Pompage-turbinage avec de la petite-hydro – une option ?

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This paper contributes towards exploring the technical and institutional feasibility of small hydropower storage and pumped-storage schemes in Switzerland. Within the European and Swiss context of the facilitation of renewable energy technologies, which includes small hydropower (SHP), intermittent sources such as solar and wind increase the need for additional energy storage capacities. Hydropower pumped-storage schemes remain the most efficient and profitable option to “store” electricity. In Switzerland, most of the large scale hydropower potential is already exploited. The potential of SHP (<10 MW) for storage and pumped-storage applications, especially with a decentralised energy supply and grid balancing perspective (“smart grid”), has not yet been evaluated. SHP storage and pumped-storage schemes can use streams and lakes, or existing infrastructures, such as irrigation and snow-making facilities or inoperative galleries (i.e. multipurpose infrastructures). These facilities offer unexplored opportunities using existing reservoirs. The methodology has been applied in Switzerland but can be easily transposed to other countries. The research evaluates the small storage and pumped-storage hydropower potential in a qualitative and explorative manner. It includes a concrete case study in Torgon (Valais, Switzerland). Based on an existing high head run-of-river SHP study with a net annual production of 9 GWh, the storage and pumped-storage are added as possible extensions of the initial project. The proximity of the ski lift station of Torgon offers the possibility to use snow-making lakes as upstream/downstream reservoirs. Finally, this paper formulates some institutional recommendations in order to facilitate such a development (e.g., remuneration instruments).

Cet article explore la faisabilité technique et institutionnelle du stockage et du pompage-turbinage pour la petite hydraulique en Suisse. Dans le contexte européen et suisse de promotion des énergies renouvelables (qui comprennent les petites centrales hydroélectriques et les sources intermittentes comme le solaire et le vent), le besoin en capacité de stockage augmente. Les installations de pompage-turbinage demeurent l’option la plus efficace et la plus rentable comme batterie du réseau. En Suisse, la majorité du potentiel hydroélectrique à grande échelle est déjà exploité. Le potentiel de la petite hydraulique pour des applications de stockage et de pompage-turbinage surtout avec un approvisionnement énergétique décentralisé et une perspective d'équilibrage du réseau ("smart grid") n'a pas encore été évalué. Des systèmes de stockage et de pompage-turbinage avec de la petite hydro peuvent utiliser des lacs ou des infrastructures existantes telles que des systèmes d’irrigation ou d’enneigement ou encore des galeries inutilisées (infrastructures à buts multiples). Ces installations offrent des possibilités inexplorées utilisant des réservoirs existants. La méthodologie a été appliquée en Suisse mais peut être aisément transposée à d’autres pays. La recherche évalue le potentiel de stockage et de pompage-turbinage avec de la petite hydro de façon qualitative et exploratoire. Elle inclut un cas d’étude concret à Torgon (Valais, Suisse). A partir d’un projet de mini-centrale hydroélectrique à haute chute avec une production annuelle de 9 GWh, le stockage et le pompage-turbinage sont ajoutés comme des possibilités d’extension au projet initial. La proximité de la station de ski de Torgon offre la possibilité d’utiliser des lacs d’enneigement comme réservoirs supérieurs et inférieurs. Finalement cet article formule des recommandations institutionnelles de façon à faciliter un tel développement, en particulier les instruments de rémunération.

Key words

Small hydropower, pumped-storage multipurpose infrastructures, institutional frameworks, Switzerland

I INTRODUCTION

The Swiss Energy law stipulates an increase in the electricity production from renewable energy technologies (RET) by an additional 5'400 GWh by the year 2030 compared to figures in 2000. Among the measures contributing towards reaching this target is the facilitation of hydropower, including small hydropower (SHP). The likely phase out of nuclear power in Switzerland will increase further the pressure to produce more electricity with indigenous sources, such as SHP.

