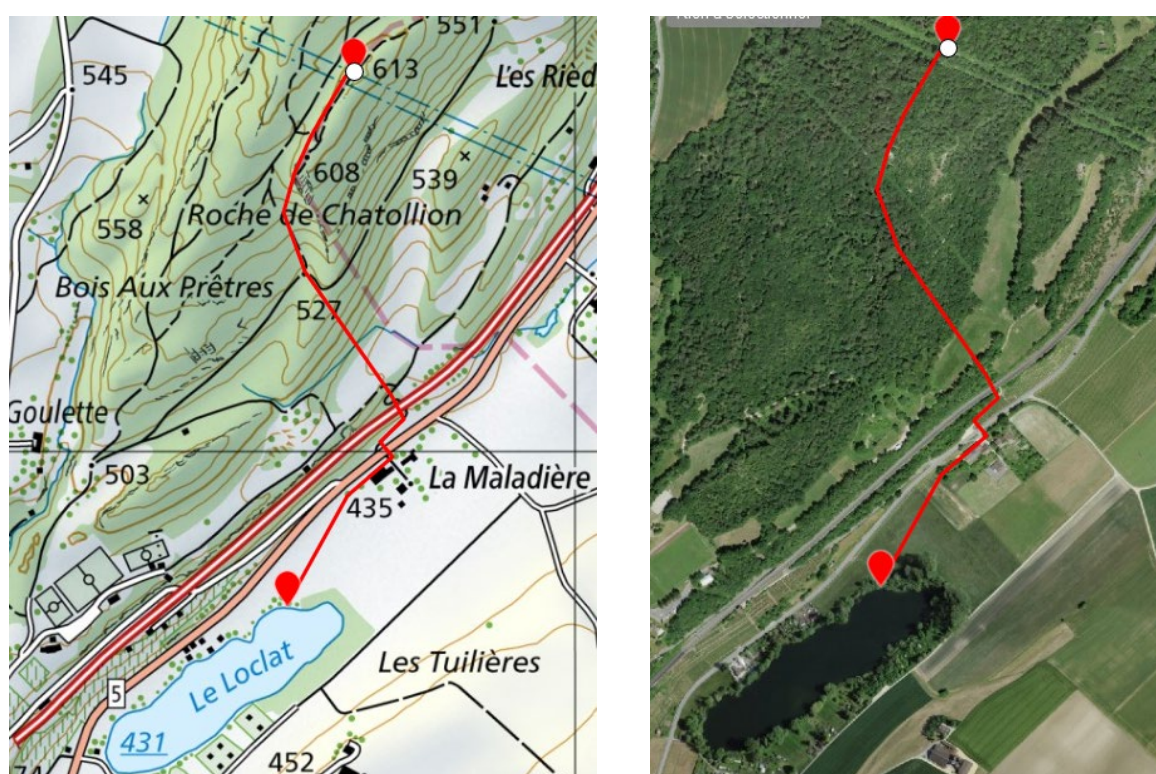


Figure 77 : Location map of the new upstream reservoir with the route of the penstock from this reservoir to le Loclat Lake

A first penstock route has been defined by following the existing paths and roads.

Hydropower plant characteristics

The following tables summarise the main characteristics of the site.

Table 97 : Difficulty coefficients for the site

Components	Difficulty coefficients	Comments
New reservoir	1.4	Steep, inaccessible area
Powerhouse	1.1	Accessible area, no difficulties if ecological issues are not considered
Penstock	1.3	The penstock stock route depends on the possibility to follow the present road which crosses the railway tracks under a bridge.



Table 98 : Reservoirs characteristics of the site NE3

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	604.7
Upstream reservoir volume	m ³	50'000 (new reservoir)
Downstream reservoir altitude	m	431.7
Downstream reservoir volume	m ³	420'000
Elevation difference	m	173
Available storage volume	m ³	45'000
Energy storage potential	MWh/cycle	21.1

Table 99 : Penstock characteristics of the site NE3

Penstock characteristics	Units	Sizing
Material		Ductile iron
Diameter	mm	1200
Length	m	1100

Table 100 : Powerhouse equipment characteristics of the site NE3

Characteristics	Turbine	Pump
Type of machine [-]	one reversible Francis turbine	
Nominal discharge per machine [m ³ /s]	3.85	2.61
Net head at nominal discharge [m]	164.7	18.1.7
Operating time [h]	3.2	4.9
Rotation speed [rpm]	1 000	
Hydraulic power [MW]	6.5	4.3
Electrical power [MW]	5.4	
Electricity production / consumption [MWh/cycle]	17.6	26.7

Economic analysis (cf. chapter 6.4.6.3)

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (16%). Piping costs and civil engineering represent more than half of the cost (60 %).

NE3 is close to NE1.



2.9.4. Summary

The following table presents the electrical capacity and energy storage potential of each site of the canton of Neuchâtel.

Table 101 : Summary of the potential of each site of the canton of Neuchâtel.

Sites	P_{eP} [MW]	P_{eT} [MW]	Energy storage potential [MWh]
NE1	5.6	5.6	22.3
NE2	5.0	5.0	18.0
NE3	5.4	5.4	21.1
Total	16.0	16.0	61.4

The following figure shows the distribution of investment costs for each site of the canton of Neuchâtel.

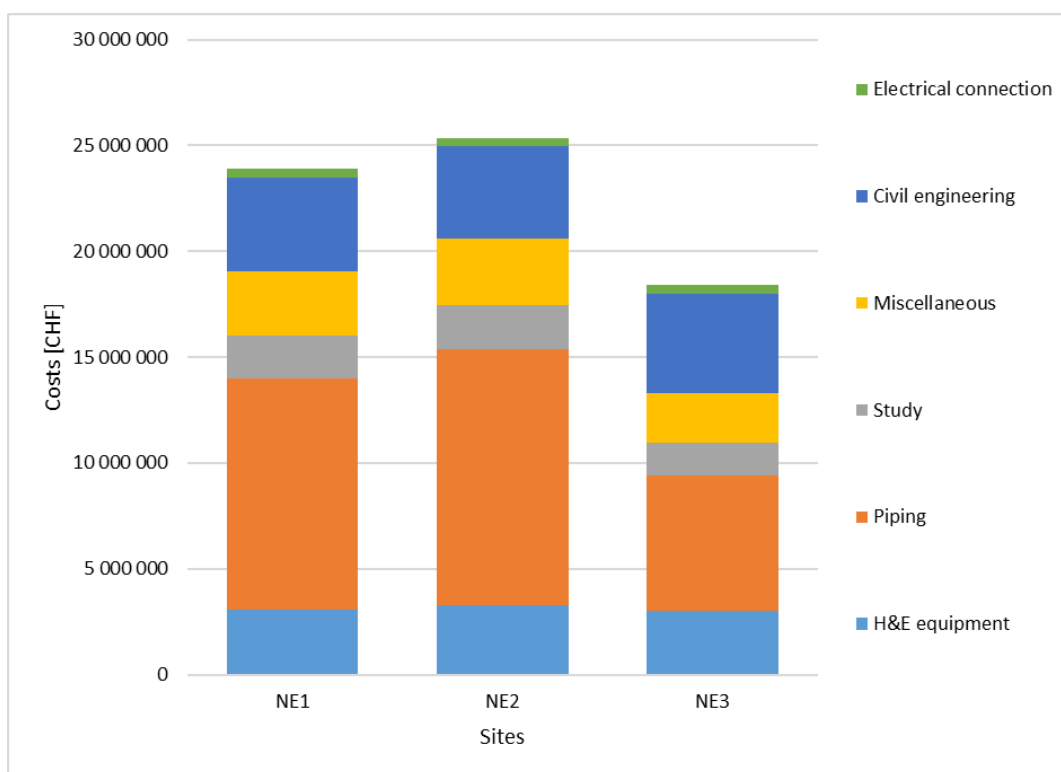


Figure 78 : Distribution of investment costs for each site of the canton of Neuchâtel.



2.10 Potential sites in the canton of Ticino

As the Valais canton, the canton of Ticino is an Alpine canton characterised by high mountains and deep valleys.

The canton of Ticino has 138 lakes, 21 artificial ones and 117 natural ones, located as presented in Figure 79. The two main lakes are the Lake Maggiore and the Lake Ceresio, both shared between Switzerland and Italy.

In the canton there exist a total of 41 hydropower plants which 32 have an installed capacity larger than 300 kW (cf. Figure 80). Plants having pumping facilities are those in Robiei (160MW of turbine and 160 MW of pump), Peccia (48 MW of turbine and 24 MW of pump) and Lucendro. A new large pumped storage plant replacing the one build in 1920 is under construction in Quinto. It will turbine the water coming from the Ritom lake with two turbines of 60 MW and one pump of 60MW allowing to pump water from the basin of Airolo into the Ritom lake.

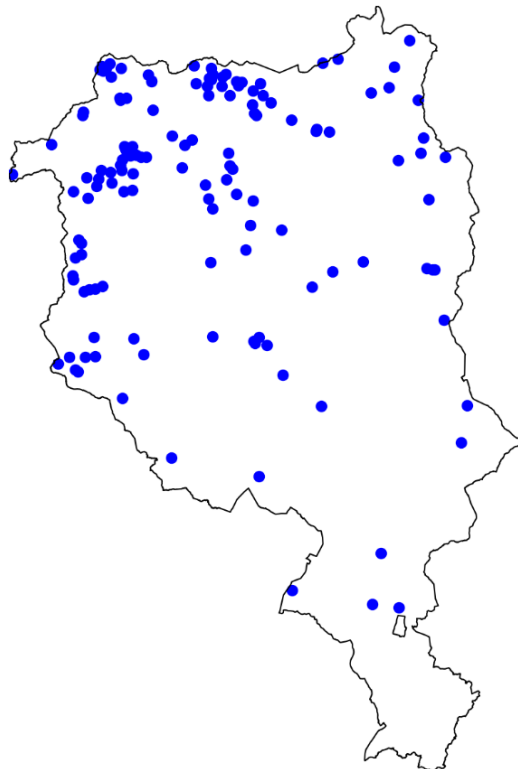


Figure 79 : Locations of the natural and artificial reservoirs in the Ticino canton.

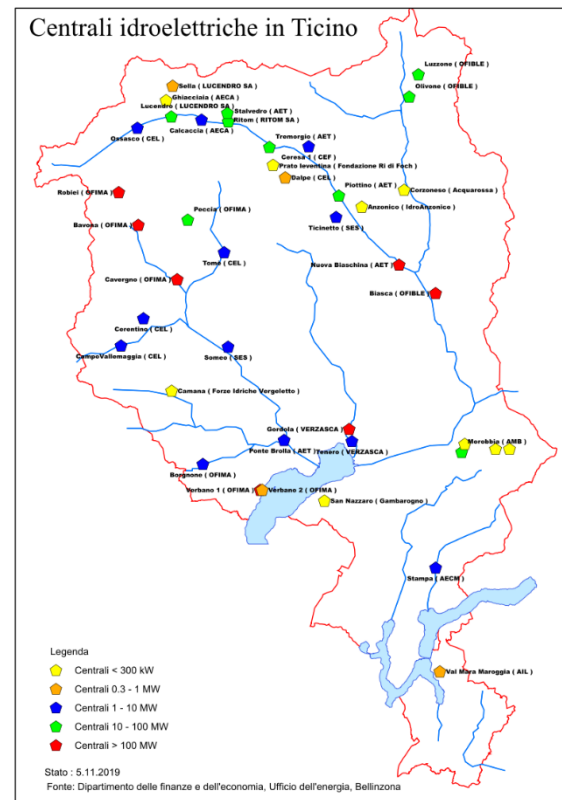


Figure 80 : Location of the existing hydroelectric power plant in the canton of Ticino [41].

In the context of this project, two distinct potential sites are identified for the lakes of Tremorgio and Luzzone.

Two large potentials are already under investigation and are reported hereafter only for information purposes. It concerns projects of Val d'Ambra II and Gordola.

An additional site has been identified for the Verbano hydroelectric power plant, but again, it is presented for informational purposes only due to its significant potential, which exceeds the scope of our project.

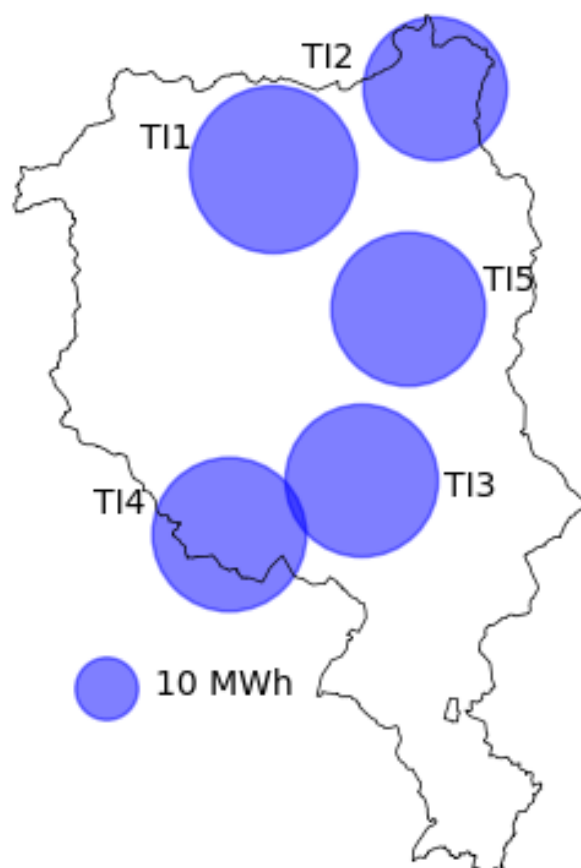


Figure 81 : The five selected sites for Ticino canton.



2.10.1. Site T11 : Centrale Tremorgio - Bacino di Rodi



Figure 82 : Location map of site T1183

Context

The existing Tremorgio hydroelectric power plant, owned by Azienda Elettrica Ticinese, is part of the Leventina production chain. The Hydropower plant is composed of a Pelton turbine of 10 MW producing about 7GWh per year. It turbines the waters from the Lake Tremorgio and discharges them into the Rodi basin. Given the small size of the lake, the plant only produces electricity for 1'000 hours per year.

Originally, this power plant also housed a pump that allowed water to be pumped back into the upstream lake.

The existing infrastructure could be used to build a new pumping station with a capacity of 10 MW and a storage of about 70 MWh.

Site plan and longitudinal profile

The profile of the existing pressure pipe is shown in the Figure 84. The first section (3) is a pressure tunnel of about 180 meters long with a diameter of 1.8 meters until the valve chambre (4). Then, the penstock is 1'570 meter long (5 and 6), divided into four sections corresponding to a reduction in diameter from 700 to 500 mm. For simplicity's sake, we have assumed a constant diameter of 650 mm along the entire length of the waterway in our calculations. The new pumping and transformation station, which will control the three groups consisting of three multistage main pump and a booster pump each, can be built on the land adjacent to the existing power plant (C). The new pumps will be connected to the existing penstock via a system of pipes.

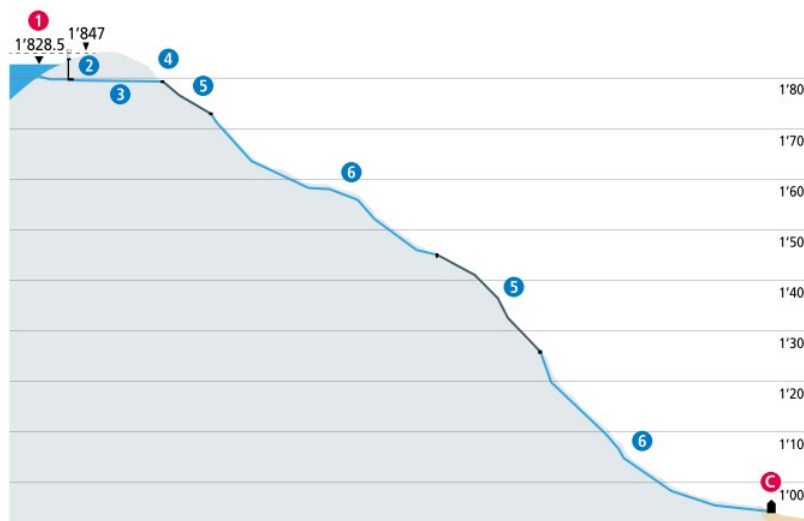


Figure 84 : Longitudinal profile of the penstock's route from the existing lake to the existing power plant [42].

Hydropower plant characteristics

The following tables summarises the main characteristics of the site.



Table 102 : Difficulty coefficients for site T11.

Components	Difficulty coefficients	Comments
Powerhouse	1.0	The new pumping station can be located near the existing powerhouse. Accessible area, no difficulties.
Penstock	1.3	The last part of the penstock is buried. Connecting to the pumps could prove difficult.

Table 103 : Reservoirs characteristics of site T11.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1 830
Upstream reservoir volume	m ³	9 000 000
Downstream reservoir altitude	m	945
Downstream reservoir volume	m ³	130 000
Elevation difference	m	885.0
Available storage volume	m ³	30 000
Energy storage potential	MWh	72

Table 104 : Powerhouse equipment characteristics of site T11.

Characteristics	Turbine	Pump
Type of machine [-]	Existing Pelton turbine	Multi-stage horizontal axis pump (+ booster pump)
Number of machines [-]	1	3
Nominal discharge [m³/s]	1.6	0.89
Net head at nominal discharge [m]		902.2
Operating time [h]		9.7
Rotation speed [rpm]	750	2960
Hydraulic power [MW]	12.1	7.5
Electrical power [MW]	10.0	

Economic analysis (cf. chapter 6.4.7.1)

The total investment reached approximately to 9.6 million Swiss Francs, i.e. 953 CHF/kW. The main investment is in H&E equipment, which accounts for 56% of the total price. The price per kW is low compared to the average of the selected sites as the penstock and the turbine are already in operation.



2.10.2. Site TI2 : Centrale Luzzone



Figure 85 : Location map of site TI2.

Context

The existing Luzzone hydropower plant is an underground power station located in the upper Blenio Valley. It is equipped with a Francis unit of 15 MW exploiting the water coming from the Carassina reservoir (1708msm). The average head at disposal of the turbine is about 120m.

Description

A new pumping station can be built near the existing powerhouse. The existing access tunnel could be used for excavation and erection works. Three pumps, each of a capacity of 2.8MW, could be used to pump water from the Luzzone lake to the upper reservoir of Carassina

It should be noted that the Carassina reservoir is currently filled by natural inflows one to twice times per day. This aspect may reduce immediate interest in this project.

An additional critical point could be that during the winter period when the level in the Luzzone lake is very low, the outlet pipe of the turbine is above the water level.

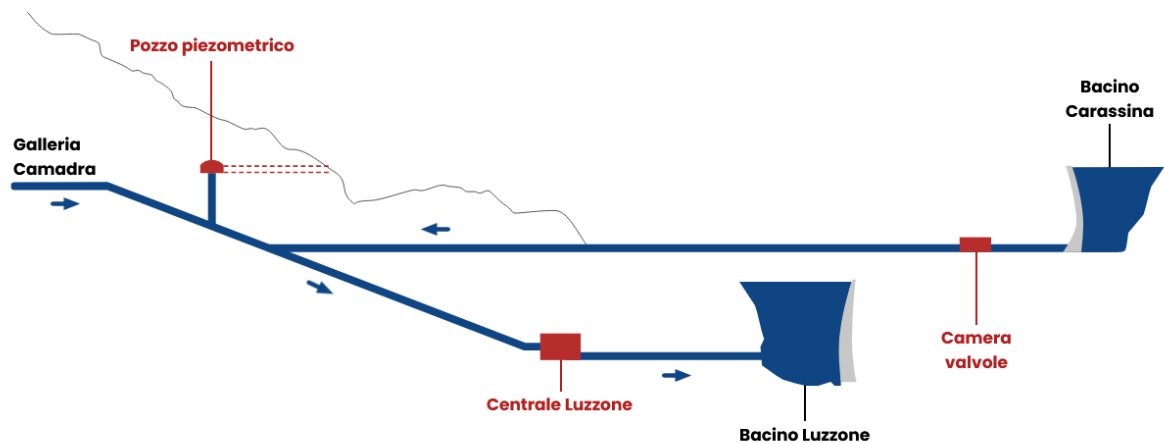


Figure 86 : Schematic view of the existing infrastructure of the Luzzone power plant.

Hydropower plant characteristics

The following tables summaries the main characteristics of the site.



Table 105 : Difficulty coefficients for site T12.

Components	Difficulty coefficients	Comments
Powerhouse	1.5	Powerhouse in caverns

Table 106 : Reservoirs characteristics of site T12.

Reservoirs characteristics	Units	Values
Upstream reservoir altitude	m	1708.0
Upstream reservoir volume	m ³	181 000
Downstream reservoir altitude	m	1606.0
Downstream reservoir volume	m ³	1.07E+08
Elevation difference	m	102.0(*)
Available storage volume	m ³	163 000
Energy storage potential	MWh	53.1

Table 107 : Powerhouse equipment characteristics of site T12.

(*): this head does not take into account the reservoir water level variations

Characteristics	Turbine	Pump
Type of machine [-]	Existing Francis turbine	Pump
Number of machines [-]	1	3
Nominal discharge [m ³ /s]	-	5.89
Net head at nominal discharge [m]	120	123.1
Operating time [h]	-	7.9
Rotation speed [rpm]		990
Hydraulic power [MW]	-	6.7
Electrical power [MW]	>10	8.5

Economic analysis (cf. chapter 6.4.7.2)

The total investment reached approximately to 10.9 million Swiss Francs, i.e. 1297 CHF/kW. The main investment is in H&E equipment, which accounts for 51% of the total price. The price per kW is low compared to the average of the selected sites as the penstock and the turbine are already in operation.



2.10.3. Site T13 : Centrale Gordola – Lago Maggiore

This site was not studied as part of the HiDeStor project, as studies have already been conducted and are currently underway for a capacity exceeding our scope. This project is also cited in the Cantonal Structure Plan [45].



Figure 87 : Location map of site T13.

Context

The pumped storage project of Gordola consists in the enhancement of the existing hydroelectric power plant located in Gordola with a pumping station. The hydro-power plant is equipped with three Francis turbines and a total installed capacity of 105MW. The new pumped storage power plant would allow water to be pumped from Lake Maggiore to the Verzasca reservoir.

The aim of the project is not so much to increase energy production as to improve the stability of the electricity grid, especially in winter, by enabling a rapid response to fluctuations in the electricity supply.

