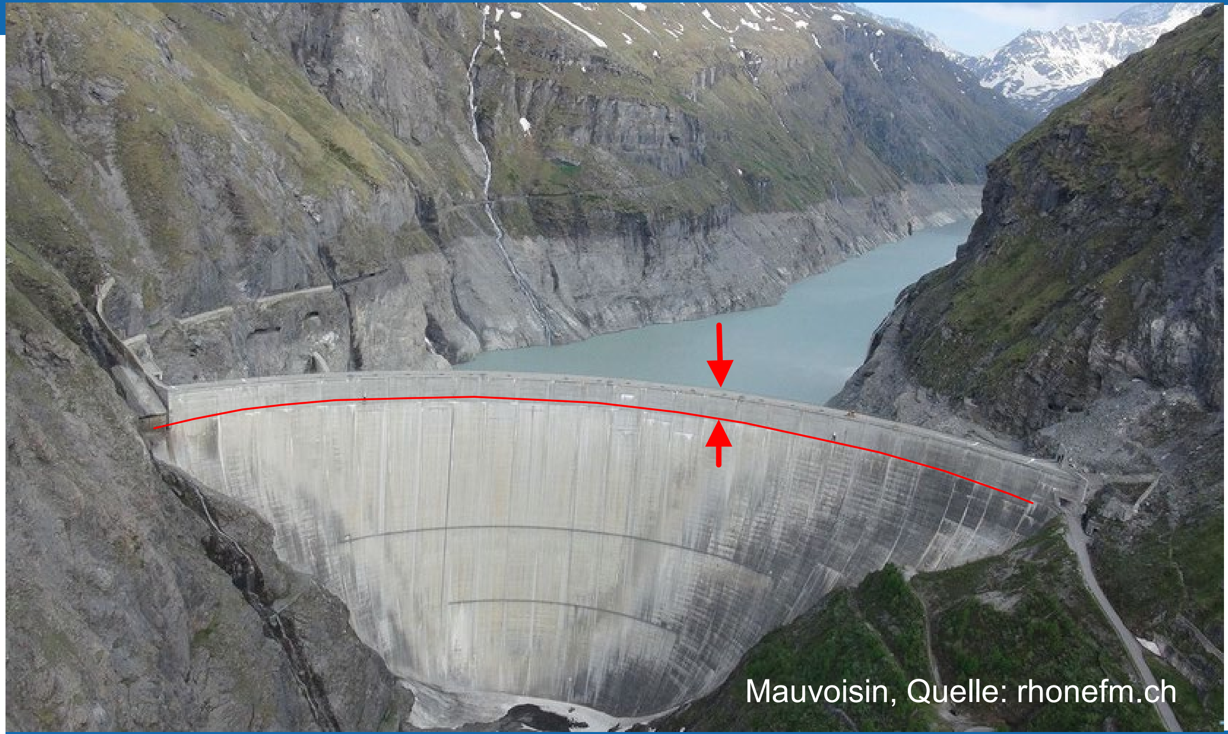

Increasing the electricity production in winter by dam heightening

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SUPPLY of ELECTRICITY

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Seasonal electricity balance in the last 10 years