In Switzerland, SHP is defined by an installed capacity of up to 10 MW[1] [1]. In 2010, SHP produced 3'630 GWh and covered 5.48% of the Swiss electricity production [2]. The institutional frameworks are very complex as SHP is not only affected by cross-sectorial regulation (e.g., water and energy sector, spatial planning), but also has to develop within a multi-level governance framework. Some administrative procedures are completed at the federal level (e.g., feed-in remuneration), others at the cantonal level (e.g. water concession) and finally some at the commune level (e.g. construction permit). The latest major institutional change was the introduction of the feed-in remuneration (FIR) in 2009. It is a cost-effective net metering and applies to RET which are not yet competitive in the liberalised electricity market, including SHP. In September 2011, 232 SHP projects were financed through the FIT with 475 GWh/year and 104 MW installed. In addition, there are 420 announced projects (1'393 GWh and 350 MW)[2].

Within the dynamics of the electricity sector, the increase of distributed and intermittent RET production leads to the need for more storage capacities to operate the grid. Storage capacities are complementary to the ICT developments which also contribute to grid balancing ("smart grids"). RET facilitation should therefore not only focus on increasing the electricity production, but also take storage RET into account. The institutional facilitation must consider the alignment between production and the actual electricity demand and the contribution to peak production and ancillary services.

In Switzerland, large storage and pumped-storage schemes have a national and continental role to play within the electricity sector in line with the role of electricity hub which Switzerland holds in Europe. Small scale schemes on the other hand have a local and regional role. The potential of storage and pumped-storage SHP in Switzerland is evaluated below. SHP with storage capacities could play a significant role in distributed energy storage, producing distributed peak electricity, and local and regional grid balancing. In addition, it could contribute to flood mitigation as extreme weather events are forecasted to increase in Switzerland due to global warming. In 2010, there were 2 pumped-storage SHP plants and 18 storage SHP plants in Switzerland (see Table 2).

This paper summarises some key findings of current research on the technical and institutional feasibility of SHP storage and pumped-storage schemes in Switzerland [3] and develops a concrete case study from a project of the engineer office e-dric.ch.

II LOOKING AT EXISTING RESERVOIRS

In order to optimise the use of infrastructures and to reduce investment costs as well as environmental opposition, existing and planned reservoirs were primary targets for the evaluation of the technical potential of SHP storage and, where feasible, pumped-storage schemes. Such schemes can be built on watercourses and within multipurpose infrastructures such as snow making and irrigation structures (increasingly needed due to climate change). The methodology was bottom-up and explorative. The Canton of Valais was chosen as the unit of evaluation due to its considerable remaining potential for SHP development.

The options for reservoirs include damned lakes, natural lakes, future lakes (melting glaciers), as well as snow-making, irrigation and drinking water infrastructures. Unused galleries from the army or existing hydropower plants were considered as well. Several reference types (e.g. SHP plant where storage capacity can be increased, unused lakes as storage, and infrastructures in which pumped-storage can be developed)

[1] Mini hydropower is <1 MW.
[2] https://www.guarantee-of-origin.ch/reports%5CDownloads%5Cwarteliste_DE.pdf

were defined [4]. A brief technical evaluation was conducted for each type, followed by identifying some reference cases which were evaluated in more depth (such as the case study below). The main variables are the volume, coordinates and altitude of the reservoirs, the distance to the nearest road and electrical grid, and, if existing, the length and diameter of the pipes, as well as the existence/non-existence of the different components which are necessary for a SHP plant (e.g. dam, power station, etc.). The evaluation leads to first estimates on production, costs and required remuneration to enable economically viable projects. The results for the Canton of Valais were extrapolated for the whole country based on the rule of proportion and criteria taking into account geographical surface, population, FIR projects and existing SHP plants [4].

III RESULTS

The research has been focused on projects with an installed capacities between 0.3 and 10 MW. 10 MW is the upper limit for SHP and 0.3 MW is the lower limit of plants included in the national hydropower statistics.

In this chapter, the evaluation of the technical potential of SHP storage and pumped-storage schemes is firstly discussed followed by the analysis of the institutional feasibility.