Situation

The layout of the Gordola power plant is presented in the schema of Figure 88. The power plant is built in a cavern 220 feet below ground level.

The available data indicate that two variants have been identified for this project. The first, smaller one involves 140 MW of turbine and 70 MW of pumping, while the second involves 300 MW of pump-turbine [46].

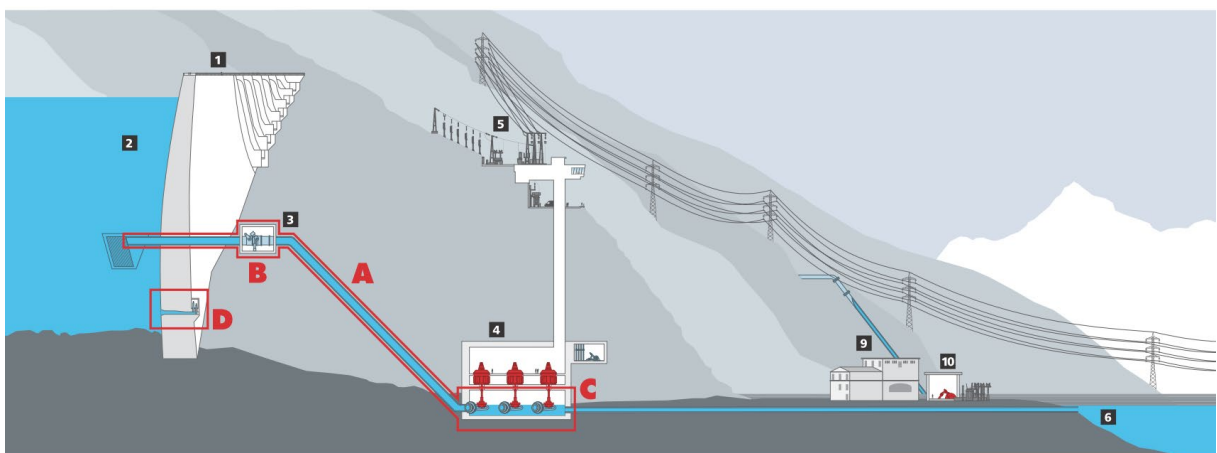


Figure 88 : Schematic view of the existing infrastructure of the Gordola power plant [47].



Hydropower plant characteristics

The following tables summaries the main characteristics of the site.

Table 108 : Reservoirs characteristics of site TI3.

Reservoirs characteristics	Units	Values
Upstream reservoir max. altitude	m	470
Upstream reservoir volume	m ³	94 000 000
Downstream reservoir altitude	m	195
Elevation difference (max)	m	275
Energy storage potential	MWh	44 800 ¹¹

¹¹ Data from [43].



2.10.4. Site TI4 : Centrale Verbano – Lago Maggiore

This site represents significant new potential in pumped storage mode. The existing reservoirs already represent a capacity of 1'268 MWh in turbine mode. We do not know whether studies have already been conducted about the enhancement of the existing hydroelectric power plant of Verbania, but the capacity will be beyond the scope for our HiDeStor project. For this reason, the potential of this site has not been studied in depth and is presented only as a theoretical potential.



Figure 89 : Location map of site TI4.

Context

The Verbano power plant, located in Brissago, turbines water from the Palagnedra reservoir and is equipped with five Francis units with a total installed capacity of 150 MW. It exploits an average head of 255 m. The water flows into Lake Maggiore. The Palagnedra reservoir, at 487 m above sea level, has a capacity of 2 million m³ [48].

Site plan and longitudinal profile

A schematic view of the existing infrastructure of the Verbano power plant is presented in Figure 90.

A new pumping facility can be erected near the existing powerhouse and can be connected to the existing penstock and headrace tunnel. The installed pumping capacity may be similar to that of turbinage, around 150 MW. The distance between the two reservoirs is more than 2 km and the total length of the existing pipelines is estimated at approximately 8 km.

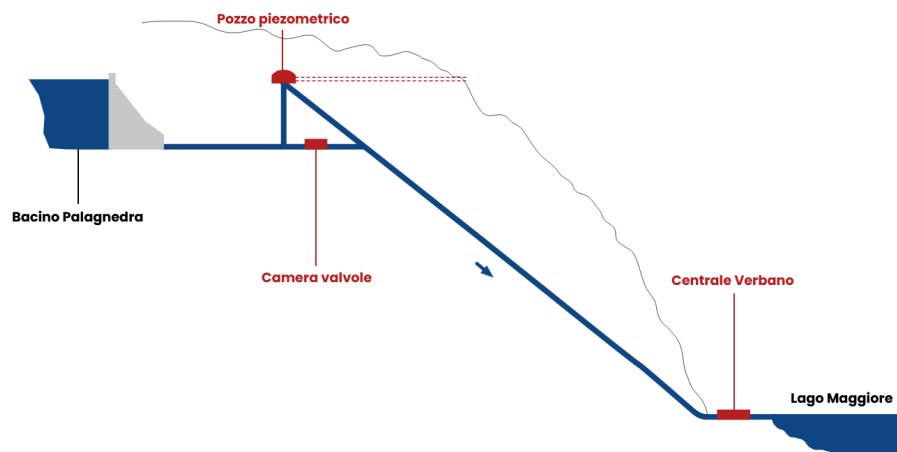


Figure 90 : Schematic view of the existing infrastructure of the Verbano power plant.



Hydropower plant characteristics

The following table summarises the main characteristics of the site.

Table 109 : Reservoirs characteristics of site TI4.

Reservoirs characteristics	Units	Values
Upstream reservoir max. altitude	m	487.0
Upstream reservoir volume	m ³	2 000 000
Downstream reservoir altitude	m	193.4
Elevation difference	m	293.6
Energy storage potential	MWh	1300



2.10.5. Site T15: Val d'Ambra II project

Same as the Gordola project, this site was not studied in the framework of the HiDeStor project because studies have already been conducted for a capacity exceeding our scope.

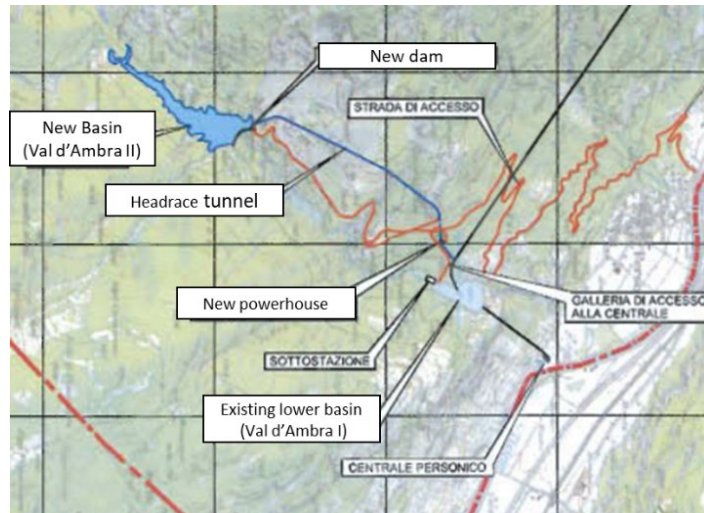


Figure 91 : Schematic view of the Val d'Ambra II project [49].

Context

The Val d'Ambra II project consist in the creation of a large storage capacity basin (2.3 million m³) in the Ambra Valley and a new pumped station with an installed capacity of 70 MW [49]. The new powerplant will turbine water coming from the new reservoir Ambra II and pump from the existing Ambra I. The studies have demonstrated the technical feasibility with an annual production estimated at 105 GWh (without pump consumption).

This project has currently been put on hold by AET because the financial uncertainties are still too high.

Site plan and longitudinal profile

A new reservoir is being created above the existing one. The new dam will store water from the Rierna river, and the water pumped from the existing reservoir Ambra I. The approximately 1'350-meter-long headrace tunnel connects the upper reservoir to the valve chamber located at 790 meters above sea-level (see Figure 92). The penstock has a head of 255m and a diameter of 2.7m. The new powerhouse is located underground at 535 meters above sea-level. The tailrace tunnel is then connected to the existing lower reservoir.

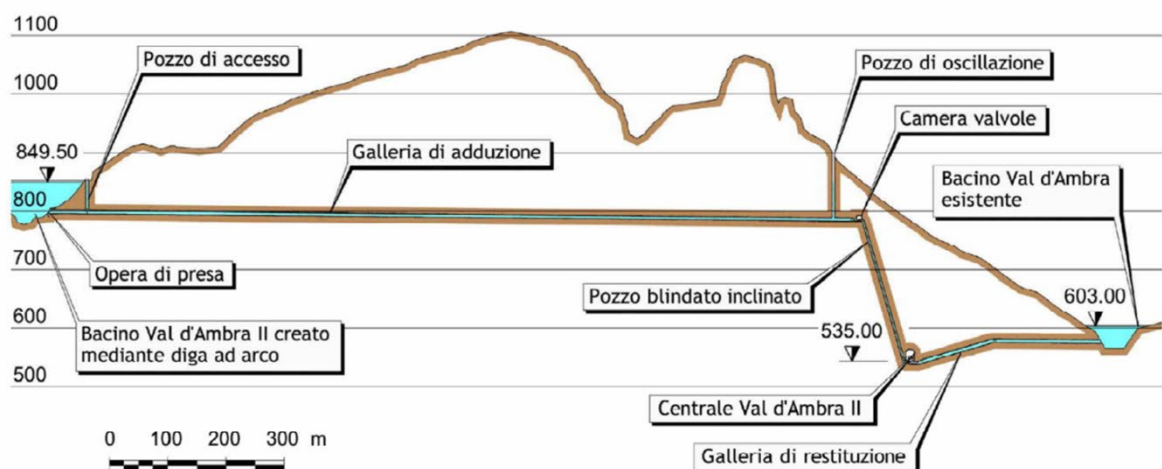


Figure 92 : Longitudinal profile of the Val d'Ambra II project [49].



Hydropower plant characteristics

The following table summarises the main characteristics of the site.

Table 110 : Reservoirs characteristics of site TI5.

Reservoirs characteristics	Units	Values
Upstream reservoir max. altitude	m	849.5
Upstream reservoir volume	m ³	2 300 000
Downstream reservoir altitude	m	603
Elevation difference	m	246.5
Energy storage potential	MWh	1 500



2.10.6. Summary

The following table presents the electrical capacity and energy storage potential of each site of the canton of Ticino. Finally, only two of the five identified sites are considered in the scope of HiDeStor project. As the last three sites have ongoing project development, it was decided to not take them into account for the technical analysis.

Table 111 : Summary of the potential of each site of the canton of Ticino

Sites	P_e [MW]	Energy storage potential [MWh]
T11	10.0	72.1
T12	8.5	53.1
Total	18.5	125.2

The following figure shows the distribution of investment costs for each site of the canton of Ticino.

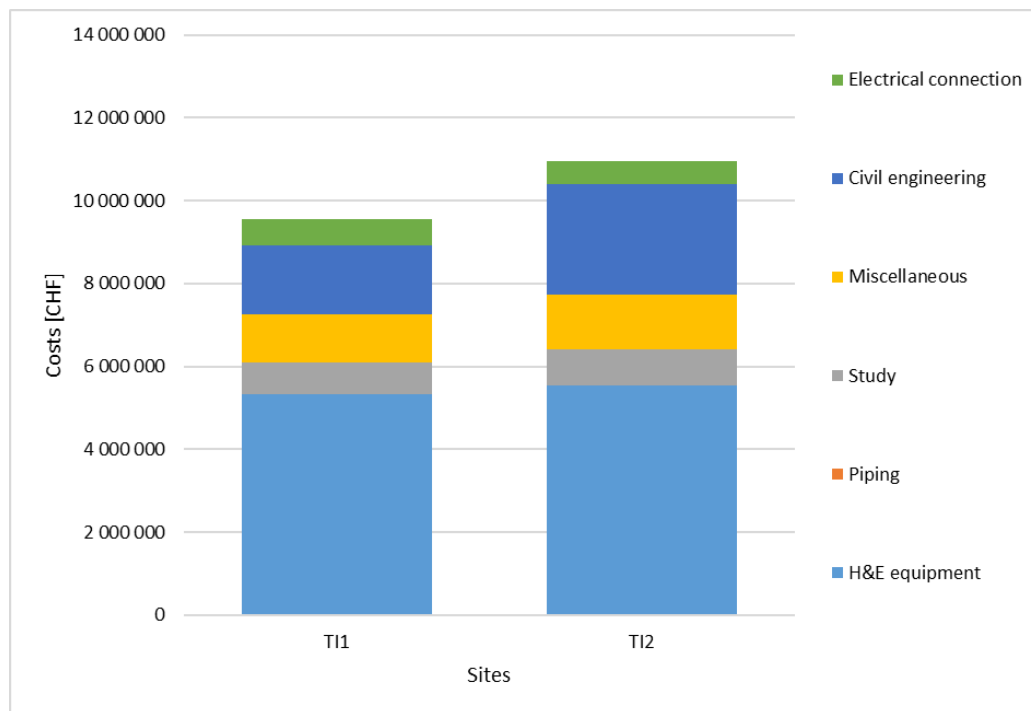


Figure 93 : Distribution of investment costs for each site of the canton of Ticino



2.11 Comparison of the selected sites of the seven studied cantons

At the end of the analysis, the economic potential of the seven selected cantons is composed of 24 medium and small pumped storage hydropower plants.

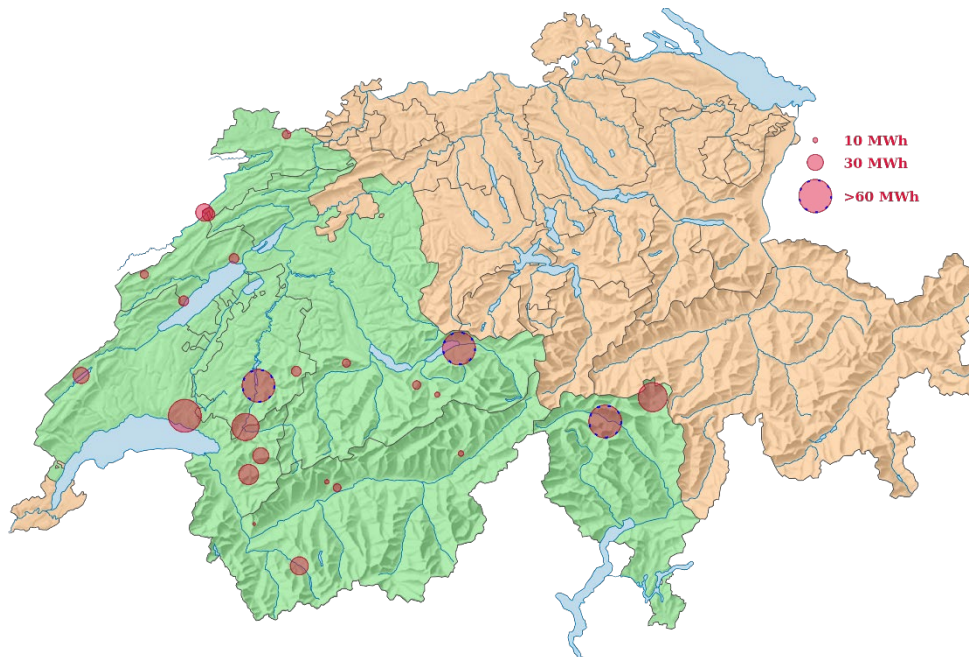


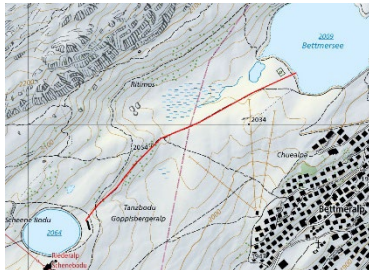
Figure 94 : The 24 MS PHS located in the West part of Switzerland selected for their economic potentials

The 24 MS PHS sites in the cantons of Bern (4 sites), Fribourg (3 sites), Jura (3 sites), Neuchâtel (3 sites), Tessin (2 sites)¹², Valais (5 sites) and Vaud (4 sites), correspond to the following characteristics, regarding:

- Gross head: strong variation from 55 to 951m due to the topography of the country (minimal gross head for site VS3 and maximal one for BE1 as presented in Figure 95 and Figure 96) with an average of 301 m (cf. Figure 97).
- Electrical capacity: from 5 to 10 MW as the range defined as initial parameter, except from site BE1 at 2 MW, with an average of 6.5 MW, a cluster of sites at 5 MW since it was one expected need identified with the interviews achieved in the WP2 (cf. Figure 97 and Figure 98), and a total of 155 MW.
- Available storage of energy: from 6 to 119 MWh (maximal for BE1 as presented in Figure 95), with an average of 34 MWh and a total of 809 MWh (cf. Figure 98). Limiting the maximum capacity to 60 MWh, the average available storage of energy would be 30 MWh and the total 715 MWh.
- If the last 3 sites in TI are retained, i.e. 27 sites, the previously available storage of energy becomes without limitation on the storage size: averaged storage energy of 37 MWh with a maximum at 119 MWh for a total of 991 MWh. Restricting the maximal size to 60 MWh reduces the averaged storage capacity to 33 MWh and the total to 895 MWh.
- Investments: from 2 to 44 million Swiss Francs, the lowest corresponding to existing power plants, for which the turbines and the penstock are already in operation and only a pumping unit has to be added; the highest corresponding to the site VD1 with an especially long new buried penstock set in a complicated area regarding topography (cf. Figure 99).

¹² Three sites (TI3, TI4 and TI5) were excluded, since they rely on very large reservoirs currently being examined for large-scale pumped-storage projects.





Site VS3

Canton: Valais
Upstream lake: Scheene Bodu
Downstream Lake: Bettmersee
Gross Head: **55 m (min)**
Energy storage potential:
10.9 MWh
Capacity: 5.0 MW
Reversible unit
Cf. chapter 2.4.3

Site BE1

Canton: Bern
Upstream lake: Hinterburgerseeli
Downstream Lake: Brienzensee
Gross Head: **951 m (max)**
Energy storage potential:
118.8 MWh
Capacity: 10 MW
Separate unit with a Pelton
Cf. chapter 2.5.1

Site FR1

Canton: Fribourg
Upstream lake: Gruyère
Downstream Lake: Montsalvens
Gross Head: 120 m
Energy storage potential:
199.4 MWh (max)
Capacity: 10 MW
Separate unit with the existing Francis turbines
Cf. chapter 2.6.1

Figure 95 : Three examples of sites with completely different characteristics

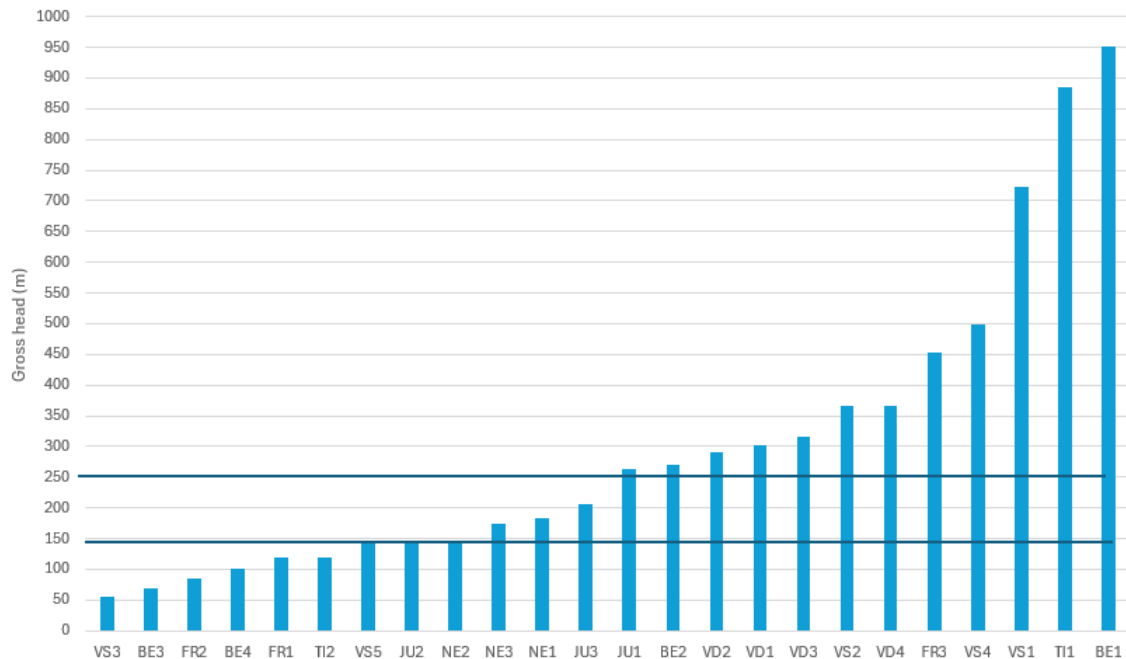


Figure 96 : Classification of the 24 sites based on their gross heads: from 55 to 951 m, with an average of 301 m (150 m: minimal gross head for sites with new reservoirs / 250 m: maximal head for reversible units)

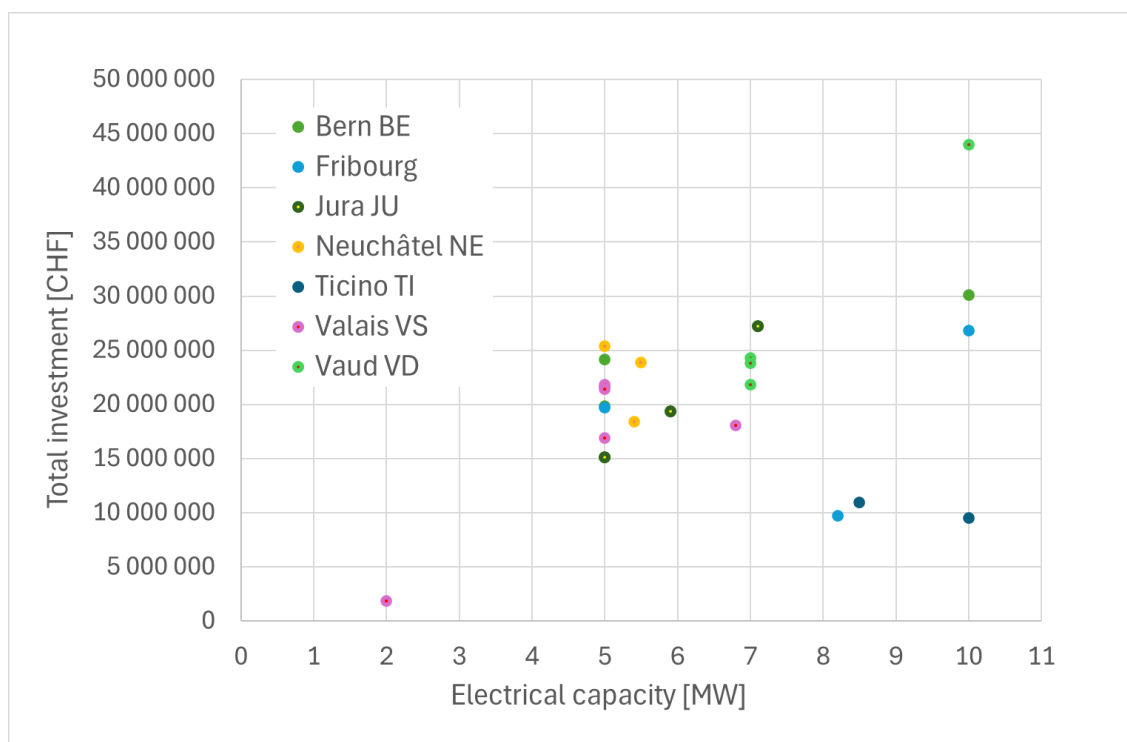


Figure 99 : Total investment as a function of the electrical capacity for the 24 selected sites



2.12 LCOS for the selected sites of the seven studied cantons

To compare the MS PHS solution to other types of energy storage, an estimation of the LCOS (cf. chapter 1.1.2) of 24 sites identified in the seven cantons has been performed. Different values have been assessed; taking only into account the electromechanical cost or the total cost with or without the pumping costs, with or without miscellaneous costs:

- The mean LCOS without miscellaneous costs nor pumping energy costs, presented in Figure 100, varies from 0,05 and 0,09 CHF/kWh.
- Different definitions of the LCOS are presented in Figure 101 without miscellaneous costs.