III.1 Technical potential evaluation for Switzerland

Table 1 shows the results for Switzerland compared to the existing plants. SHP accounts for about 6.3% of the total hydropower installed capacity. However, for storage schemes SHP accounts for only 1.3 % of the installed capacity and for pumped-storage schemes it is even less with 0.7%.

Table 1: Technical potential evaluation of storage and pumped-storage SHP

Switzerland	**2010 (in operation, [2])**	**Additional technical potential**
Storage SHP	18 plants with a total of 106 MW	100 – 200 MW
Pumped-storage SHP	2 plants: 2.35 and 7.3 MW	70 – 180 MW

The important deltas in the final values are due to two reasons. Firstly, the evaluation in the Canton of Valais considers minimum and maximum values, which can vary significantly per project depending on the final project design. Secondly, the final extrapolation ratio with a delta contributes to increase the difference between the lower and higher value. Nevertheless, it illustrates the scale of additional technical potential of SHP storage and pumped-storage schemes in Switzerland.

The SHP storage potential lies mainly with SHP plants on watercourses. About 2/3 of this potential is with existing plants where the increase of the reservoir capacity could be evaluated.

The SHP pumped-storage potential is mainly found within infrastructures and some lakes. SHP plants have already been built within infrastructures, mainly in drinking and waste water networks. However, there remains a considerable potential for pumped-storage schemes in the case of the rehabilitation or construction of new infrastructures. The aim should be to optimise the use of reservoirs whilst converging different sectors (e.g. electricity, tourism, agriculture and drinking water). When the water is stored but not used for its final purpose (e.g., snow, irrigation), it can be used within closed systems for pumped-storage.

The potential evaluation is conservative. It does not consider potential with future SHP plants on watercourses, glaciers melting to future lakes and additional weirs for flood protection. Neither does it consider future available military infrastructures and galleries becoming inoperative in the next years.

The potential must be compared to large storage and pumped-storage hydropower. For example, if the whole SHP pumped-storage potential is constructed, it would only equal the size of the second largest existing pumped-storage plant Force Motrices Hongrin-Léman (FMHL) which has currently an installed capacity of 240 MW [2]. However, small and large scale plants are not in competition, but can be seen as complementary. Large scale schemes are built with an international perspective of operation, whereas small scale schemes should be built with a regional and so-called “smart grid” perspective.

In conclusion, the technical potential is important enough to shape the institutional frameworks in order to develop adequate remuneration instruments.

III.2 Institutional feasibility of SHP pumped-storage in Switzerland

The institutional feasibility was studied along the possible remuneration instruments (i.e. financial incentives) and the administrative procedures. This paper only discusses the remuneration instruments. The methodology was based on expert-interviews and a survey sent to all SHP plant operators receiving the FIR in 2010.

SHP pumped-storage plants are only part of RET if the pumping energy comes from RET as well. SHP pumped-storage which pump with electricity from not RET have to be remunerated with instruments outside of the RET facilitation schemes (e.g. spot market). However, if there are natural inflows in the upper reservoir, SHP pumped-storage plants can differentiate their production between renewable (i.e. natural inflows) and not-renewable and thus benefit from RET remuneration schemes.

In Europe, only the Czech Republic and Portugal have remuneration instruments taking into account flexible production from SHP storage capacities. In Portugal, the feed-in tariffs depend on the time of electricity generation (i.e. peak/off peak) [5]. In the Czech Republic, the guaranteed tariff differentiates between run of river and storage plants in peak or semi-peak production[3]. The additional income for peak and semi-peak production is 25%.

It is not the scope of this research to compare the different instruments. The objective is to identify and develop the most promising remuneration instruments which would facilitate the economically viable implementation of SHP pumped-storage schemes (see Table 2).