These values are competitive to other short-term storage solutions.

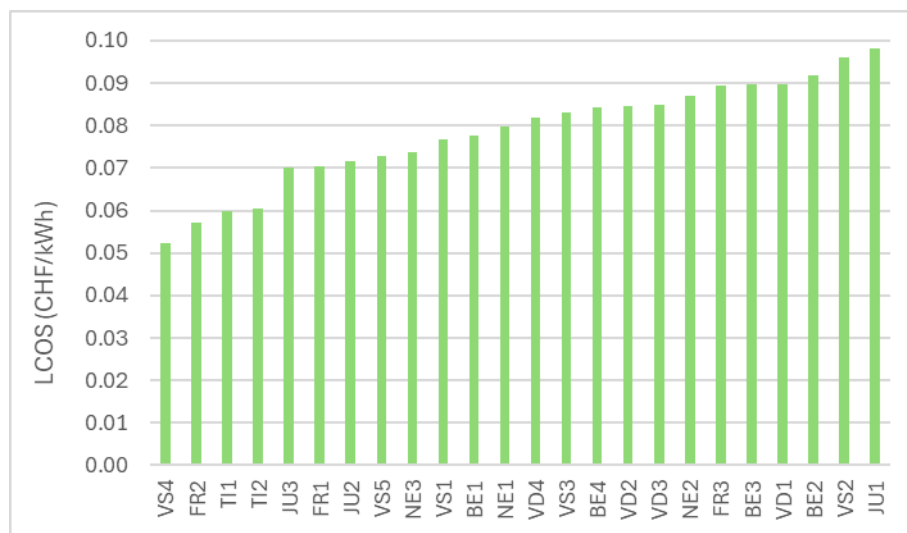


Figure 100. Classification of the sites based on the mean LCOS without miscellaneous nor pumping energy costs.

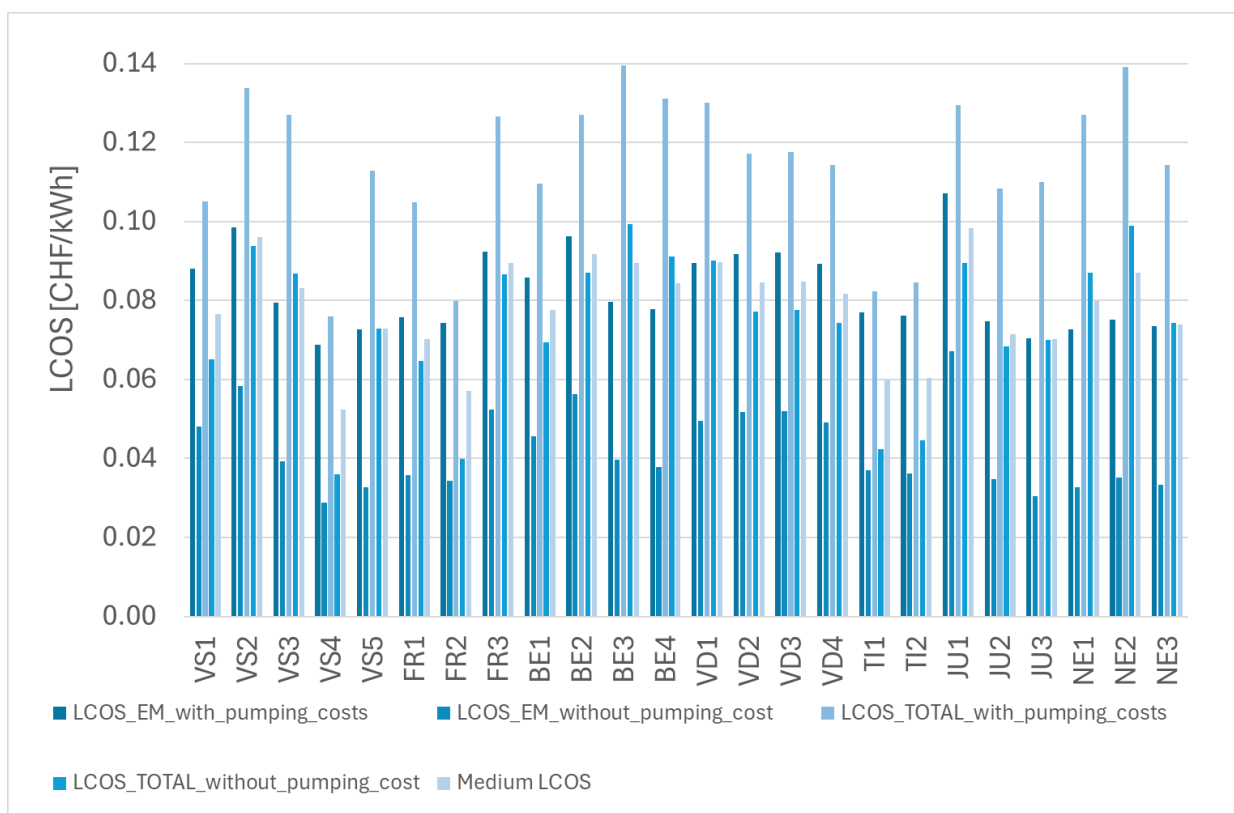


Figure 101 : Different calculations of LCOS for the selected sites of the cantons Valais, Vaud, Fribourg, Bern, Neuchâtel, Jura and Ticino.



2.13 Extrapolation of hydropower potential to the national level

2.13.1. Methodology

The selected methodology to extrapolate the hydropower potential to the national level is to perform an exhaustive analysis of the theoretical potential by connecting two lakes. The data used are the Swiss Map Vector 10¹³, which offer a 1:10'000 scale map in vector format. Extracting the relevant lakes, a pairing is carried out to find the best connection between two lakes by either maximising the head or the storage energy. The results provide an estimate to extrapolate the hidden storage to the national level.

2.13.2. Data

The data used are the Swiss Map Vector 10, which contains a layer specifically dedicated to river and reservoirs. The layer comes also with metadata as for example the type of the geometry (river or lake), the altitude and the name of the geometrical shape if it exists. The water data are shown in Figure 102.

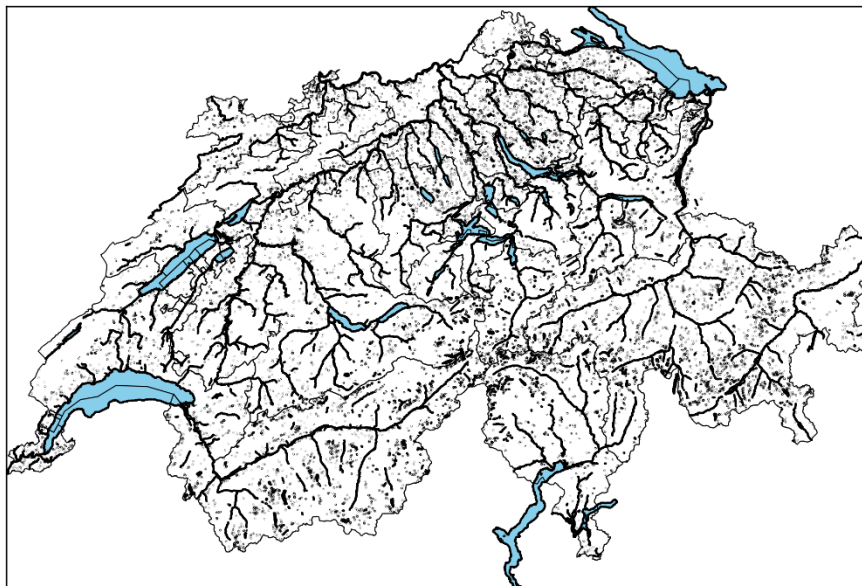


Figure 102: Layer of the Swiss Map Vector 10 containing water details.

The pre-processing steps are to extract the layer containing the water data (river & lakes) shown in Figure 102, to keep only the lake data and to exclude some lakes. The first lakes to be removed are the ones simply too small to offer a storage potential. Based on the experience of the authors, it could be observed that a typical artificial reservoir, used for example for artificial snow, has a capacity around 15'000 m³. The resulting reservoir has a surface area of approximately 4'000 m². As this kind of reservoir is considered as the smallest reservoir usable, the ones with a lower surface are, therefore, excluded. The second type of lakes to be removed are the one already used by large pumped storage power plants. These hydropower plants have an installed pumping power greater than 10 MW and their locations are shown in Figure 103.

¹³ <https://www.swisstopo.admin.ch/en/national-map-swiss-map-vector-10>

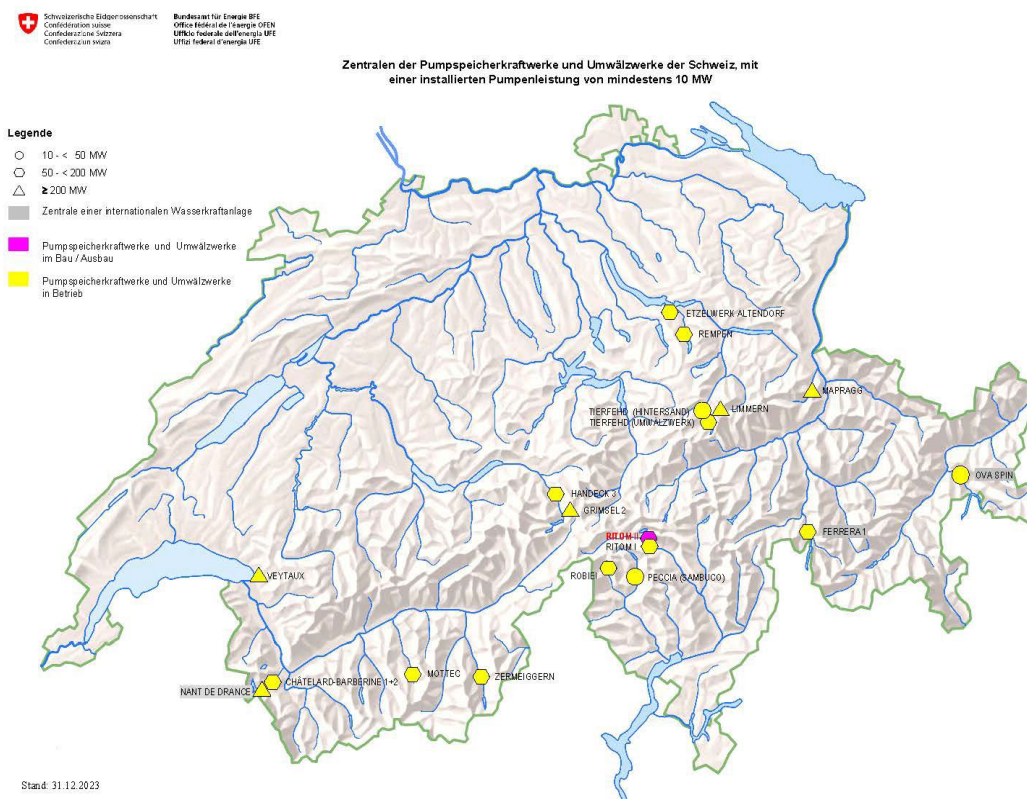


Figure 103: Locations of the 18 pumped storage hydropower plants¹⁴.

The lakes associated with these pumped storage hydropower plants are given in Table 112. However, this list should contain an additional lake which is Léman Lake used by the FMHL pumped storage hydropower plant. Since its size is significant, this lake is kept within the lakes database.

Table 112: List of lakes used by large (>10 MW) pumped storage hydropower plants in Switzerland. This list should also contain Lake Léman, but since its significant size it was kept in the database.

1. Sihlsee	7. Räterichsbodensee	13. Lago del Naret	19. Lago dei Cavagnöö
2. Rämpensee	8. Grimsensee	14. Lago Cadagno	20. Lago di Robièi
3. Wägitalersee	9. Sufnersee	15. Lago Ritóm	21. Lac d'Emosson
4. Mapraggsee	10. Lago di Livigno	16. Lago del Sambuco	22. Lac du Vieux Emosson
5. Limmerensee	11. Oberaarsee	17. Lago di Lei	23. Lac de Moiry
6. Mutsee	12. Lago Sfundau	18. Lac de l'Hongrin	24. Stausee Mattmark

The pre-processing procedure is summarised in Figure 104. The lakes database obtained is used for the following analysis. The initial database contains 17'616 lakes and the final one 2'053 lakes.

¹⁴ « 2023 Pumpspeicherkraftwerke und Umwälzwerke mit einer installierten Pumpenleistung von mindestens 10 MW » downloadable from <https://www.bfe.admin.ch/bfe/fr/home/approvisionnement/energies-renouvelables/force-hydraulique.html/#kw-117206>

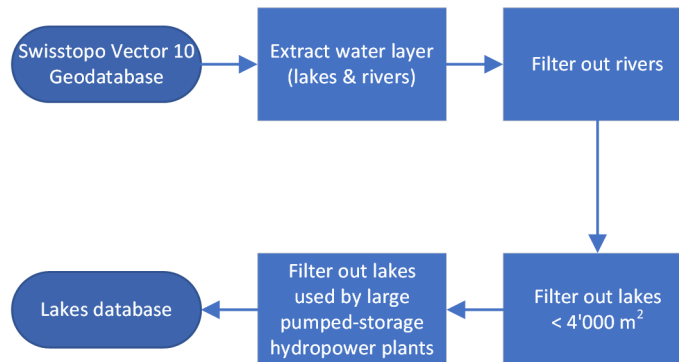


Figure 104: Pre-processing of the swisstopo vector data. Large pumped storage hydropower plants are the ones with a pump installed capacity greater than 10 MW.

2.13.3. Pairing lakes

To find the best connection between lakes, graph theory was applied to model the problem as a weighted graph, where nodes represent lakes and edges represent possible connections between them, each with an associated weight. Two approaches were used to define the weight: in one case, it was defined as the raw head between the two lakes, and in the second approach, as the storage energy. To compute the storage energy, the knowledge of the available volume is required. To estimate it, the smallest surface of the two lakes is selected, and it is assumed that a depth of 1 m is usable. The gravity is set to 9.81 m/s^2 and the water density to $1'000 \text{ kg/m}^3$.

To consider the impact of the distance between two lakes, 25 graphs are built ranging from a maximum allowed distance of 1 km to 25 km. Then an optimisation is performed to find the best connection while ensuring that two nodes (lakes) are only connected to a single edge.

Finally, the location of the upper lake was used to assign the pair and its potential to one of the 26 cantons in Switzerland. An example of the pairing when maximising the energy with a maximum allowed distance between the two lakes of 2 km is shown in Figure 105.

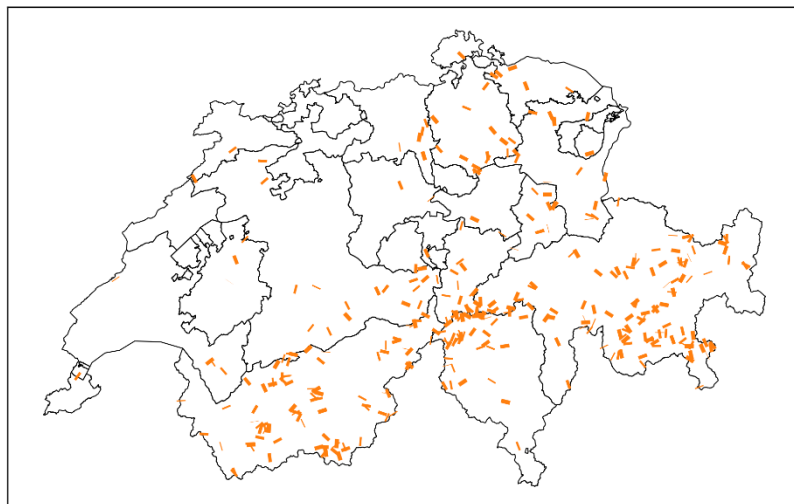


Figure 105: Example of the resulting pairing when maximising the energy with a maximum allowed distance between the two lakes set to 2 km.

2.13.4. Estimation of the hidden Swiss potential

Following the two weighting approaches, the storage potential in Switzerland with regards to the maximal distance allowed between two lakes is given in Figure 106. The evolution of the total storage energy significantly changes regarding the approach used. Indeed, when maximising the head, a plateau is reached from a radius of approximately 12 km. Whereas, when optimising the energy, the total keep increasing while widening the radius. The jump observed between 17, and 18 km is the result of the connection of Lake Léman with Joux Lake resulting in an energy storage of approximately 15 GWh. The corresponding raw head is about 630 m. However, for small distances (<5 km) there is no significant difference between the two approaches.

When increasing the maximal allowed distance between the two lakes, the number of pairs naturally also increase. The evolution of the number of pairs is shown in Figure 107. From a maximal distance of approximately 20 km, all the lakes within the database are used as a maximum of 1'026 pairs is possible (i.e. 2'053 lakes present in the database). Table 113 provides the obtained number of pairs of lakes with the corresponding energy storage using the two proposed maximising approaches.

Table 113: Number of pairs of lake with the corresponding total energy storage when limiting the distance between the two reservoirs to 2 km.

Pairs number & Potential	Switzerland	7 cantons
Maximising the Head	348 pairs 3.9 GWh	161 Pairs 2.3 GWh
Maximising the Energy	341 pairs 4.6 GWh	158 pairs 2.6 GWh

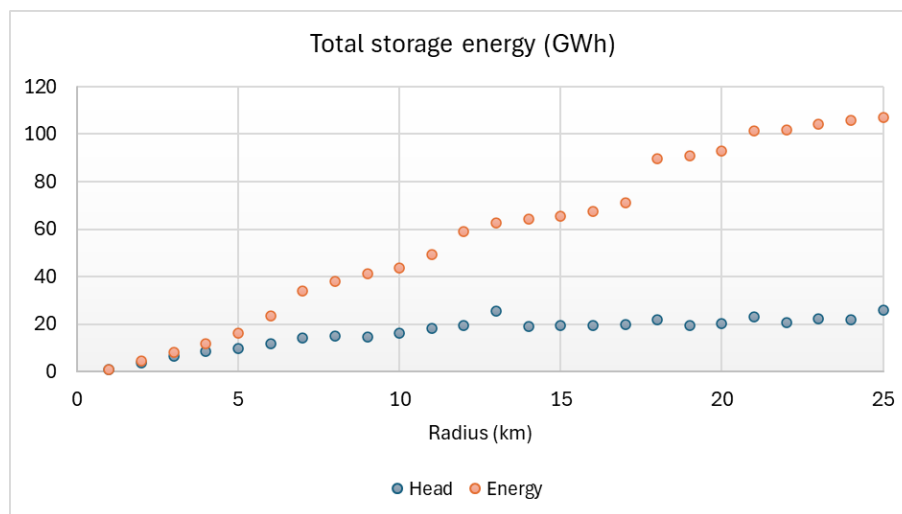


Figure 106: Total storage energy (GWh) obtained if every lake in the database could be connected. The blue points show the evolution when the head is maximised and the orange points when the storage energy is maximised.

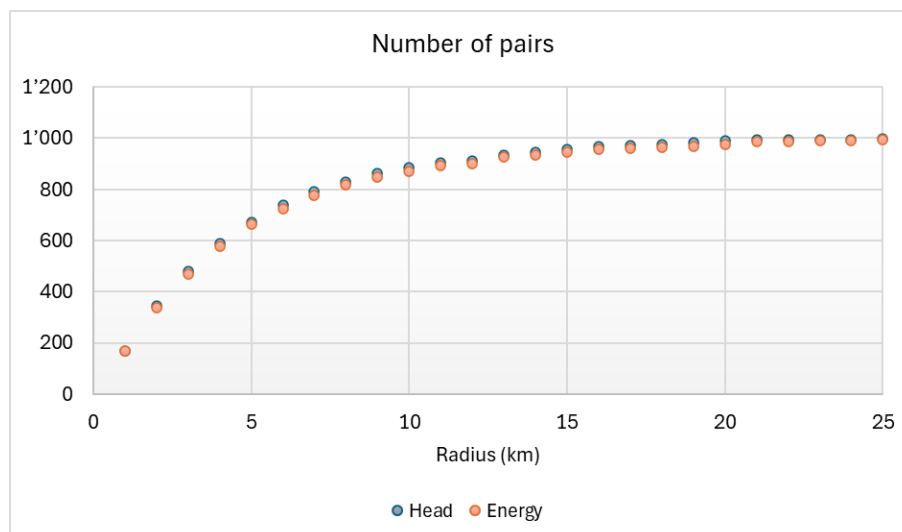


Figure 107: Evolution of the number of pair of lake with regards to the maximum distance connecting lakes.

To illustrate the kind of connexion found by the algorithm, two examples are given in Figure 108 and Figure 109. These are results when maximising the energy with a maximum allowed distance between the lakes of 2 km. The first example (Figure 108) shows one pair of lakes in the Alps with the following characteristics: potential of 3 MWh, raw head of 196 m and the shortest distance equal to 1'046 m. This example is closed to one selected in the Valais canton, i.e. VS3. Since the database used does not have the knowledge of the type of the lake (artificial/lake/pond/...) neither the available volume of water, it is quite expected that the lakes selection shown in Figure 108 is preferred to the one in VS3 that selected the artificial reservoir "Scheene Bodu" as upper reservoir. This example shows one of the limits of the present approach.

The second example illustrates one site in the Alpine foothills, see Figure 109, with the following characteristics: potential of 155 MWh, raw head of 304 m and the shortest distance equal to 955 m. The upper lake named "Seel" seems to be used mainly for touristic purposes. Therefore, an assumption of the usable volume of water represented by 1 meter depth is probably not applicable to this site. However, reducing it to a depth of approximately 30 cm would still offer a storage of about 50 MWh.



Using the two examples presented, it can be shown that this approach is useful to quickly identify possible connections between lakes. However, the feasibility of the connection should be individually assessed.

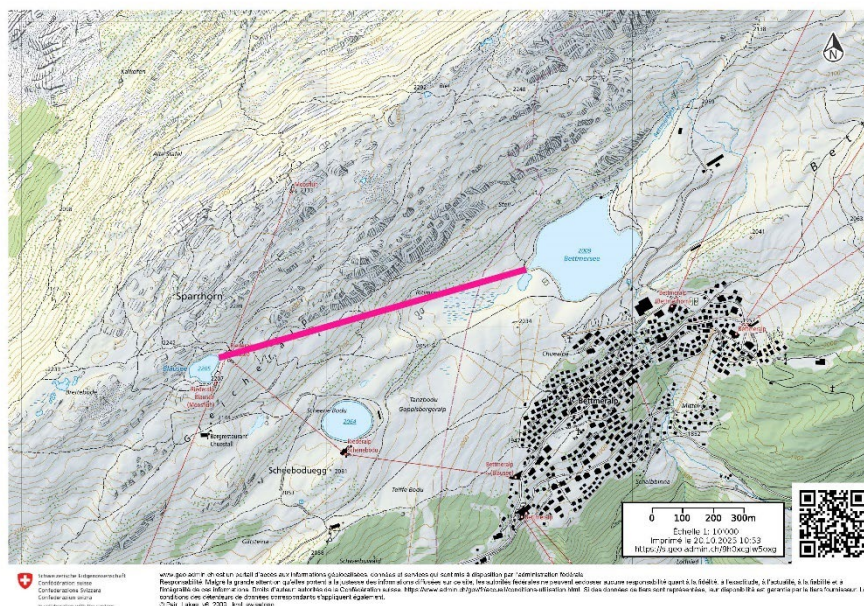


Figure 108: Example of lake connection when maximising the energy with a maximum radius of 2 km in the Alps. Blausee with Bettmersee: raw head = 196 m, distance = 1'046 m, energy = 3 MWh.

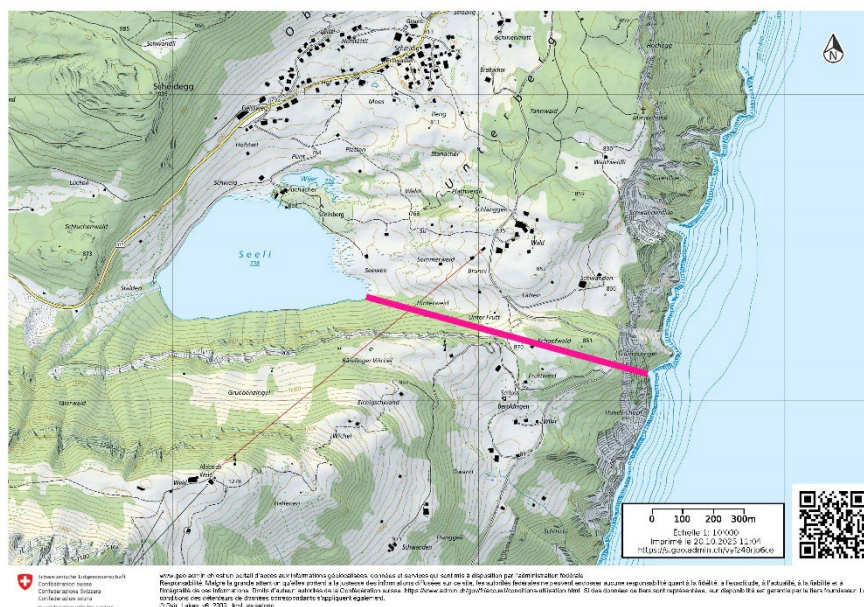


Figure 109: Example of lake connection when maximising the energy with a maximum radius of 2 km at "low" altitude. Lake Seeli with lake Urnersee: raw head = 304 m, distance = 955 m, energy = 155 MWh.

Among the two approaches, maximising the head or the energy, the geographic evolution per canton is shown in Figure 110 and Figure 111. In both approaches, the highest potential is found in the Alps. However, maximising the energy significantly surpasses the one obtained while maximising the head when increasing the distance allowed between two lakes. However, it should be recalled that these



results are a first estimation, and no analysis was carried out to assess the feasibility of a lake connection. For example, a connection passing by a valley or another lake is considered in the global analysis.

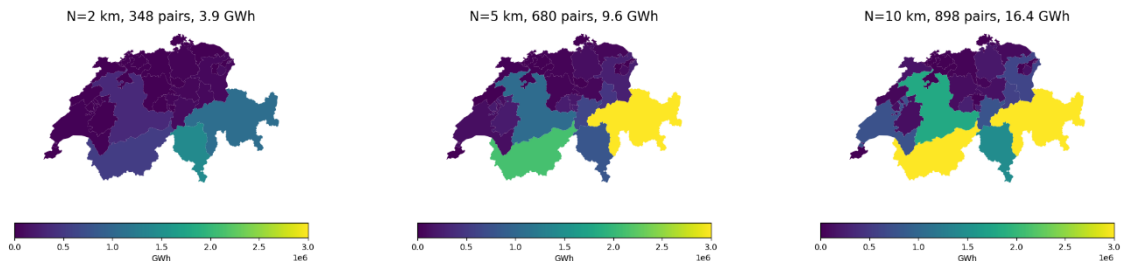


Figure 110: Potentials by canton for different radii of Influence (N) when maximising the head.

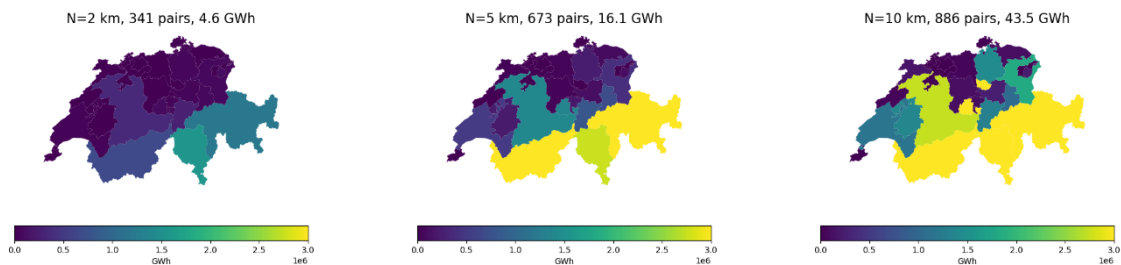


Figure 111: Potentials by canton for different radii of Influence (N) when maximising the energy.

With the wish to extrapolate the findings with the “manual” analysis, presented in sections 2.4 to 2.10 representing 7 cantons and 27 sites, to the entire country, an analysis on the potential obtained with the swisstopo data is first carried out. For this purpose, the data when maximising the energy is selected. For each radius, representing the maximum allowed distance between two lakes, the potential obtained by the graph theory analysis considering only the 7 cantons are summed up and compared with the rest of the entire country, those results were already presented in Figure 106. The comparison is shown in Figure 112. Interestingly, there is a correlation between the growth of potential within the 7 cantons with regards to the entire country. One explanation is that 7 cantons represent approximately one third of the country in term of canton but represent roughly half the country in term of surface. In addition, these 7 cantons represent the different topographic conditions that the country has: plains, mountainous.

Therefore, one would be tempted to assume that the number of feasible sites would be correlated with the number of theoretical sites. For small distances (radius smaller than 5 km), the fitted curve through the entire data approaches quite well the data, i.e. country potential is approximated by 1.88 times the potential studied in the 7 cantons. If such assumption is considered valid, it could be estimated that the technical potential for the entire country is in the order of 1.7 GWh (895 MWh time 1.88).

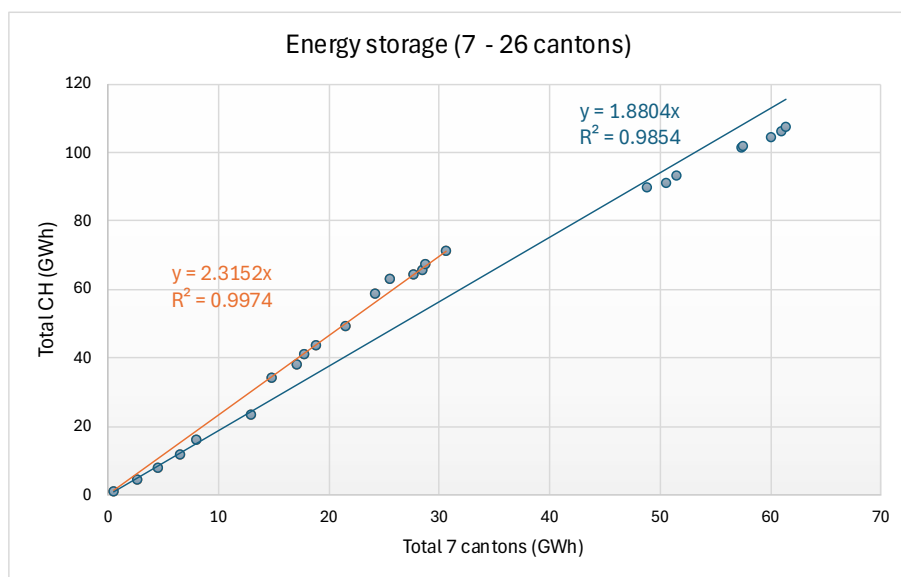


Figure 112: Correlation of the computed potential between the 7 cantons involved in the economic potential with regards to the rest of the country. The linear blue fitting curve includes all the data, whereas the linear orange fitting curve includes data for a maximal radius of 17 km.



3 Conclusions and outlook

The HiDeStor project demonstrated that medium and small pumped storage hydropower plants (MS-PHS), using existing reservoirs and infrastructures, represent a promising and realistic solution to provide decentralized, renewable, and flexible electricity storage in Switzerland. These systems can help integrate intermittent renewable production, stabilize local distribution grids, and support the transition defined by the Swiss Energy Strategy 2050.

Through a series of interviews with key stakeholders, mainly distribution system operators (DSO), and an on-line questionnaire with answers from the whole country, the project identified a growing need for local short-term storage solutions to manage renewable variability, reduce congestion, and provide ancillary services. Stakeholders underlined that MS-PHS could complement batteries by offering competitive leveled cost of storage (LCOS), larger capacity, longer lifetimes, and higher power output, while being one of the best candidates regarding the life cycle analysis.

Building on these needs, a multi-criteria methodology was developed to identify in detail potential medium and small pumped storage hydropower sites, prioritizing the reuse of existing infrastructures across seven cantons — Vaud, Valais, Fribourg, Bern, Neuchâtel, Jura, and Ticino — representing roughly 50% of Switzerland's territory. By considering a maximum distance of 2 km both between reservoirs and to the nearest grid connection point, as well as accounting for other water uses (thereby limiting the share of usable reservoir volume), 27 technically feasible sites were identified. Most of these sites exhibit target power capacities between 5 and 10 MW and energy storage between 6 and 60 MWh per site, corresponding to a total of approximately 895 MWh of economically exploitable storage potential.

At the national scale, a graph-theory-based methodology was developed to assess the theoretical potential of pumped storage hydropower by systematically connecting existing reservoirs across Switzerland using geospatial data from a 1:10,000 national map. All water surfaces larger than 4,000 m² were identified, excluding those already used by Switzerland's 20 largest pumped storage plants (except Lake Léman). The usable volume of each reservoir was estimated as surface area $\times$ 1 m depth, a deliberately conservative assumption that accounts for potential competing water uses. An optimization algorithm was then applied to identify reservoir pairings under two strategies: maximizing hydraulic head and maximizing storage energy capacity. For a maximum inter-reservoir distance of 2 km, the analysis identified 348 pairs when maximizing head (totalling 3.9 GWh) and 341 pairs when maximizing energy (totalling 4.6 GWh), showing a high level of consistency between both approaches.

Furthermore, this analysis at the country scale was used to propose an estimate on the hidden storage capacity. Using the lake database and applying the same methodology to the 7 cantons (BE, FR, JU, NE, TI, VD, VS) an evolution of the storage capacity, when maximising the storage energy, with regards to the maximum allowed distance between two lakes was obtained. The comparison of the result for each radius between the 7 cantons and the entire country showed a good correlation. The storage capacity in Switzerland is approximately 1.88 times more than the one represented by the 7 cantons. The technical potential assessment performed for the 7 cantons reached a value of 895 MWh. Therefore, a first evaluation of the estimated hidden storage capacity is approximately of 1.7 GWh.

This project provides the first consistent national mapping of potential decentralized pumped storage pairs in Switzerland, highlighting key regions in the Alps and Pre-Alps.

Future work should aim to translate this identified potential into realizable projects through:

- Detailed feasibility studies for priority sites, integrating hydraulic design, permitting, and environmental aspects;
- Business model development combining multiple market products (energy, reserves, congestion relief);
- Hybridization with other technologies, such as solar PV and batteries;
- Further refinement of the national database considering the real useful volume of the reservoirs.



By providing a standardized methodology, a consistent national assessment, and a clear link between stakeholder needs and technical potential, HiDeStor establishes a foundation for deploying decentralized hydropower storage, a cornerstone of Switzerland's sustainable and flexible energy future.

4 National and international cooperation

The HiDeStor project was carried out through a national collaboration between HES-SO Valais-Wallis and Mhyllab, combining academic research and applied engineering expertise in small hydropower. This partnership enabled the development of innovative methodologies to assess the theoretical pumped storage potential across Switzerland and to conduct a detailed economic analysis for seven cantons. Regular exchanges with cantonal energy offices, distribution system operators, and hydropower operators ensured that the results remained aligned with regional and national energy strategies.

At the international level, HiDeStor is actively involved in the IEA Technology Collaboration Programme on Hydropower (TCP Hydropower) – Task 16 “Hidden and Untapped Hydropower Opportunities”, which promotes international knowledge exchange on the identification and valorisation of small and medium pumped storage potential. A dedicated subtask on hidden storage was created within this framework, and the HiDeStor results have been regularly presented and discussed during expert meetings. The project has also achieved strong international visibility through scientific communications at the Hydro 2023, 2024, and 2025 conferences, as well as at the HydroES 2025 conference.

5 Publications and other communications

V. Denis, A. Bullani, L. Smati, O. Pacot, L. Moret, S. Martignoni, C. Münch-Alligné, “HiDeStor project: Identification of hidden renewable and sustainable solutions for decentralised electricity storage at the distribution grid level: medium and small pumped storage power”, Hydro 2023, Edinburgh, October 2023

V. Denis, A. Bullani, A. Choulot, O. Pacot, L. Moret, C. Münch-Alligné “Projet HiDeStor, Analyse du potentiel de développement du petit pompage-turbinage en Suisse”, Magazine de l'association Swiss Small Hydro, N°111, June 2024.

C. Münch-Alligné, O. Pacot, L. Moret, N. Babey, A. Bullani, A. Choulot, V. Denis, “HiDeStor: Hidden storage potential using medium and small pumped storage hydropower plants”, Hydro 2024, Graz, November 2024

C. Münch-Alligné, O. Pacot, L. Moret, N. Babey, A. Bullani, A. Choulot, V. Denis, « HiDeStor, identification du potentiel caché, renouvelable et durable pour le stockage décentralisé de l'électricité au niveau du réseau de distribution : centrales de pompage-turbinage de petite et moyenne taille », HydroES 2025, Grenoble, France, September 2025

C. Münch-Alligné, O. Pacot, L. Moret, N. Babey, A. Bullani, A. Choulot, V. Denis, “HiDeStor: Hidden storage potential using medium and small pumped storage hydropower plants”, Hydro 2025, Thessaloniki, October 2025



6 Appendices

6.1 WP2- List of prequalified bidders for ancillary services in Switzerland



Swissgrid AG
Bleichemattstrasse 31
Postfach
5001 Aarau
Schweiz

T +41 58 580 21 11
info@swissgrid.ch
www.swissgrid.ch

Prequalified bidders for ancillary services in Switzerland

Version 20.09.2024

Company	Primary control power	Secondary control power	Tertiary control power	Compensation of active power losses	Control pooling
Alpiq AG	x	x	x	x	x
Axpo Power AG	x	x	x		x
Axpo Solutions AG	x	x	x	x	
Azienda Elettrica Ticinese		x	x	x	
BKW Energie AG	x	x	x	x	x
Centralschweizerische Kraftwerke AG	x	x	x		x
Elektrizitätswerk der Stadt Zürich	x	x	x	x	x
Elektrizitätswerk Obwalden		x	x		x
EnAlpin AG	x	x	x		
Energie Wasser Bern				x	
FMV SA	x		x	x	
Groupe E SA		x	x		
Industrielle Werke Basel	x	x	x	x	x
MVM Partner Zrt				x	
OMPEX AG				x	
Primeo Energie AG	x	x	x		x
Repower AG	x	x	x	x	x



Company	Primary control power	Secondary control power	Tertiary control power	Compensation of active power losses	Control pooling
Schweizerische Bundesbahnen			x	x	
SN Energie AG				x	
Virtual Global Trading AG	x	x	x		x
Vitol SA				x	

All bidders who have a valid contract for the delivery of active power ancillary services with Swissgrid. With control pooling process it is possible to deliver secondary and tertiary control power from units in external balance groups.



6.2 WP2 - Long Questionnaire



Projet HiDeStore

**« Identification d'une solution renouvelable et durable pour
le stockage décentralisé de l'électricité au niveau du
réseau de distribution : petites et moyennes centrales de
pompage-turbinage »**

HES-SO Valais-Wallis

Cécile Münch-Alligné
Shadya Martignoni
Line Moret
Olivier Pacot

Mhylab

Vincent Denis
Laurent Smati
Alberto Bullani

**Description du projet :**

Le pompage-turbinage est la solution la plus efficace et la plus rentable pour stocker l'électricité, représentant aujourd'hui 99% de la capacité mondiale de stockage d'électricité. En Suisse, il existe à ce jour 20 grandes installations de pompage-turbinage représentant une puissance installée de 3'600 MW. Avec le développement attendu de la production d'électricité solaire et le développement de la mobilité électrique, il devient crucial de pouvoir stocker localement le surplus d'électricité produit, puis de restituer rapidement cette électricité à haute puissance, de manière locale, renouvelable et durable.

Dans le cadre actuel du marché de l'électricité, ce projet étudiera le potentiel caché de petites et moyennes centrales de pompage-turbinage utilisant des réservoirs existants dans sept cantons Suisses (Vaud, Valais, Fribourg, Berne, Jura, Neuchâtel et le Tessin) représentant environ 50% du territoire national. Tout en considérant la nouvelle dynamique des prix de l'électricité, la pertinence du développement de sites rentables sera ainsi évaluée en définissant des critères de sélection des sites et en dimensionnant les centrales en fonction des besoins futurs.

Objectifs de l'interview :

Ce projet de recherche, mené par le groupe hydroélectricité de la HES SO Valais et la fondation Mhyllab, financé par l'office fédéral de l'énergie prévoit d'évaluer le potentiel technique et économique du pompage-turbinage de petite puissance (<10MW).

Compte tenu de la gamme de puissance, ce type de projet vise à s'intégrer au réseau de distribution, et à créer des prestations, ainsi que de procurer des avantages techniques ou économiques, soit aux acteurs de la distribution d'énergie, soit aux clients finaux. Dans ce cadre, les GRD, les GRT, les responsables de groupes bilans ou encore les gestionnaires de pool de réglage sont bien placés pour percevoir les intérêts et les possibilités offertes par ce type d'infrastructure.

L'objectif de cette interview est de :

- Comprendre et évaluer les besoins au niveau du réseau de distribution pour faciliter et améliorer l'intégration de nouvelles énergies renouvelables et de nouveaux consommateurs à forte demande de puissance comme les véhicules électriques
- Identifier différentes situations où un pompage-turbinage à petite échelle peut s'avérer intéressant
- Définir la dimension attendue du stockage électrique de petite et moyenne taille (puissance, énergie, cycles) afin de définir les critères de sélection des sites.
- Identifier et évaluer les mécanismes de rémunération possibles pour de telles infrastructures
- En synthèse, évaluer l'intérêt des différents acteurs du secteur de l'énergie pour un pompage-turbinage à petite échelle



1 Caractéristique de l'interviewé

1.1 Entreprise :

1.2 Code postal :

1.3 Cantons sur lesquels se trouvent vos installations :

- ☐ Vaud
- ☐ Valais
- ☐ Fribourg
- ☐ Bern
- ☐ Neuchâtel
- ☐ Jura
- ☐ Tessin

1.4 Région linguistique :

- ☐ DE
- ☐ FR
- ☐ IT
- ☐ RM

1.5 Service fournis par l'entreprise

- ☐ GRD
- ☐ Producteur d'énergie renouvelable
- ☐ Service dans la mobilité
- ☐ Responsable groupe bilan
- ☐ Gestionnaire de pool de réglage



2 Influence de producteurs d'énergie renouvelable à caractère intermittent ou sujet à de fortes variations de production sur le réseau du GRD

2.1 Est-ce que vous êtes producteurs de toute l'énergie renouvelable intermittente distribuée sur votre réseau ou êtes-vous impacté par d'autres producteurs d'énergie renouvelable intermittente (photovoltaïque et/ou éolien) ?

- ☐ Raccordé à des producteurs d'énergies renouvelables intermittentes
- ☐ Producteur d'énergie renouvelable intermittente
- ☐ Les deux
- ☐ Aucun

En cas de « aucun », passer directement au point 3.