Table 2: New and adapted remuneration instruments for SHP pumped-storage schemes

Instrument	Description	Required adaptations	RET / not RET	Storage / Pumped-storage
Alpine sustainable mobility	Ski resorts use their infrastructure to produce electricity from RET to cover their demand.	Exploit the pumped-storage SHP potential within snow making infrastructures.	RET/ not RET	Pumped-storage
Ancillary services – green services	Based on the percentage of electricity from RET in the electricity mix, the same percentage is asked from RET for ancillary services.	Apply the same quota of electricity production from RET to the amount of electricity from RET used for ancillary services.	RET	First storage, then pumped-storage once superfluous electricity from other RET.
Ancillary services – regional/local approach	Distributed plants contribute at lower voltage level to ancillary services.	Implement within smart grids developments decentralised ancillary services from distributed plants.	Not RET	Both
CO_2 compensation scheme for peak production	CO_2 compensations for emissions during peak demand are traded separately to the base compensation.	Create a separated trading scheme for CO_2 compensation generated by peak production.	RET	Storage
FIR – peak premium	A premium is paid for producing during peak demand.	Adapt the existing Federal Energy Ordinance for the FIR.	RET	Storage
Labelled green electricity - quota for peak production	Customers buying labelled green electricity have to be supplied with peak labelled green electricity as well according to their consumption profile.	Adapt the current market for labelled green electricity to account for peak production as well.	RET	Storage

SHP pumped-storage schemes can also sell their electricity on the sport market or within current ancillary services frameworks. However, for the former the price difference between peak and low price is mostly too low, and for the latter the remuneration for tertiary control reaches only about half of the current feed-in remuneration.

[3] http://www.streammap.esha.be/29.0.html (accessed on 01.09.2011)

IV CASE STUDY

IV.1 Introduction

A concrete case is studied in the ski lift station of Torgon in the Swiss Alps (Valais). The site presents attractive conditions of hydrology and relief for a high head run-of-river SHP project (~300 l/s and head of 760 m). Beside the study of the run-of-river SHP project itself, the feasibility of storage and pumped-storage extensions is explored.

IV.2 Hydrology with RS 3.0

The project is based on the river Avançon (8.8 km^2 at the water intake). Less than one year of interrupted flow measures is available which is not enough to directly design the project. To obtain a significant flow duration curve, an hydrological model is built in RS 3.0 [6].

RS 3.0 software allows to model complex hydrological systems. With temperature and precipitation, the hydrological processes are modelled in each sub-catchment area [7]. Variation of the temperature due to altitude is integrated with the elevation band concept. The semi-distributed conceptual GSM-SOCONT model integrates the snow and glaciers processes as well as the runoff and the soil infiltration. The general behaviour of the model is presented at Figure 1. Based on hourly input data, the model is solved at the same step for a typical duration of 20 years.

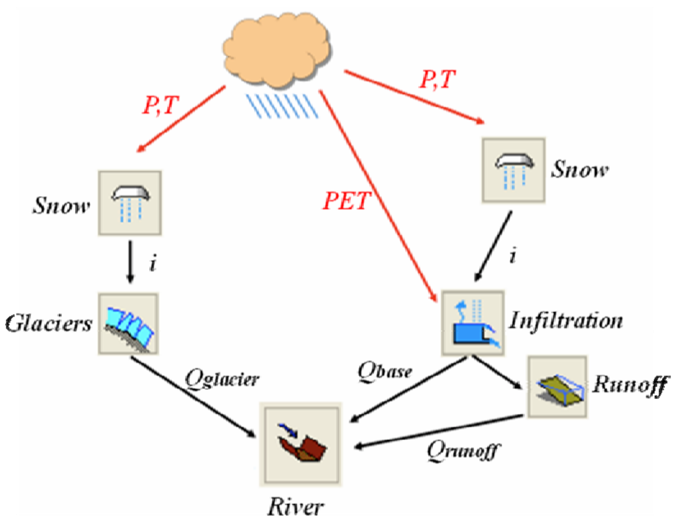

Figure 1: Routing System operating scheme

A procedure of calibration and validation is required in order to fit the model with the flow measurement. Based on a limited measured flow vector, the main parameters are adjusted in order to reduce the difference between the measured and the computed flow. The global volume as well as the Nash parameter are used to estimate the difference. The validation is made using data from near rivers and adjusting the flow rates proportionally to the sizes of the catchment areas.