2.2 Quelles sont les caractéristiques des différentes centrales de production d'énergie renouvelable raccordées sur votre réseau (type, nombre, puissance installée, production annuelle) ?

Type	Nombre	Puissance installée totale [MW]	Production annuelle totale [GWh]	Remarques	Êtes-vous propriétaire de l'installation
Hydraulique					
Photovoltaïque					
Thermique (Déchets, biocarburants etc.)					
Biomasse					
Eolien					

2.3 Quel est le pourcentage de production d'énergie renouvelable intermittente par rapport à la production globale injectée sur votre réseau ?

2.4 Est-ce que vous avez planifié dans un avenir proche une production massive d'énergie renouvelable intermittente sur votre réseau ?

- ☐ Oui
- ☐ Non

Quelle production annuelle envisagez-vous ?

2.5 Est-ce que vous avez observé ou pensez avoir des problèmes liés à la production d'énergie renouvelable intermittente sur votre réseau ?

- ☐ Oui
- ☐ Non, aucun





Quel(s) type(s) de problème(s) avez-vous rencontré(s)/pensez-vous rencontrer ?

En cas de « aucun », passer directement au point 3.

2.5.1 Avez-vous déjà réfléchi à une(des) solution(s) pour pallier ces problèmes ?

☐ Oui

☐ Non

Quel(s) type(s) de solutions(s) avez-vous mis/pensez-vous mettre en place ?

2.5.2 Avez-vous déjà installé une ou plusieurs capacités de stockage ?

☐ Oui

☐ Non

Quel(s) type(s) de stockage (s) avez-vous mis en place ?

Quelle(s) est (sont) la (les) capacité(s) du stockage d'énergie mise(s) en place ?



3 Influence des modifications en cours et futur de la courbe de charge (électrification croissante de la société : mobilité, chauffage, climatisation, digitalisation, télétravail, etc.)

3.1 Est-ce que vous observez des modifications de la courbe de charge ?

☐ Oui

☐ Non

Quel(s) type(s) de modification(s) avez-vous observés ?

3.2 Comment imaginez-vous l'avenir ?

3.3 Est-ce qu'un petit PT pourrait répondre à ces besoins ?

☐ Oui

☐ Non/Ne sait pas

En cas de non, passer directement au point 4.

3.4 Comment un petit pompage-turbinage pourrait répondre à ces besoins ?

3.5 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?



4 Interface GRD / GRT¹

4.1 Est-ce que vous êtes directement raccordé au réseau de transport ?

- ☐ Oui
☐ Non

En cas de non, passer directement au point 5.

4.2 Les coûts des réseaux de transport sont principalement des coûts imputables. Néanmoins, les structures de prix des réseaux aval et la facturation au Clients finaux sont relativement complexes.

4.2.1 Entre ces coûts qui vous sont imputés par les réseaux amont et les facturations à vos Clients (autres GRD ou Clients Finaux), est-ce que votre marge financière a encore un degré de liberté ?

- ☐ Oui
☐ Non

Si oui, quel(s) degré(s) de liberté avez-vous ?

¹ GRT : Gestionnaire de réseau de transport - Swissgrid



5 Interface GRD / GRD

5.1 Avez-vous des relations contractuelles avec un/des autre(s) GRD ?

- ☐ Oui
- ☐ Non

En cas de non, passer directement au point 6.

5.2 Dans le cadre de ces relations, est-ce qu'il y a un poste de coût qu'il serait possible d'influer favorablement avec une petite unité de Pompage-Turbinage et qui permettrait d'améliorer votre marge financière ?

- ☐ Oui
- ☐ Non/Ne sait pas

En cas de non, passer directement au point 6.

5.3 Comment un petit pompage-turbinage pourrait influencer votre marge financière ?

5.4 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?



6 Prestations supplémentaires du GRD à ses clients

6.1 Pour un ou plusieurs clients (GRD ou consommateurs finaux), à titre de prestations supplémentaires, est-ce qu'il vous semble envisageable et/ou intéressant d'utiliser une unité de stockage de petite puissance (<10MW) pour :

- ☐ Disposer d'une installation de compensation d'énergie réactive ?
- ☐ Alimenter des bornes de recharge publiques de véhicules électriques (voitures, vélo, etc.) ?
- ☐ Garantir la fiabilité de l'approvisionnement électrique (alimentation de secours) ?
- ☐ Gestion des congestions et contrôle de la tension dans les réseaux de distribution ?
- ☐ Autres ?

6.2 Rencontrez-vous des situations critiques au niveau de la stabilité du réseau (tension) ?

- ☐ Oui
- ☐ Non

En cas de non, passer directement au point 6.6.

6.3 Quel(s) est(sont) les situations critiques rencontrées sur votre réseau ?

6.4 Est-ce qu'un petit pompage-turbinage (<10MW) vous aiderait à diminuer ces situations critiques ?

- ☐ Oui
- ☐ Non

En cas de non, passer directement au point 7.

6.5 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?

6.6 Si non, pensez-vous que de futures installations électriques (PV, station de recharge EV) pourraient engendrer des surcharges de votre réseau ?

- ☐ Oui
- ☐ Non



7 Pool de réglage et Services système (SDL)

7.1 Etes-vous un gestionnaire de pool de réglage (PSS) ou fournissez-vous des prestations SDL à un gestionnaire de pool de réglage ?

- ☐ Gestionnaire de pool de réglage (PSS)
- ☐ Fournisseur de prestations SDL
- ☐ Les deux
- ☐ Aucun

En cas de « aucun », passer directement au point 7.2.

7.1.1 Les puissances minimales pour participer aux services système sont de ± 1 MW pour le FCR², et ± 5 à ± 100 MW pour le aFRR³, mFRR et RR⁴. Pensez-vous que, sur votre réseau, il serait possible d'intégrer une petite unité de Pompage-Turbinage dans une Unité de production virtuelle pour participer aux services système (secondaire ou tertiaire) ?

- ☐ Oui
 - ☐ Pour quel(s) réglage(s) ?
 - ☐ Emplacement ?
- ☐ Non

En cas de non, passer directement au point 8

7.1.2 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?

7.2 Pensez-vous qu'une petite unité de Pompage-Turbinage vous permettrait ou vous faciliterait dans la création d'un Pool de réglage (ou dans la participation à un Pool de réglage) pour participer aux services système (secondaire ou tertiaire) ?

- ☐ Oui
- ☐ Non
 - Pour quelle/s raison/s ?

² Frequency Constraint Reserves (FCR) correspond aux réserves de réglage primaire actuelles (< 30s)

³ Automatic Frequency Restoration Reserves (aFRR) correspond aux réserves de réglage secondaire actuelles. (30s à 5 minutes)

⁴ Manual Frequency Restoration Reserves (mFRR) et Replacement Reserves (RR) correspond aux réserves de réglage tertiaire actuelles, rapides et lentes. (5 et 60minutes et lent > 60minutes)



8 Groupe bilan et énergie d'ajustement

8.1 Est-ce que vous faites partie d'un groupe bilan ou êtes-vous le Responsable de Groupe-Bilan (RGB) ?

- ☐ Oui je fais partie d'un groupe bilan
 - ☐ Lequel ?
- ☐ Oui je suis responsable d'un groupe bilan

8.2 Quels sont les valeurs clefs (min, moy, max) des prix de l'énergie d'ajustement de votre groupe-bilan ?

8.3 Avez-vous eu dans vos unités de décompte un (plusieurs) jour(s) affichant un déficit (short) ?

- ☐ Oui
 - ☐ Non
- Si oui, à combien s'élevai(ent)-t'il(s) ?

8.4 Avez-vous eu dans vos unités de décompte un (plusieurs) jour(s) affichant un excédent (long) ?

- ☐ Oui
 - ☐ Non
- Si oui, à combien s'élevai(ent)-t'il(s) ?

8.5 A quoi sont liés ces décomptes déficitaires / excédentaires ?

- ☐ Mauvaise prévision des producteurs d'énergie renouvelable ?
- ☐ Mauvaise prévision de la consommation ?
- ☐ Incident imprévu sur le réseau de distribution ?
- ☐ Autre(s) ?

8.6 Est-ce que vous pensez qu'un petit pompage-turbinage (<10MW) permettrait d'avoir un effet significatif sur l'énergie d'ajustement ?

- ☐ Oui
- ☐ Non

En cas de non, passer directement au point 9.

8.6.1 Quel pourrait être l'apport d'un Pompage-Turbinage de petite puissance pour l'établissement des programmes prévisionnels ?

8.6.2 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?



9 Synthèse

Au vu des échanges précédents :

9.1 Comment noteriez sur une échelle de 1 à 5 votre intérêt pour un Pompage-Turbinage à petite échelle ? (1 = peu d'intérêt, 5=beaucoup d'intérêt)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9.2 En admettant que vous ayez un site de petit pompage turbinage idéal pour vous, comment l'utiliseriez-vous ?

9.3 Quel serait alors, selon vous, les puissances, les temps d'utilisation du stockage⁵ et les nombres de cycles⁶ de pompage-turbinage adapté à cet usage ?

Puissance installée	Temps d'utilisation du stockage		Nombre de cycles par jour
☐ < 300 kW ☐ 300 kW < ... < 1 MW ☐ 1 MW < ... < 5 MW ☐ 5 MW < ... < 10 MW Autre ?	Turbinage ☐ < 1h ☐ 1h < ... < 3h ☐ 3h < ... < 6h ☐ 6h < ... < 12h Autre ?	Pompage* ☐ < 1h ☐ 1h < ... < 3h ☐ 3h < ... < 6h ☐ 6h < ... < 12h Autre ?	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Autre ?

* : S'il n'y a pas de besoins spécifiques en termes de pompage, le temps de pompage correspond au temps entre 2 cycles de turbinage

9.4 Quelle serait alors, le type de rémunération possible de ce Pompage-Turbinage, et son ordre de grandeur ?

9.5 Selon vous, quel serait le coût maximal d'investissement par kW pour qu'une installation de Pompage-Turbinage à petite échelle soit viable économiquement ?⁷

⁵ Le temps d'utilisation du stockage représente la durée de turbinage.

⁶ Le nombre de cycle est le nombre de fois qu'on souhaite utiliser la capacité de stockage par jour. Il comprend donc le temps de turbinage et le temps de pompage.

⁷ En faisant l'hypothèse que le convertisseur est le point faible d'une installation hydroélectrique et que sa durée de vie est de 25 ans



9.6 Avez-vous un ou plusieurs sites pouvant présenter un potentiel intéressant (un réservoir existant) pour ce type de système sur votre réseau de distribution d'énergie ?

☐ Oui

☐ Non

Si oui, le(s)quel(s) ?

9.7 Auriez-vous d'autres remarques concernant le stockage par petit pompage-turbinage ou de possibilité d'utilisation et de rémunération d'un petit pompage-turbinage ?

Les réponses fournies lors de cet entretien resteront confidentielles et anonymisées.



6.3 WP2-Short questionnaire

Summary

1. To thank you for your participation, we will provide you with a summary of this questionnaire at the end of the project.

Meanwhile, you can find an example of a potential analysis here:
<https://www.tandfonline.com/doi/full/10.1080/27678490.2022.2101392>

2. Would you be interested to receive this summary?
 - a. Yes
 - b. No

General information

1. What is your name? (All data will subsequently be anonymised)
2. What is your e-mail address?
3. What company do you work for?
4. Postcode, town
5. What type of job do you do?
 - a. Director
 - b. Executive
 - c. Engineering
 - d. Technical

Current demands on your electricity network

6. Have you ever had problems in the past with your electricity network being overloaded?
 - a. Yes
 - b. No
7. What was the cause?
 - a. Too much production
 - b. Too much demand
8. What did you do about it?
 - a. Increased in electricity imports?
 - b. Increased hydroelectric production on the grid?
 - c. Increased solar production on the grid?
 - d. Increased wind generation on the grid?
 - e. Modified the network (e.g., addition of new high or medium voltage lines)?
 - f. Added storage resources (batteries, hydrogen, etc.)?
 - g. Limited the maximum injectable power?
 - h. Other?
9. If other?

Future demands on your electricity network

10. How do you see the future for the load curve on your network?
 - a. No change
 - b. Little change
 - c. Significant change



11. If significant change
 - a. Problem with the intermittency of new renewable energies
 - b. Problems with peak demand (electrification of mobility)
 - c. Others?
12. If other, which one(s)
13. What steps are you planning to take?
 - a. Increase in electricity imports?
 - b. Increase hydroelectric production on the grid?
 - c. Increase solar production on the grid?
 - d. Increase wind generation on the grid?
 - e. Modification to the network (e.g., addition of new high or medium voltage lines)?
 - f. Addition of storage resources (batteries, hydrogen, etc.)?
 - g. Limitation of maximum injectable power?
 - h. Other?
14. If other?

Small pumped storage power plant

15. Do you think that a small pumped storage power plant on your network could be of benefit to you?
 - a. Yes
 - b. No
16. What would be the ideal amount of energy storage?
 - a. Less than 1 MWh
 - b. Between 1 and 5 MWh
 - c. Between 5 and 10 MWh
 - d. Between 10 and 25 MWh
 - e. Between 25 and 50 MWh
 - f. More than 50 MWh
 - g. Unknown to date
17. How long would the turbine be used?
 - a. <1h?
 - b. 1h - 3h?
 - c. 3h - 6h?
 - d. 6h - 12h?
 - e. Unknown to date
18. How many times a day would the turbine be used?
 - a. 1
 - b. 2
 - c. 3
 - d. 4+
 - e. Unknown to date
19. How would you use such a facility?
 - a. Primary frequency control (Ancillary services)
 - b. Secondary frequency control (Ancillary services)
 - c. Reactive power adjustment
 - d. Virtual storage
 - e. Installation available to the balance group managers



- f. Smoothing of power peaks
- g. Other?

20. If other?

21. Still, if you had a small pumped storage power plant at your disposal, how could you use it to diversify your offers?

- a. Primary frequency control (Ancillary services)
- b. Secondary frequency control (Ancillary services)
- c. Reactive power adjustment
- d. Virtual storage
- e. Installation available to the balance group managers
- f. Smoothing of power peaks
- g. Other?

22. If other?

Existing artificial and natural reservoirs

23. Are there any artificial or natural water reservoirs in the region where your network operates?

- a. Yes
- b. No

24. Where are these reservoirs located, NPA?

25. What are the names of these reservoirs?

26. How much water are available?

27. Do you see any potential for using one as a reservoir for a small pumped storage system?

- a. Yes
- b. No

28. If so, which one(s)?

Conclusion

Thank you very much for your time and your answers.

Feel free to add any comments on the subject and the questions asked.



6.4 WP3 & WP4 - Cost details

6.4.1. Valais

6.4.1.1. Site VS1

Economic analysis

The distribution of the investment cost is given in Table 114. The total investment reached approximately 18 million Swiss Francs, i.e. 1.33 CHF/Watt using the total installed capacity (turbine & pump).

Table 114 : Distribution of investment costs for site VS1

Parts of the investment	Costs [CHF]
H&E equipment	8'860'000.-
Piping	4'200'000.-
Civil engineering	820'000.-
Electrical connection	540'000.-
Study	1'450'000.-
Miscellaneous	2'170'000.-
Total	18'040'000.-

Observation

For this site, which requires separate equipment for pump and turbine cycles, the electromechanical investment component, including the pump, turbine, motors, and control-command system, represents the largest share, amounting to over 49% of the total investment cost. The second major expense is the penstock, accounting for just over 23% of the total cost. The Figure 113 shows the distribution of investment costs for this site.

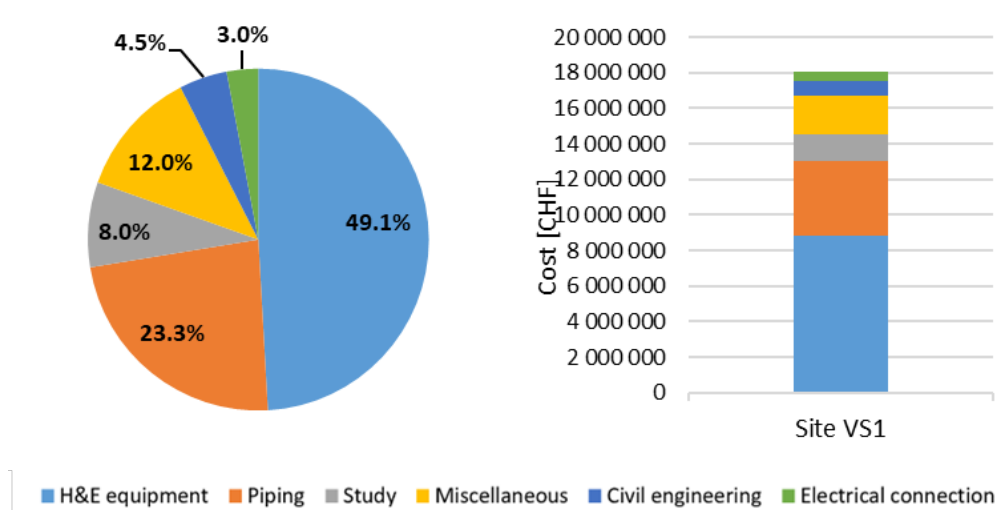


Figure 113 : Distribution of investment costs for the site VS1



6.4.1.2. Site VS2

Economic analysis

The distribution of the investment cost is given in Table 115. The total investment reached approximately 21.8 million Swiss Francs, i.e. 2.10 CHF/Watt using the total installed capacity (turbine & pump).

Table 115 : Distribution of investment costs for site VS2

Parts of the investment	Costs [CHF]
H&E equipment	8'580'000.-
Piping	7'360'000.-
Civil engineering	1'110'000.-
Electrical connection	380'000.-
Study	1'750'000.-
Miscellaneous	2'620'000.-
Total	21'800'000.-

Observation

For this site, which requires separate equipment for pump and turbine cycles, the electromechanical investment component, including the pump, turbine, motors, and control-command system, represents the largest share, amounting to over 39% of the total investment cost. The second major expense is the penstock, accounting for just under 34% of the total cost. The Figure 114 shows the distribution of investment costs for this site.

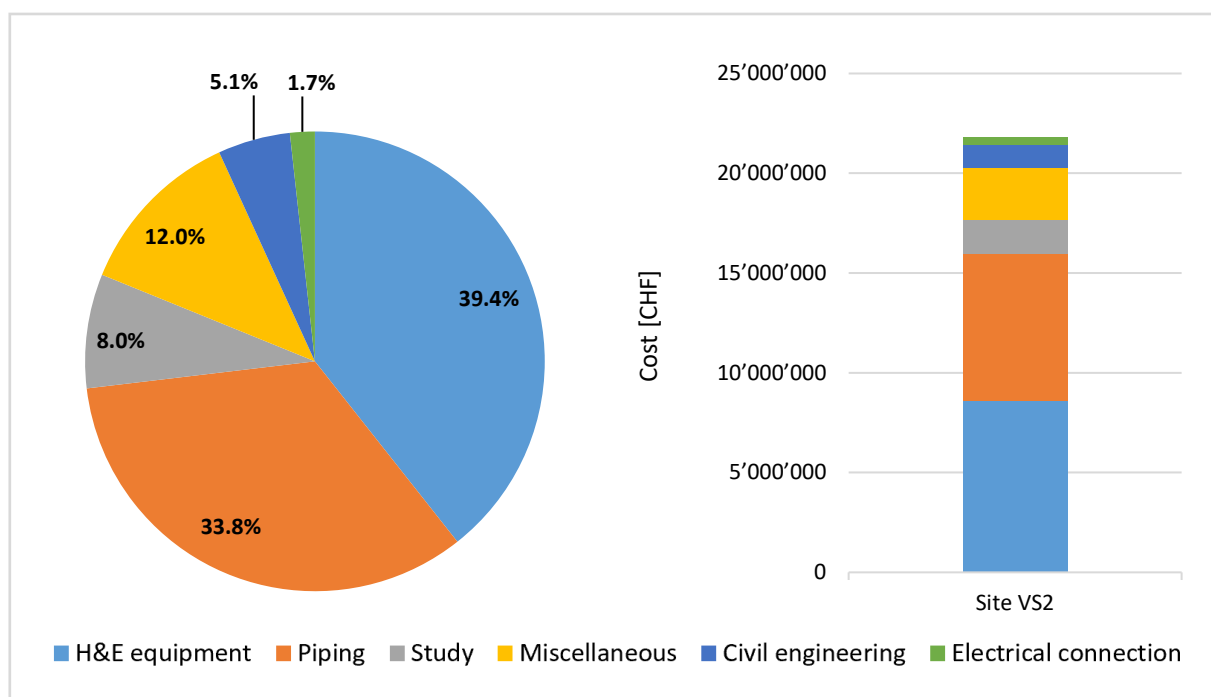


Figure 114 : Distribution of investment costs for the site VS2



6.4.1.3. Site VS3

Economic analysis

The distribution of the investment cost is given in Table 116. The total investment reached approximately 21.4 million Swiss Francs, i.e. 2.14 CHF/Watt using the total installed capacity (turbine & pump).

Table 116 : Distribution of investment costs for site VS3

Parts of the investment	Costs [CHF]
H&E equipment	4'330'000.-
Piping	8'220'000.-
Civil engineering	3'708'500.-
Electrical connection	480'000.-
Study	1'860'000.-
Miscellaneous	2'790'000.-
Total	21'388'500.-

Observation

For this site, where the diameter of the pipe is large, the cost of the pipe accounts for the largest proportion of the total investment, at 38%. In second place, investment in electromechanical equipment represents more than 20% of the total cost. Figure 115 illustrates the breakdown of investment costs for this site.