Based on the validated model, the flow is generated for the whole period covered by the weather data at an hourly step. For the river Avançon, the generated flow covers 28 years from 1982 to 2010. Mathematical operators allow then to define the average classified flow curve as well as the yearly peak flow. These two results are used to design the operational infrastructures as well as the peak flood value with a Gumbel law.

IV.3 Main results of preliminary design

The main results obtained with the preliminary design [8] are the followings:

- Tyrolian intake (1147 m.a.s.l) with a fish river, a settling basin and a loading chamber
- Buried penstock of 3538 m length with diameter 500 mm on the 765 first meters and 400 mm after
- Raw head: 751 m

- Maximum discharge: 310 l/s
- Electrical power: 1'910 kW
- Annual electricity generation: 9.5 GWh/year
- Annual income: 1.47 mio CHF/an
- Total cost: 9'250'000 CHF.

IV.4 A project with many possibility of extensions

Due to many existing or planned infrastructures, extensions of the main project can be considered in order to develop a pumped-storage SHP. Figure 2 illustrates the different possibilities.

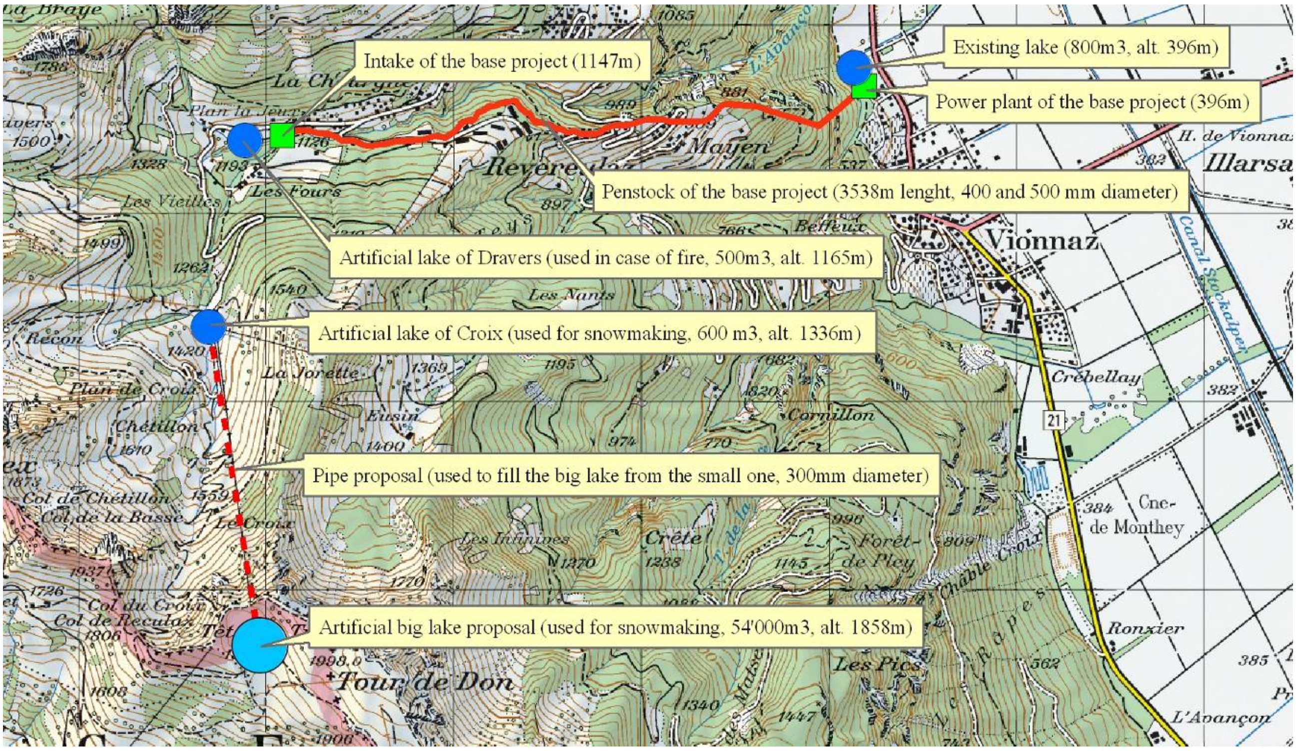

Figure 2: Existing/planned infrastructures in Torgon

In Dravers, at about 200 m upstream from the intake, a small artificial lake was built on a natural reservoir to fight forest fires. It can be easily extended to a volume of 3000 m^3. Directly beside from the powerhouse, another natural lake exists with a volume of 800 m^3.

Upstream in the valley, a large project of snowmaking is planned by Tele-Torgon. The expected infrastructures are an artificial lake in Croix of about 600 m^3, a second artificial lake near the border on the French territory of about 54’000 m^3 and a penstock between the two lakes of 300 mm diameter and 1870 m length.

IV.5 Accumulation extension on the base project

The tank of Dravers is located on the river a few meters upstream from the intake. The first extension consists in using this tank as a buffer to supply water to the intake when the river discharge does not reach the rated discharge. The reservoir volume is increased from 500 m^3 to 3'000 m^3 and a smart gate is installed (fills/empty the tank automatically depending on the flow rate at the intake).

The results are based on the year 1994 which is the most representative over the past 30 years. As illustrated by Figure 3, the tank is filled and emptied more than 15 times per year. This increases the annual production by nearly 1% and represents an additional income of 7’600 CHF per year.

Considering the costs of excavation and the installation of the gate, the annual profit finally increases by 350 CHF/year.