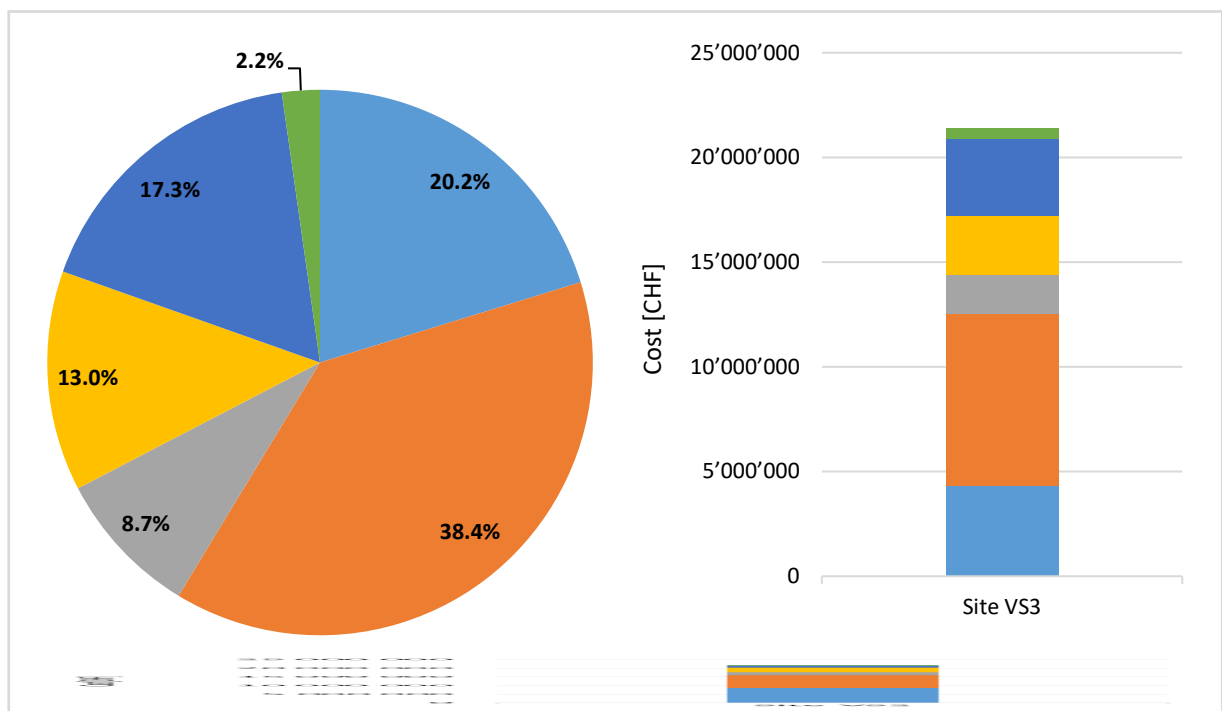


Figure 115 : Distribution of investment costs for the site VS3



6.4.1.4. Site VS4

Economic analysis

The distribution of the investment cost is given in Table 117. The total investment reached approximately to 1.9 million Swiss Francs, i.e. 0.87 CHF/Watt using the total installed capacity (turbine & pump).

Table 117 : Distribution of investment costs for site VS4

Parts of the investment	Costs [CHF]
H&E equipment	760'000.-
Piping	0.-
Civil engineering	530'000.-
Electrical connection	180'000.-
Study	150'000.-
Miscellaneous	230'000.-
Total	1'850'000.-

Observation

For this site, where the penstock and turbine are already in place, the total cost is significantly lower than for the other sites in Valais, representing less than 10% of their costs. The cost of H&E equipment represents the largest share of total investment, at over 41%. This is followed by civil engineering works, which account for more than 28% of the investment cost. The Figure 116 illustrates the cost distribution for this site.

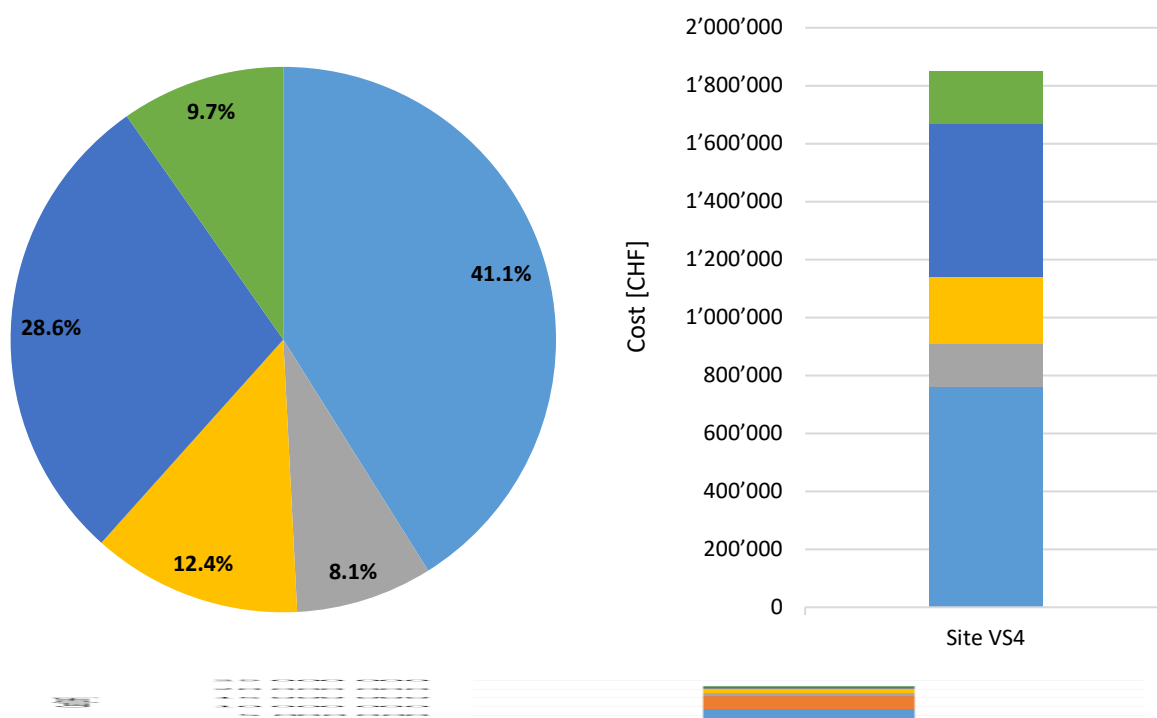


Figure 116 : Distribution of investment costs for site VS4



6.4.1.5. Site VS5

Economic analysis

The distribution of the investment cost is given in Table 118. The total investment reached approximately 16.9 million Swiss Francs, i.e. 1.69 CHF/Watt using the total installed capacity (turbine & pump).

Table 118 : Distribution of investment costs for site VS5

Parts of the investment	Costs [CHF]
H&E equipment	2'770'000.-
Piping	6'670'000.-
Civil engineering	3'440'000.-
Electrical connection	350'000.-
Study	1'470'000.-
Miscellaneous	2'210'000.-
Total	16'910'000.-

Observation

For this site, where the diameter of the pipeline is relatively large, the cost of the pipeline represents the largest proportion of the total investment, at just under 40%. In second place are civil engineering costs, which account for more than 20% of the total cost. The Figure 117 shows the breakdown of investment costs for this site.

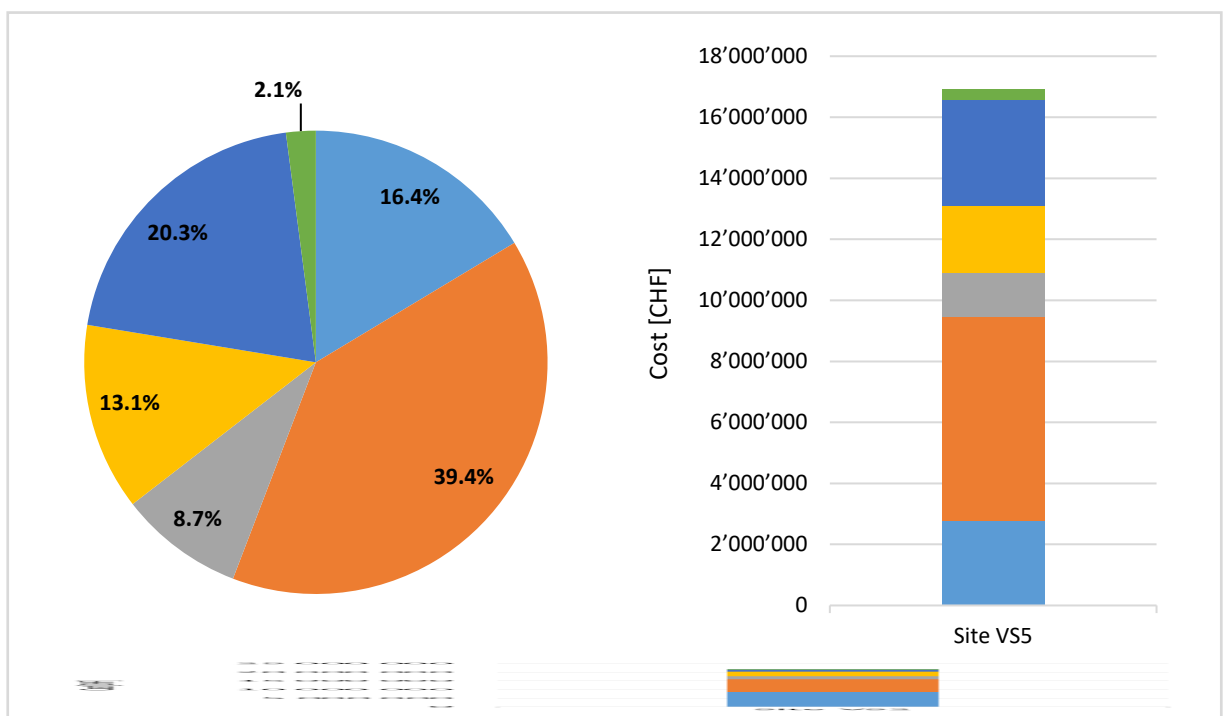


Figure 117 : Distribution of investment costs for the site VS5



6.4.2. Bern

6.4.2.1. Site BE1

Economic analysis

The distribution of the investment cost is given in Table 119. The total investment reached approximately 30.1 million Swiss Francs, i.e. 1.51 CHF/Watt using the total installed capacity (turbine & pump).

Table 119 : Distribution of investment costs for site BE1

Parts of the investment	Costs [CHF]
H&E equipment	12'000'000.-
Piping	10'290'000.-
Civil engineering	840'000.-
Electrical connection	960'000.-
Study	2'410'000.-
Miscellaneous	3'620'000.-
Total	30'120'000.-

Observation

For this site, electromechanical equipment accounts for the largest share, representing just over 39% of the total cost. The penstock is the second largest expense item, accounting for just under 34% of the investment cost. The Figure 118 shows the breakdown of costs for this site.

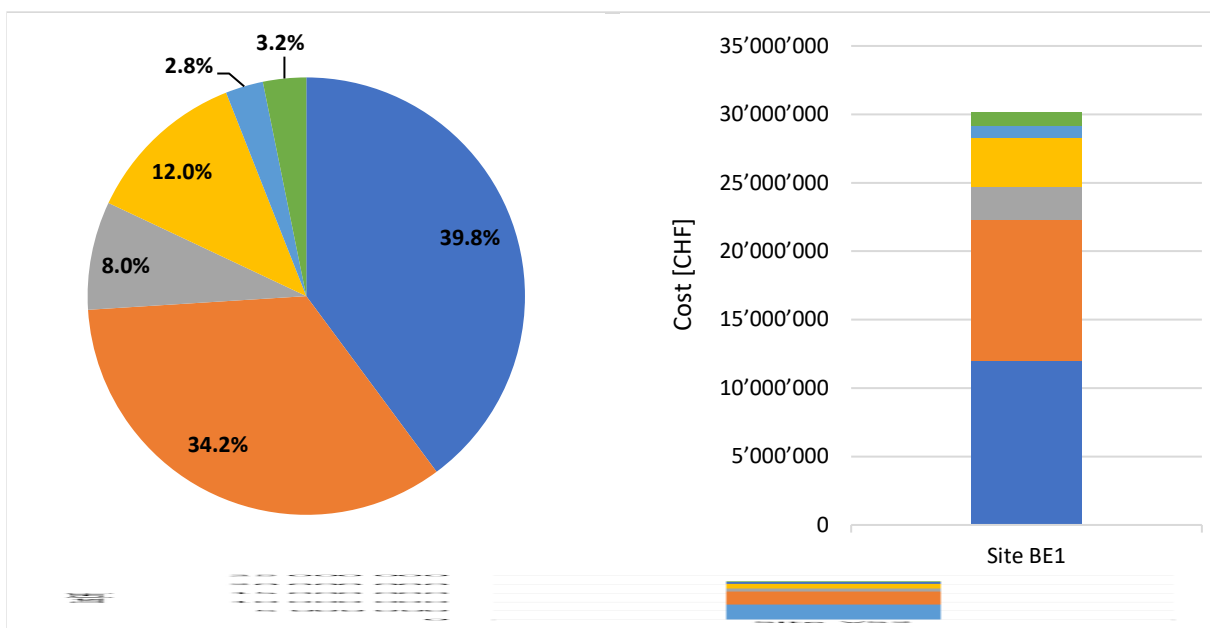


Figure 118 : Distribution of investment costs for site BE1



6.4.2.2. Site BE2

Economic analysis

The distribution of the investment cost is given in Table 120. The total investment reached approximately 19.9 million Swiss Francs, i.e. 1.99 CHF/Watt using the total installed capacity (turbine & pump).

Table 120 : Distribution of investment costs for site BE2

Parts of the investment	Costs [CHF]
H&E equipment	8'230'000.-
Piping	5'750'000.-
Civil engineering	1'460'000.-
Electrical connection	460'000.-
Study	1'590'000.-
Miscellaneous	2'390'000.-
Total	19'880'000.-

Observation

For this site, electromechanical equipment accounts for the largest share, representing just over 41% of the total cost. The penstock is the second largest expense item, accounting for just under 29% of the investment cost. The Figure 119 shows the breakdown of costs for this site.

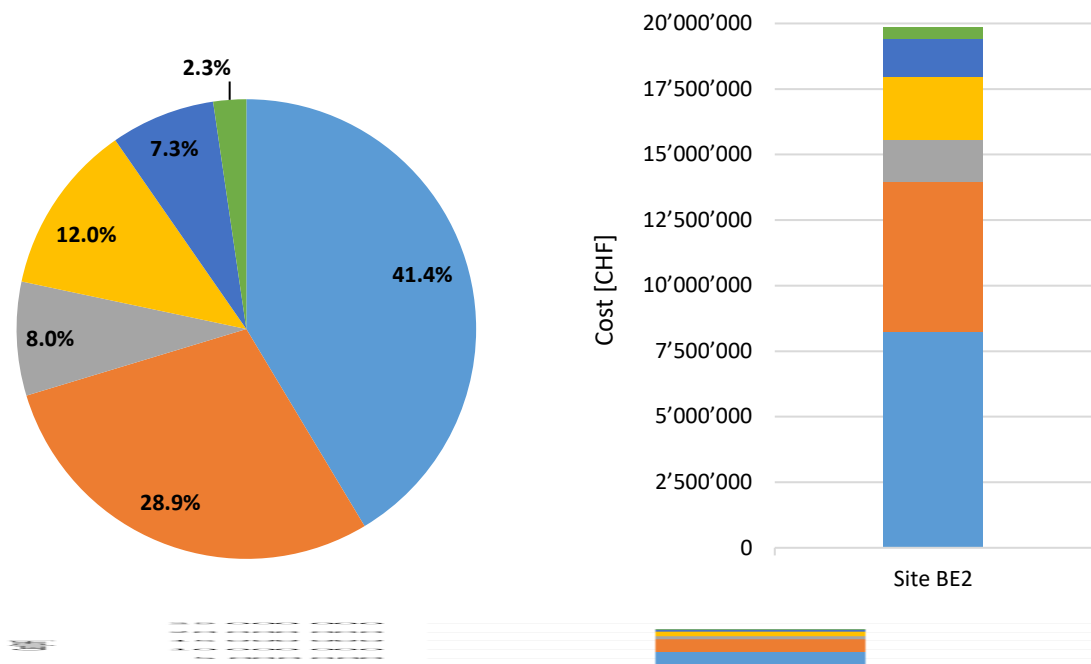


Figure 119 : Distribution of investment costs for site BE2



6.4.2.3. Site BE3

Economic analysis

The distribution of the investment cost is given in Table 121. The total investment reached approximately 24.2 million Swiss Francs, i.e. 2.42 CHF/Watt using the total installed capacity (turbine & pump).

Table 121 : Distribution of investment costs for site BE3

Parts of the investment	Costs [CHF]
H&E equipment	4'160'000.-
Piping	11'700'000.-
Civil engineering	3'625'500.-
Electrical connection	590'000.-
Study	1'630'000.-
Miscellaneous	2'450'000.-
Total	24'155'500.-

Observation

For this site, where the diameter of the penstock is relatively large, the cost of the penstock represents the largest share of the total investment, at just over 48%. In second place, investment in electromechanical equipment accounts for more than 17% of the total cost. The Figure 120 shows the breakdown of costs for this site.

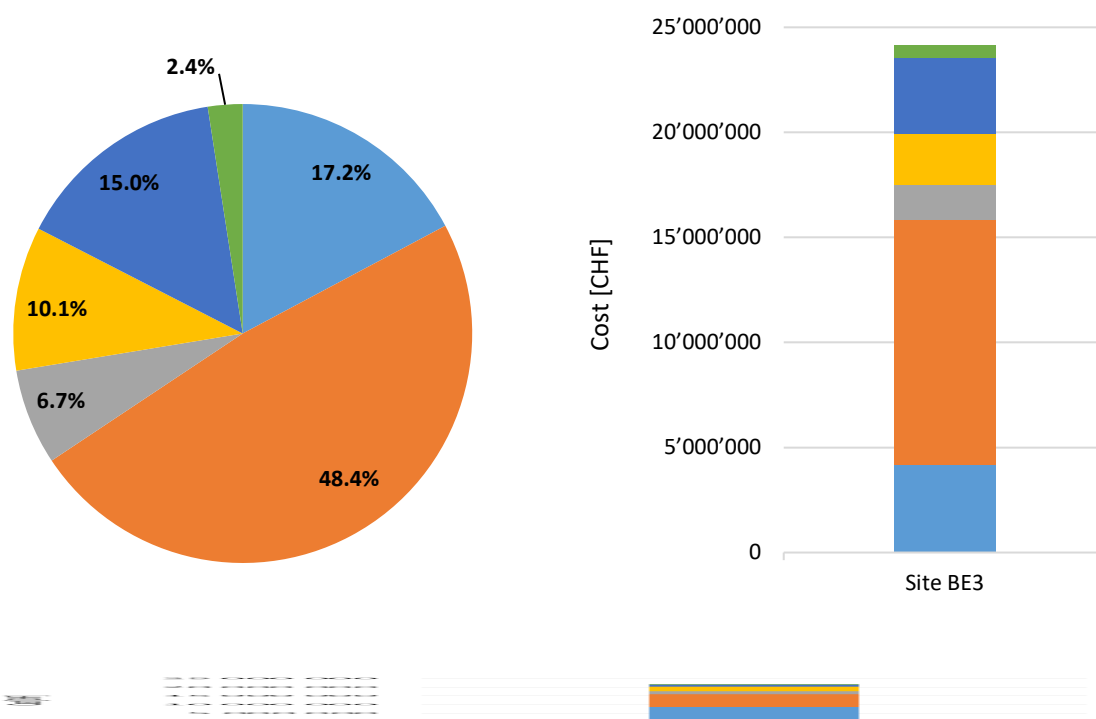


Figure 120 : Distribution of investment costs for site BE3



6.4.2.4. Site BE4

Economic analysis

The distribution of the investment cost is given in Table 122. The total investment reached approximately 21.6 million Swiss Francs, i.e. 2.17 CHF/Watt using the total installed capacity (turbine & pump).

Table 122 : Distribution of investment costs for site BE4

Parts of the investment	Costs [CHF]
H&E equipment	3'760'000.-
Piping	10'350'000.-
Civil engineering	3'531'000.-
Electrical connection	380'000.-
Study	1'460'000.-
Miscellaneous	2'180'000.-
Total	21'661'000.-

For this site, where the diameter of the penstock is relatively large, the cost of the penstock represents the largest share of the total investment, at just under 48%. In second place, investment in electromechanical equipment accounts for more than 17% of the total cost. The Figure 121 shows the breakdown of costs for this site.

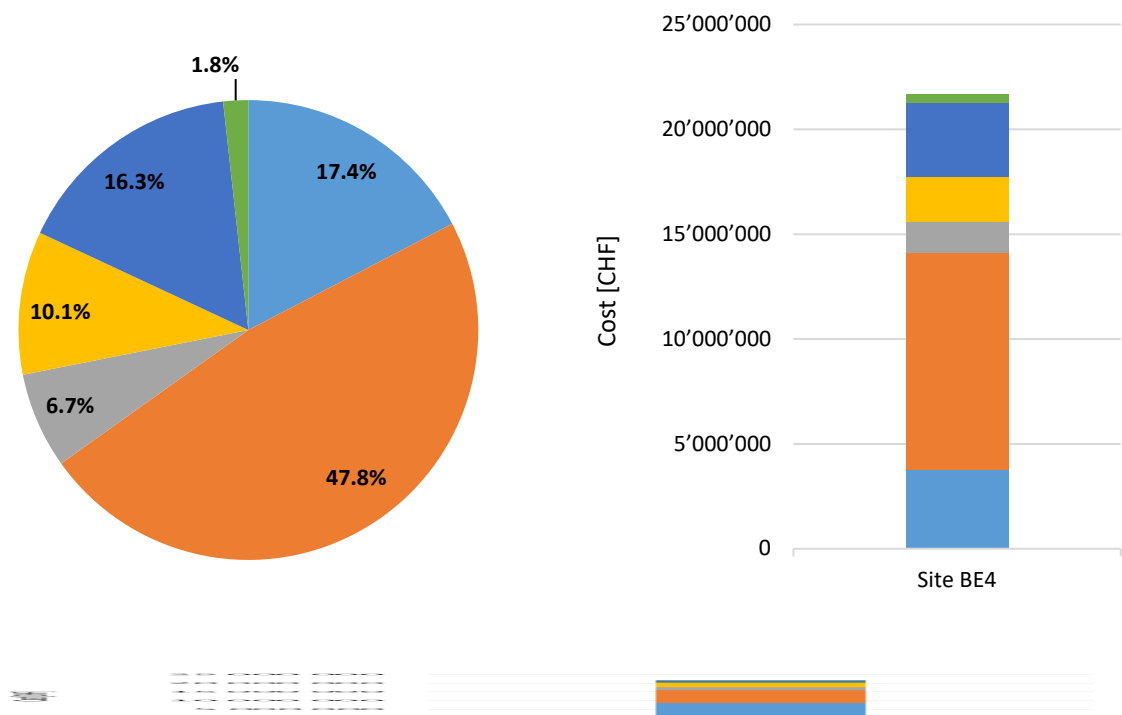


Figure 121 : Distribution of investment costs for site BE4



6.4.3.Fribourg

6.4.3.1. Site FR1

Economic analysis

The distribution of investment costs is presented in Table 123. The total investment amounts to approximately 26.8 million Swiss francs, corresponding to 2.68 CHF/Watt when considering only the installed pump capacity, since the turbines were already in place.