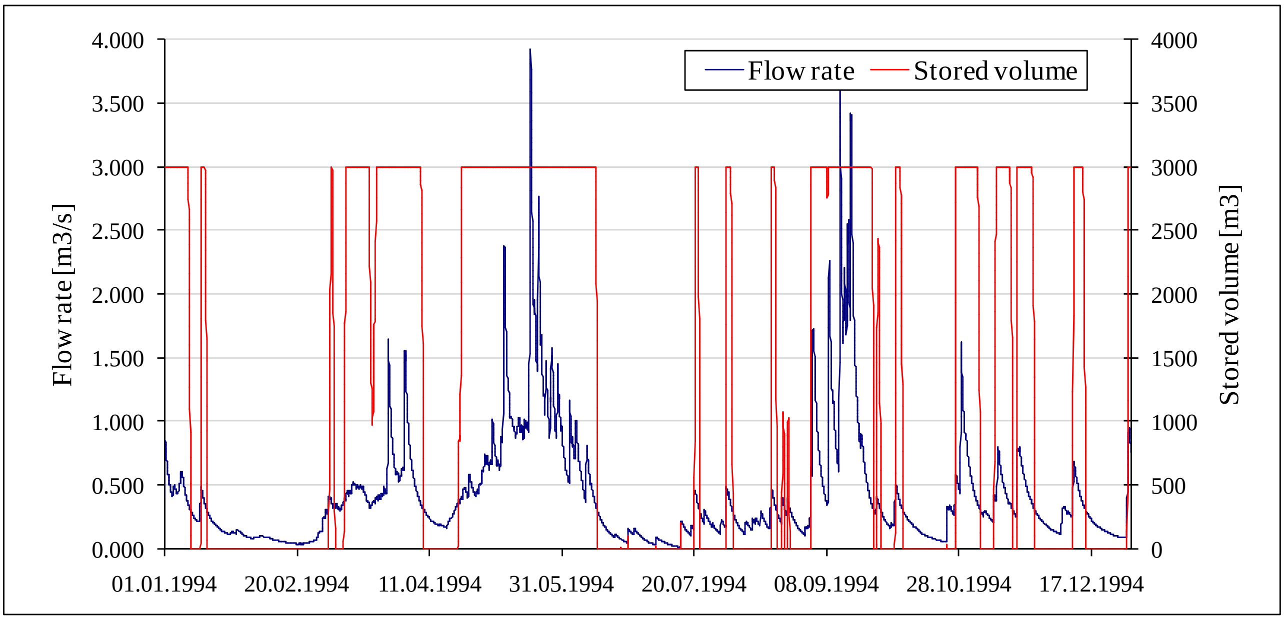

Figure 3: Behaviour of Draver's tank

IV.6 Pumped-storage on the base project and between the two snowmaking tanks

Based on the main project a pumped-storage extension can be planned. To do this the tank of Dravers (500 m^3) and the plain lake (800 m^3) are both extended up to 2’500 m^3. A 250 m pipe is laid between the intake and the tank of Dravers and two more valves and a pump are added to the system to allow the water to rise the penstock.

Because actually the RPC does not allow doing pumped-storage, the purpose of the study is to determine the difference between the purchase price and the needed resale price to obtain profitability.

The objective is to turbine at the maximum capacity (310 l/s) 5 hours per day in two separates periods of 2.5h. With a purchase price fixed at 0.08 CHF/kWh the profitability is obtained with a resale price of 0.21 CHF/kWh.

The second mini pumped-storage project considered is independent from the main one. It consists in using the snowmaking project of Tele-Torgon as an opportunity to develop a mini pumped-storage plant with reasonable costs. Only the extension of the lower lake (from 600 m^3 to 2’000 m^3) and the electromechanical part have to be paid by the pumped-storage project. The penstock and the excavation of the upper lake are paid by the snowmaking project. The powerhouse already exists. The pipe diameter (300 mm) is given by the requirements of Tele-Torgon.

The rated discharge is varied until the result is optimal. Two cycles per day are considered. With a purchase price fixed at 0.08 CHF/kWh the resale price obtained is 0.31 CHF/kWh.

The optimal results of both pumped-storage extensions are summarized in Table 3.

Table 3: results of the two pumped-storage extensions

Description	Head [m]	Power [kW]	Tank volume [m^3]	Penstock diameter [mm]	Q_{prod} [l/s]	Q_{pump} [l/s]	Investment [CHF]	Purchase price [CHF]	Resale price [CHF]
P-S on the base project	751	1’909	2'500 (2x per day)	400-500	310	200	2'450'000	0.08	0.21
P-S between the two artificial lakes	522	762	2'000 (2x per day)	300	200	100	2'670’000	0.08	0.31

IV.7 Conclusion on the extensions

The results obtained with the accumulation extension highlight the degree of feasibility of mini pumped-storage installation. With the actual FIR, investment risk is too high compared to the potential gain (365 CHF/year). But with a financing system that would reward the peak production this kind of extension could become profitable.

The results calculated for the two pumped-storage extensions allow defining the delta value that should be offset by a funding assistance. Nevertheless, considered from the point of view of local and regional electricity distributors, the possibilities offered by a pumped-storage SHP to regulate the grid could avoid paying dissuasive prices to adapt the offer to the demand.

V CONCLUSIONS

The technical potential of SHP pumped-storage in Switzerland is between 70 and 180 MW compared to 7.3 MW today. It is thus worth further developing within RET policies. SHP storage has to be included as well as both storage and pumped-storage can provide flexible generation and storage facilities required in the future for distributed energy storage and peak production, as well as decentralised grid operations.

The institutional feasibility depends mainly on the introduction of adequate remuneration instruments which should be included within the institutional frameworks facilitating RET. The instruments vary between storage and pumped-storage.

The case study showed first concrete cost-estimations. According to the existing condition, the installed capacities and the size of the reservoirs, the resale price of pumped-storage energy seems to be comprised between 0.20 and 0.35 CHF/kWh.

VI ACKNOWLEGMENTS AND THANKS

The authors thank EOS Holding (Switzerland) and the Energy Center at EPFL for the funding of the PhD research of Nicolas Crettenand. They also thank the authorities of the commune of Vionnaz for their contribution to the concrete case of Torgon.

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