Table 123 : Distribution of investment costs for site FR1

Parts of the investment	Costs [CHF]
H&E equipment	6'560'000.-
Piping	12'740'000.-
Civil engineering	1'340'000.-
Electrical connection	780'000.-
Study	2'150'000.-
Miscellaneous	3'220'000.-
Total	26'790'000.-

Observation

For this site, where the diameter of the penstock is relatively large, the cost of the penstock represents the largest share of the total investment, at just under 48%. In second place, investment in electromechanical equipment accounts for more than 24% of the total cost. The Figure 122 shows the breakdown of costs for this site.

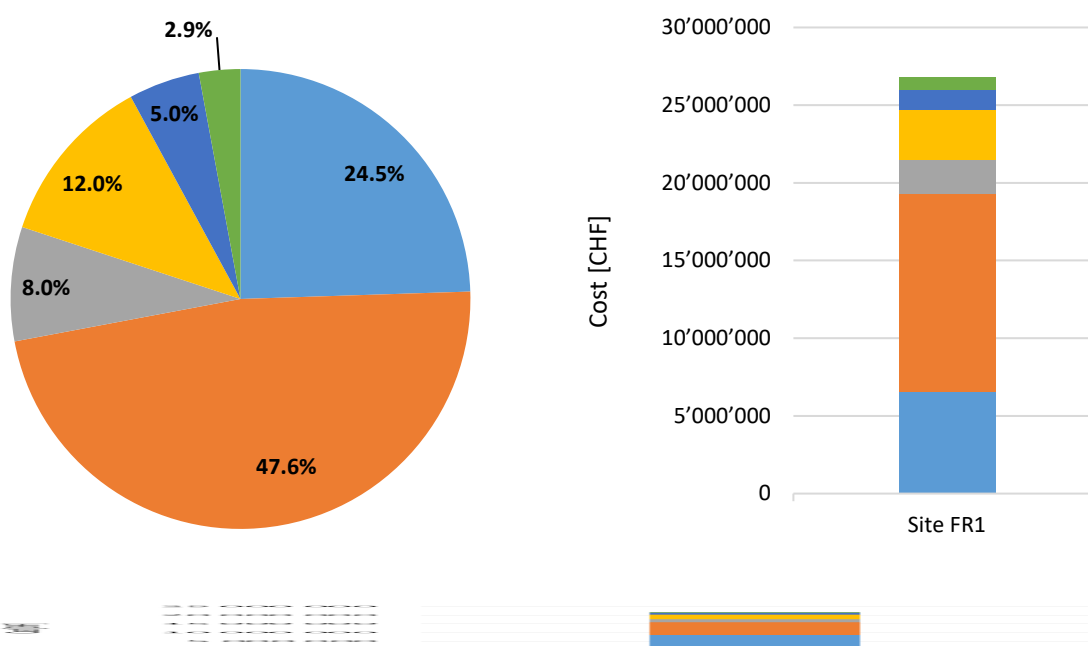


Figure 122 : Distribution of investment costs for site FR1



6.4.3.2. Site FR2

Economic analysis

The distribution of investment costs is presented in Table 124. The total investment amounts to approximately 9.8 million Swiss francs, corresponding to 1.19 CHF/Watt when considering only the installed pump capacity, since the turbines were already in place.

Table 124 : Distribution of investment costs for site FR2

Parts of the investment	Costs [CHF]
H&E equipment	5'820'000.-
Piping	1'440'000.-
Civil engineering	20'000.-
Electrical connection	520'000.-
Study	780'000.-
Miscellaneous	1'170'000.-
Total	9'750'000.-

Observation

For this site, electromechanical equipment, including the pump, motors and command and control system, accounts for the largest share, representing just under 60% of the total cost. The small section of the penstock to be constructed is the second largest item of expenditure, accounting for just under 15% of the investment cost. The Figure 123 shows the breakdown of costs for this site.

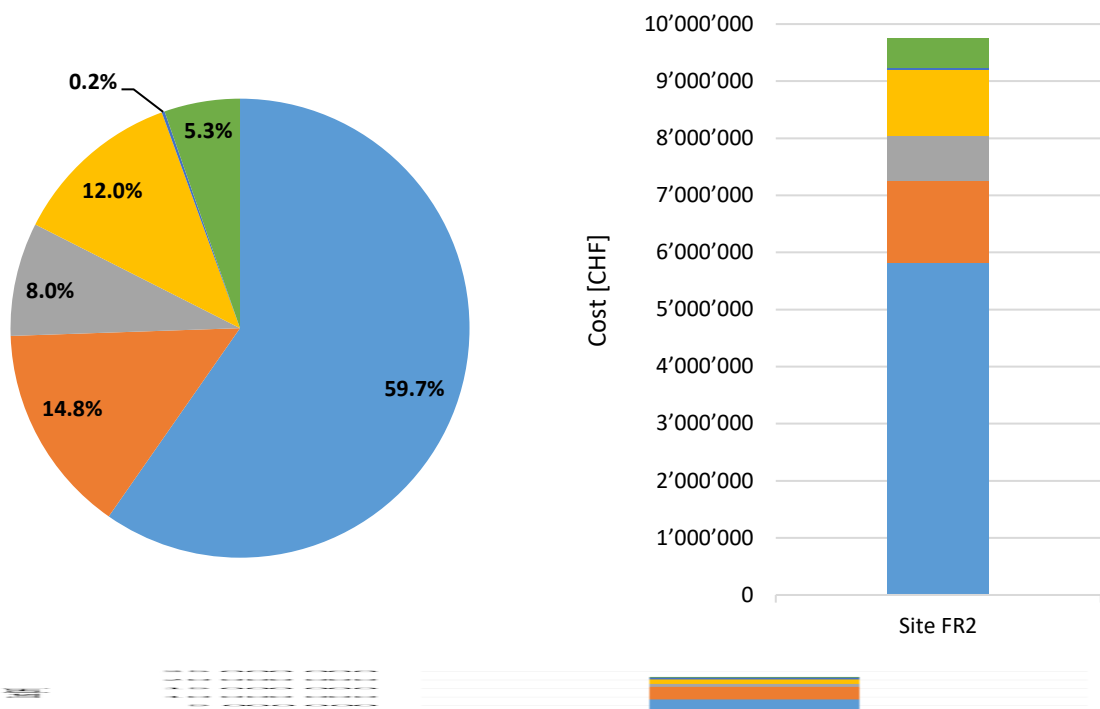


Figure 123 : Distribution of investment costs for site FR2



6.4.3.3. Site FR3

Economic analysis

The breakdown of investment costs is shown in Table 125. The total investment amounts to approximately 19.7 million Swiss francs, or 1.97 CHF/watt using the total installed capacity (turbine and pump).

Table 125 : Distribution of investment costs for site FR3

Parts of the investment	Costs [CHF]
H&E equipment	7'140'000.-
Piping	6'860'000.-
Civil engineering	1'370'000.-
Electrical connection	400'000.-
Study	1'580'000.-
Miscellaneous	2'370'000.-
Total	19'720'000.-

Observation

For this site, electromechanical equipment, including the turbine, pump, motors, and command and control system, accounts for the largest share, at just over 36% of the total cost. The penstock is the second largest expense item, accounting for just under 35% of the investment cost. The Figure 124 shows the breakdown of costs for this site.

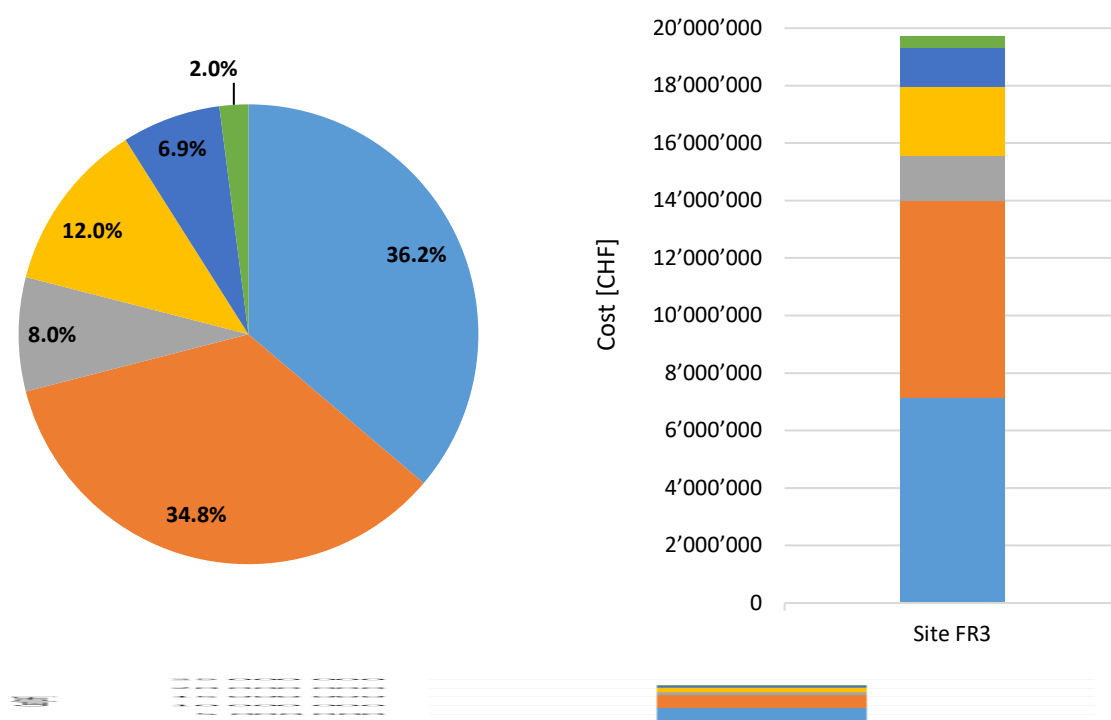


Figure 124 : Distribution of investment costs for site FR3



6.4.4.Vaud

6.4.4.1. Site VD1 (cf. chapter 2.7.1)

Economic analysis:

The distribution of the investment cost is given in the following table and figures. The total investment reaches approximately 44 million Swiss Francs, i.e. 4'281 CHF/kW, which is very high. The cost of the penstock is the highest. It should be noted that it is very difficult to address the investment for piping and civil engineering due to the specific situation due to the UNESCO World Cultural heritage.

Table 126 : Distribution of investment costs for site VD1.

Parts of the investment	Units	Costs
H&E equipment	CHF	13 850 000
Piping	CHF	15 000 000
Civil engineering	CHF	5 490 000
Electrical connection	CHF	820 000
Study	CHF	3 520 000
Miscellaneous	CHF	5 280 000
Total	CHF	43 960 000
	CHF /kW	4 281

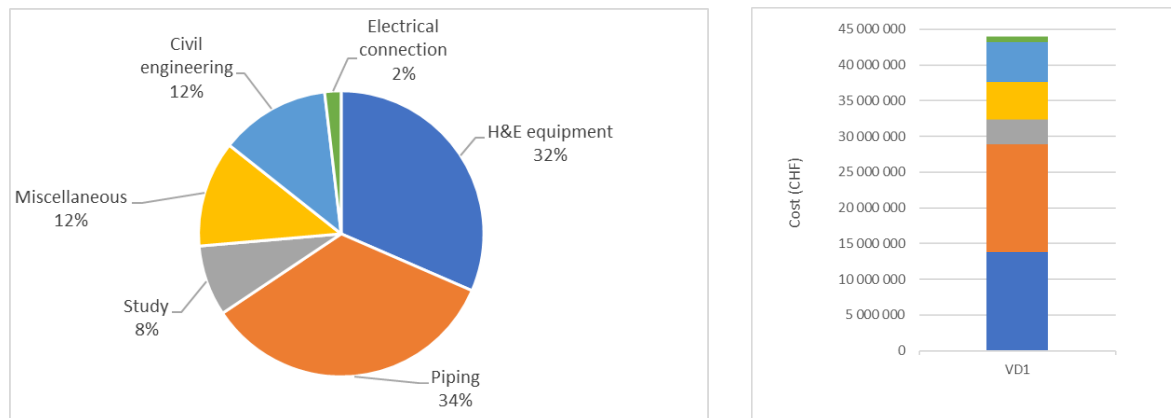


Figure 125 : Investment distribution for site VD1.



6.4.4.2. Site VD2 (cf. chapter 2.7.2)

The distribution of the investment costs is given in the following table and figures. The total investment reached approximately to 24.3 million Swiss Francs, i.e. 3'379 CHF/kW. The main investment is in H&E equipment, which accounts for 43% of the total price.

Table 127 : Distribution of investment costs for site VD2.

Parts of the investment	Units	Costs
H&E equipment	CHF	10 420 000
Piping	CHF	4 580 000
Civil engineering	CHF	3 430 000
Electrical connection	CHF	1 000 000
Study	CHF	1 950 000
Miscellaneous	CHF	2 920 000
Total	CHF	24 300 000
	CHF /kW	3 379

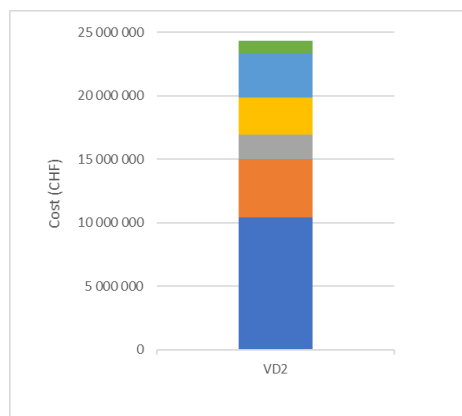
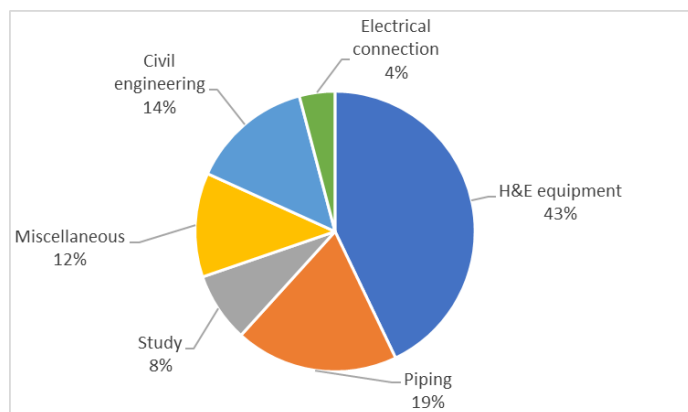


Figure 126 : Investment distribution for site VD1.



6.4.4.3. Site VD3 (cf. chapter 2.7.3)

The distribution of the investment costs is given in the following table and figures. The total investment reached approximately to 23.8 million Swiss Francs, i.e. 3'348 CHF/kW. The main investment is in H&E equipment, which accounts for 43% of the total price.

Table 128 : Distribution of investment costs for site VD3.

Parts of the investment	Units	Costs
H&E equipment	CHF	10 160 000
Piping	CHF	4 310 000
Civil engineering	CHF	2 910 000
Electrical connection	CHF	1 680 000
Study	CHF	1 910 000
Miscellaneous	CHF	2 860 000
Total	CHF	23 830 000
	CHF /kW	3 348

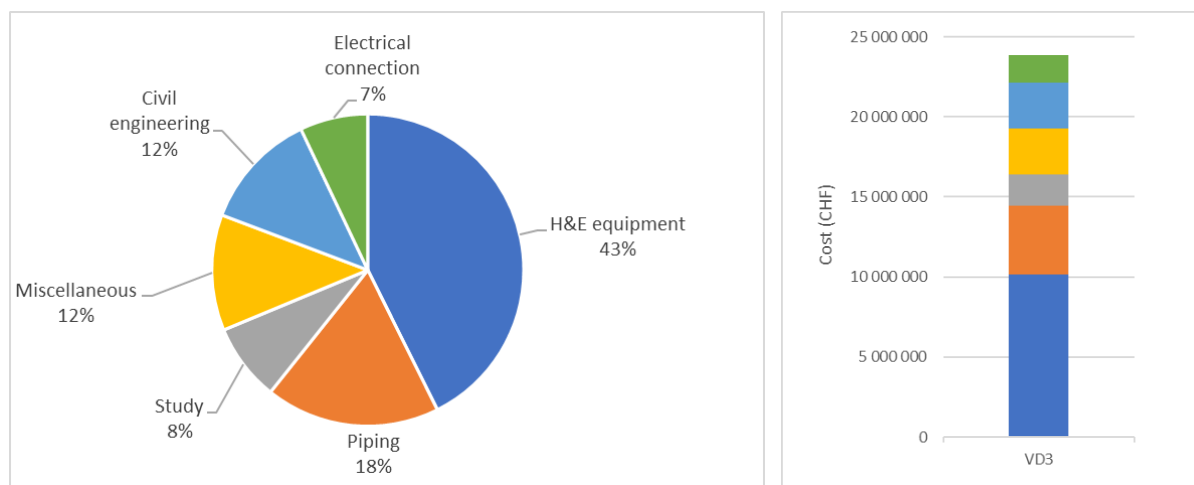


Figure 127 : Investment distribution for site VD3.



6.4.4.4. Site VD4 (cf. chapter 2.7.4)

The distribution of the investment costs is given in the following table and figures. The total investment reached approximately to 21.8 million Swiss Francs, i.e. 3'103 CHF/kW. The main investment is in H&E equipment, which accounts for almost 50% of the total price.

Table 129 : Distribution of investment costs for site VD4

Parts of the investment	Units	Costs
H&E equipment	CHF	8 840 000
Piping	CHF	4 260 000
Civil engineering	CHF	2 880 000
Electrical connection	CHF	1 460 000
Study	CHF	1 750 000
Miscellaneous	CHF	2 620 000
Total	CHF	21 810 000
	CHF /kW	3 103

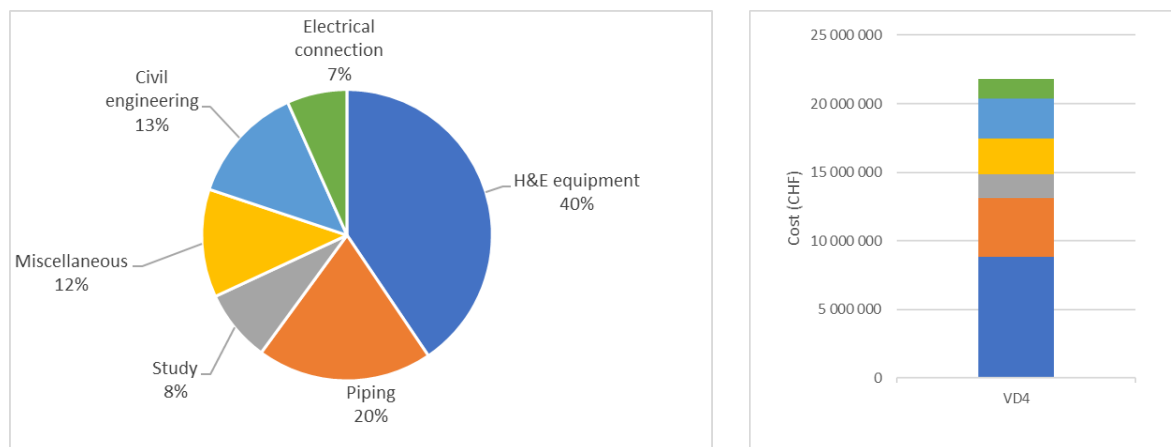


Figure 128 : Investment distribution for site VD4.



6.4.5.Jura

6.4.5.1. Site JU1 : Biaufond (cf. chapter 2.8.1)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 27 million Swiss Francs, i.e. 3 600 CHF/kW using the total installed capacity.

Table 130 : Distribution of investment costs for JU1

Parts of the investment	Costs [CHF]
H&E equipment	14 620 000
Piping	3 450 000
Civil engineering	3 210 000
Electrical connection	500 000
Study	2 180 000
Miscellaneous	3 270 000
Total	27'230'000.-

Observation

For this site, which requires separate equipment for pump and turbine cycles, the electromechanical investment component, including the pump, turbine, motors, and control-command system, represents the largest share, amounting to over 50% of the total investment cost (54%). Then the piping, the miscellaneous and the civil engineering share approximately the second major expense.

Figure 129 shows the distribution of investment costs for this site.

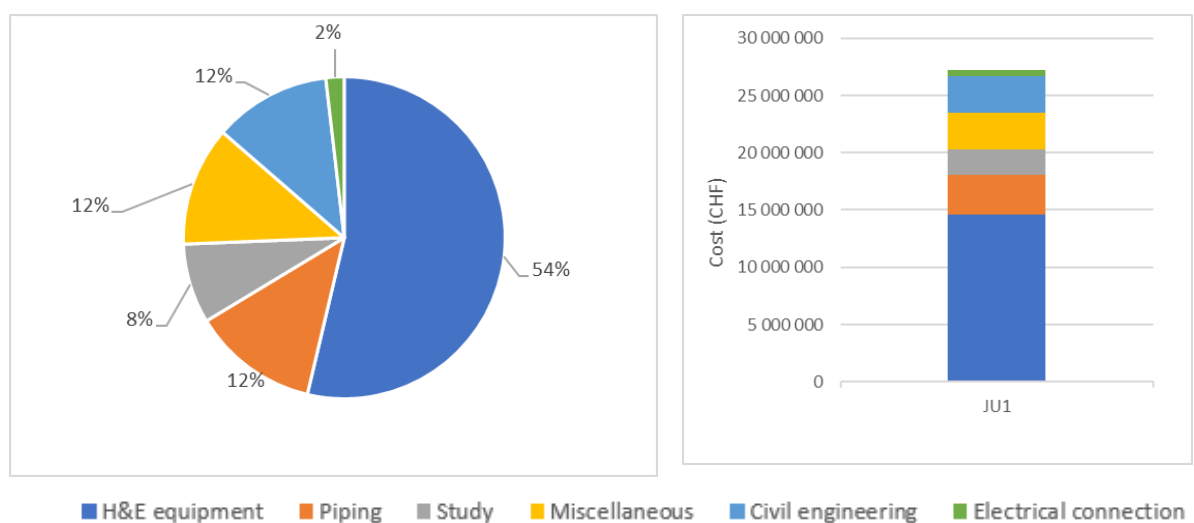


Figure 129 : Distribution costs for JU1



6.4.5.2. Site JU2 : Etang de Lucelle (cf. chapter 2.8.2)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 15 million Swiss Francs, i.e. 3 000 CHF/kW using the total installed capacity.

Table 131 : Distribution of investment costs for JU2

Parts of the investment	Costs [CHF]
H&E equipment	3 220 000
Piping	3 820 000
Civil engineering	4 533 500
Electrical connection	370 000
Study	1 280 000
Miscellaneous	1 920 000
Total	15'143'500

Observation

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (21%). Civil engineering and piping represent more than half of the cost (55 %).

The Figure 130 shows the distribution of investment costs for this site.

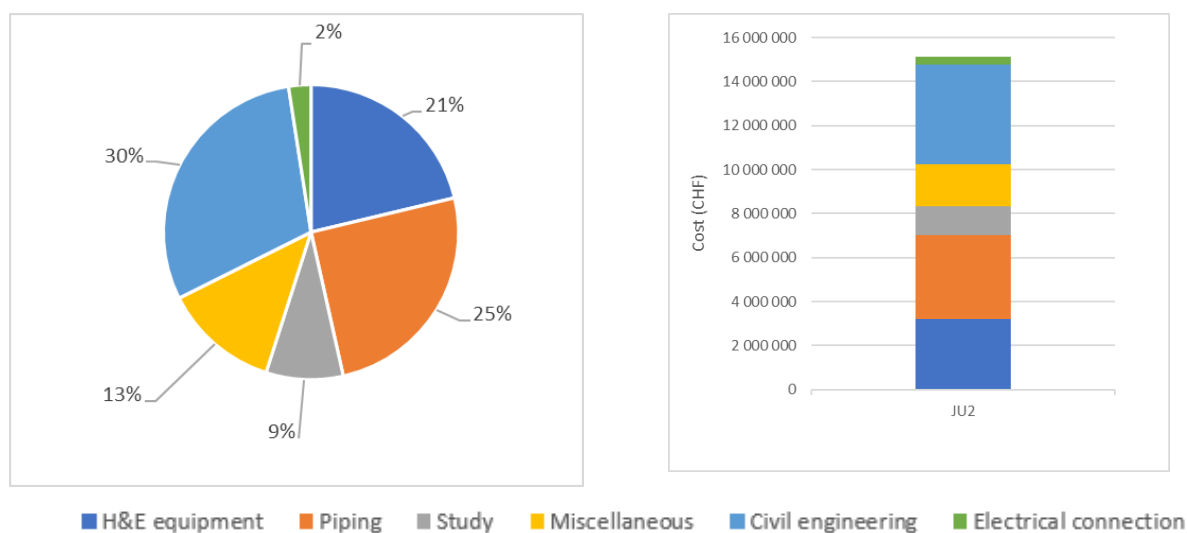


Figure 130 : Distribution costs for JU2



6.4.5.3. Site JU3 Cul-des-Prés (cf. chapter 2.8.3)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 19 million Swiss Francs, i.e. 3 200 CHF/kW using the total installed capacity.

Table 132 : Distribution of investment costs for JU3

Parts of the investment	Costs [CHF]
H&E equipment	2 820 000
Piping	6 540 000
Civil engineering	4 774 000
Electrical connection	1 030 000
Study	1 690 000
Miscellaneous	2 530 000
Total	19'384'000.-

Observation

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (14%). Civil engineering and piping represent more than half of the cost (59 %).

The Figure 131 shows the distribution of investment costs for this site.

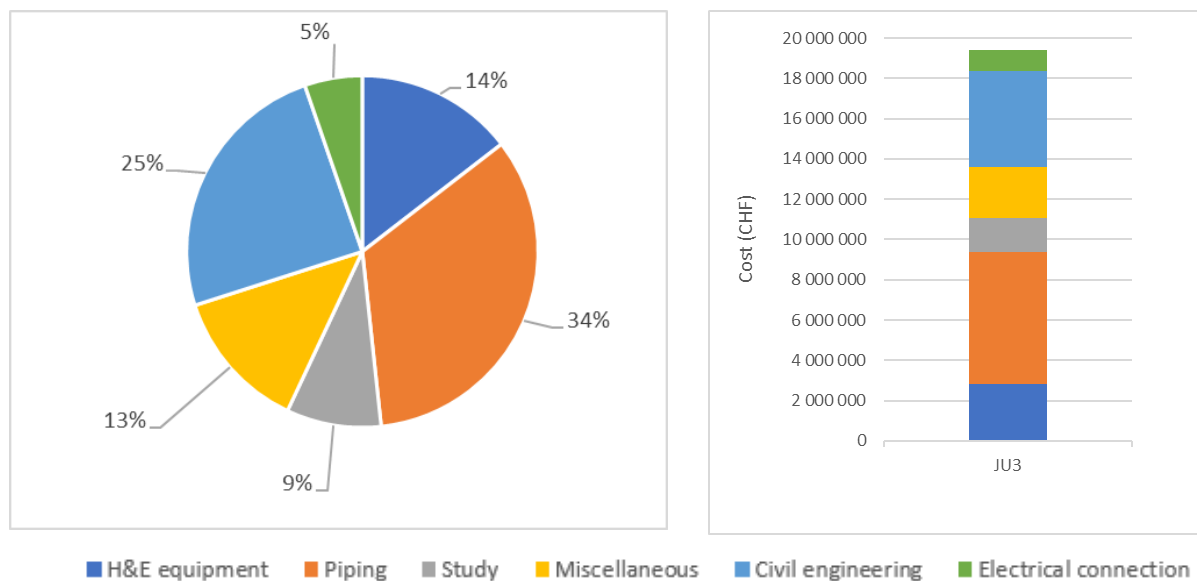


Figure 131 : Distribution costs for JU3



6.4.6. Neuchâtel

6.4.6.1. Site NE1 : Neuchâtel (cf. chapter 2.9.1)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 23 million Swiss Francs, i.e. 4 300 CHF/kW using the total installed capacity.

Table 133 : Distribution of investment costs for NE1

Parts of the investment	Costs [CHF]
H&E equipment	3 050 000
Piping	10 960 000
Civil engineering	4 419 000
Electrical connection	410 000
Study	2 020 000
Miscellaneous	3 030 000
Total	23'889'000

Observation

For this site, which requires only one unit, the electromechanical investment component, represents with miscellaneous, the third largest share of the total investment cost (13%). Piping costs represents almost half of the cost (46 %).

Figure 132 shows the distribution of investment costs for this site.

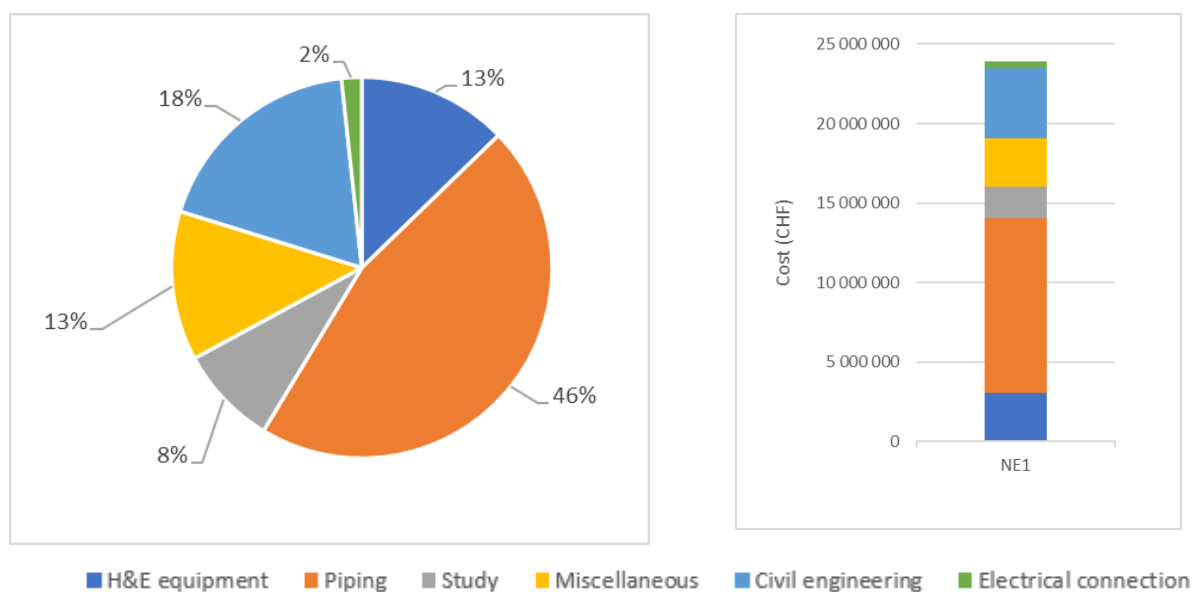


Figure 132 : Distribution costs for NE1



6.4.6.2. Site NE2 : Taillères (cf. chapter 2.9.2)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 25 million Swiss Francs, i.e. 5'000 CHF/kW using the total installed capacity.

Table 134 : Distribution of investment costs for NE2

Parts of the investment	Costs [CHF]
H&E equipment	3 270 000
Piping	12 100 000
Civil engineering	4 359 500
Electrical connection	380 000
Study	2 100 000
Miscellaneous	3 150 000
Total	25'359'500

Observation

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (13%). Piping costs represents almost half of the cost (48 %).

Figure 133 shows the distribution of investment costs for this site.

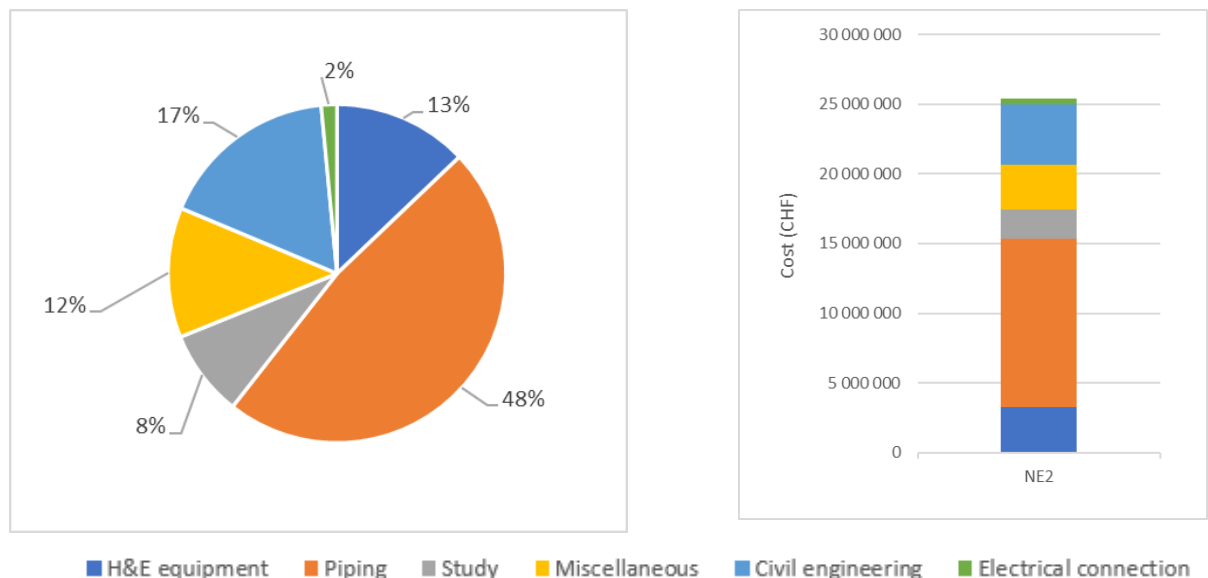


Figure 133 : Distribution costs for NE2



6.4.6.3. Site NE3: Le Loclat (cf. chapter 2.9.3)

Economic analysis

The distribution of the investment cost is given in the following table. The total investment reached approximately 25 million Swiss Francs, i.e. 5'000 CHF/kW using the total installed capacity.

Table 135 : Distribution of investment costs for NE3

Parts of the investment	Costs [CHF]
H&E equipment	3 020 000
Piping	6 370 000
Civil engineering	4 678 500
Electrical connection	410 000
Study	1 570 000
Miscellaneous	2 350 000
Total	18'398'500

Observation

For this site, which requires only one unit, the electromechanical investment component, represents the third largest share of the total investment cost (16%). Piping costs and civil engineering represent more than half of the cost (60 %).

Figure 134 shows the distribution of investment costs for this site.

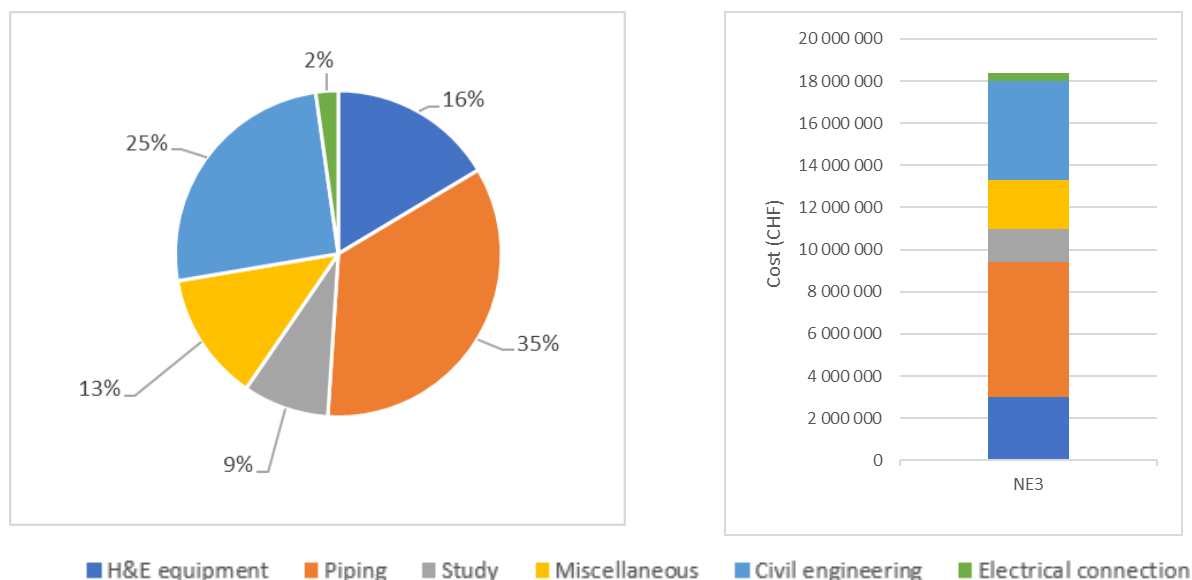


Figure 134 : Distribution costs for NE3



6.4.7.Ticino

6.4.7.1. Site T1 (cf. chapter 2.10.1)

The distribution of the investment costs is given in the following table and figures. The total investment reached approximately to 9.6 million Swiss Francs, i.e. 953 CHF/kW. The main investment is in H&E equipment, which accounts for 56% of the total price. The price per kW is low compared to the average of the selected sites as the penstock and the turbine are already in operation.

Table 136 : Distribution of investment costs for site T11

Parts of the investment	Units	Costs
H&E equipment	CHF	5 330 000
Piping	CHF	0
Civil engineering	CHF	1 670 000
Electrical connection	CHF	630 000
Study	CHF	770 000
Miscellaneous	CHF	1 150 000
Total	CHF	9 550 000
	CHF /kW	953

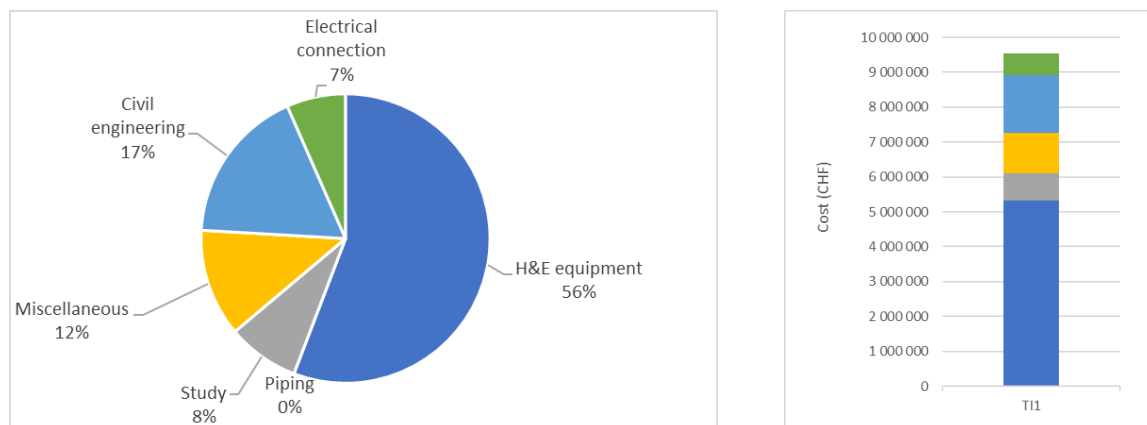


Figure 135 : Investment distribution for site T11



6.4.7.2. Site T12 (cf. chapter 2.10.2)

The distribution of the investment costs is given in the following table and figures. The total investment reached approximately to 10.9 million Swiss Francs, i.e. 1297 CHF/kW. The main investment is in H&E equipment, which accounts for 51% of the total price. The price per kW is low compared to the average of the selected sites as the penstock and the turbine are already in operation.

Table 137 : Distribution of investment costs for site T12

Parts of the investment	Units	Costs
H&E equipment	CHF	5 530 000
Piping	CHF	0
Civil engineering	CHF	2 660 000
Electrical connection	CHF	560 000
Study	CHF	880 000
Miscellaneous	CHF	1 320 000
Total	CHF	10 950 000
	CHF /kW	1'297

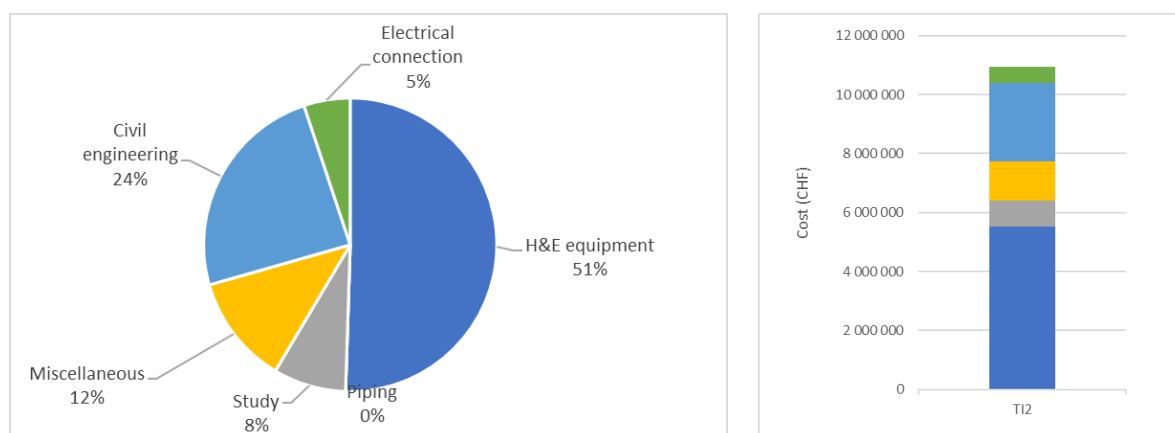


Figure 136 : Investment distribution for site T12



6.5 WP4 Environmental approach

As mentioned in chapter 2.2.10, an environment approach has been applied to the selected sites of the cantons of Jura and Neuchâtel, as example. As this approach is far from being sufficient regarding the definition of environmental potentials, it has been chosen not to apply it on all sites. All the maps are from the Federal Geoportal.

6.5.1. Jura

6.5.1.1. Site JU1: Biaufond

As shown in Figure 137, the main habitats of the site are the following ones:

- Grasslands and meadows
- Forests



Figure 137 : Habitat map for the site for JU1

6.5.1.2. Site JU2: Lucelle

As shown in Figure 138, the main habitats of the site are the following ones:

- Shores and wetlands
- Grasslands and meadows
- Forests

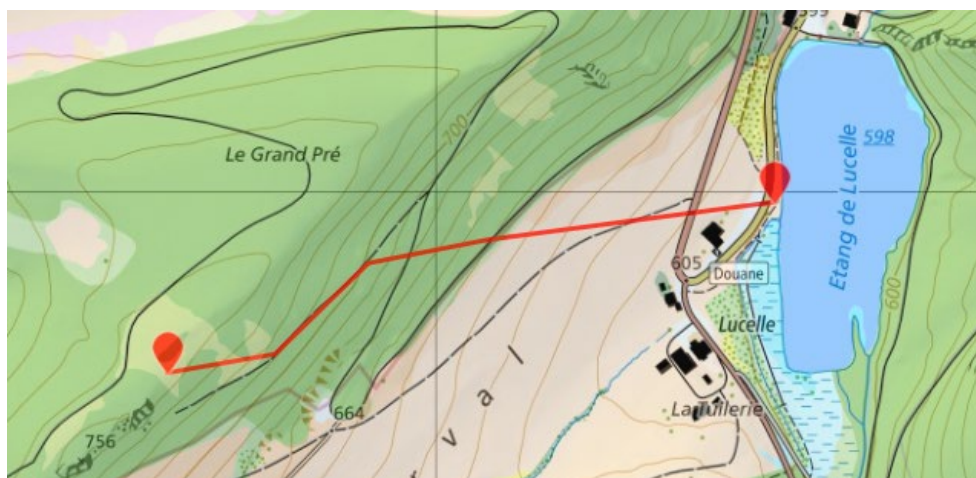


Figure 138 : Habitat map for the site for JU2

6.5.1.3. Site JU3: Cul-des-Prés

As shown in Figure 139, the main habitats of the site are the following ones:

- Shores and wetlands
- Grasslands and meadows
- Forests



Figure 139 : Habitat map for the site for JU3



Figure 141 : Habitat map for the site NE2

6.5.2.3. Site NE3: Le Loclat

As shown in Figure 142, the main habitats of the site are the following ones:

- Grasslands and meadows
- Forests



Figure 142 : Habitat map for the site NE3



7 Data management plan and open access/data/model strategy

If possible, we plan to join two files to the present report to be published on the ARAMIS portal. These two files would be in the kml file format that can be loaded on the online swisstopo maps (<https://map.geo.admin.ch>).

The first file contains the location of the 24 technical sites with metadata providing the key characteristics of the site (see 2.11).

The second file contains all the pair of lakes obtained when maximising the energy storage with a maximum distance of 2 km (see 2.13.3).



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