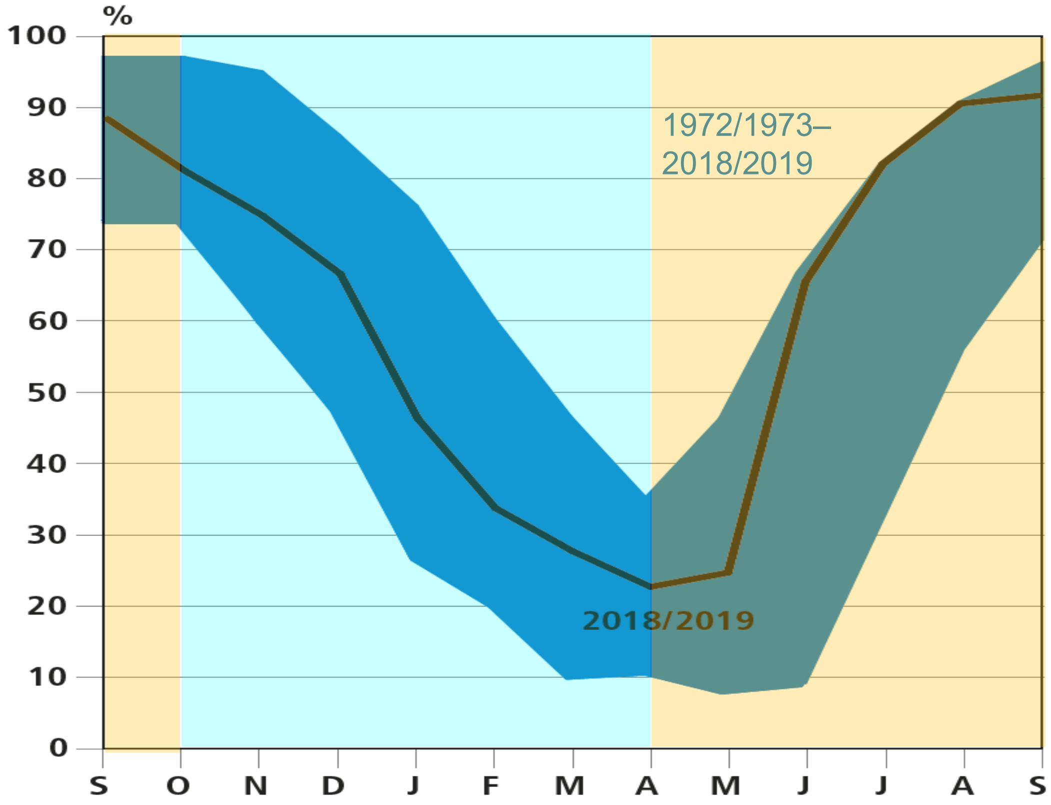
In winter

- Higher consumption than in summer
- Lower hydro-electricity production

TWh	Summer (April – Sept.)	Winter (Oct. – March)	Year
Consumption	~ 30	~ 35	~ 65
Generation	~ 35	~ 32	~ 67
- Run-of-river HP	10.9	5.8	16.7
- Storage HP	10.9	10.2	21.1
- Nuclear	~ 11	~ 14	~ 25
- Other	~ 2	~ 2	~ 4

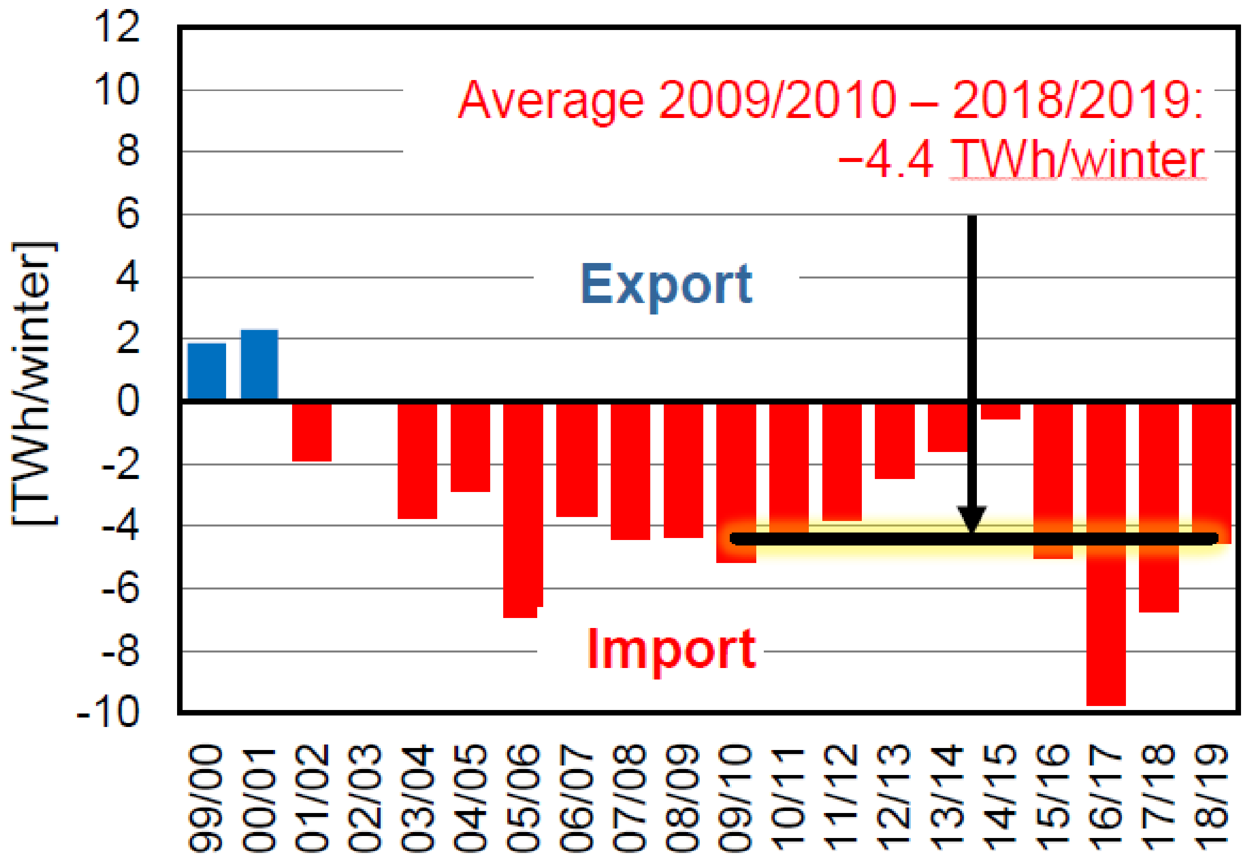
Decadal Averages 2010-2019, Source: SFOE, Electricity Statistics

8.85 TWh storage capacity in reservoirs, of which ~ 6.5 TWh are used on average



Source: SFOE (2020), Electricity Statistics

Seasonal electricity balance in the future



Source: SFOE, Electricity Statistics

In the future:
Lower electricity generation in winter due to phase-out of nuclear power plants and (much) more PV

Elcom (2020) recommends to increase the Swiss electricity generation capacity by 5 to 10 TWh per winter until 2035

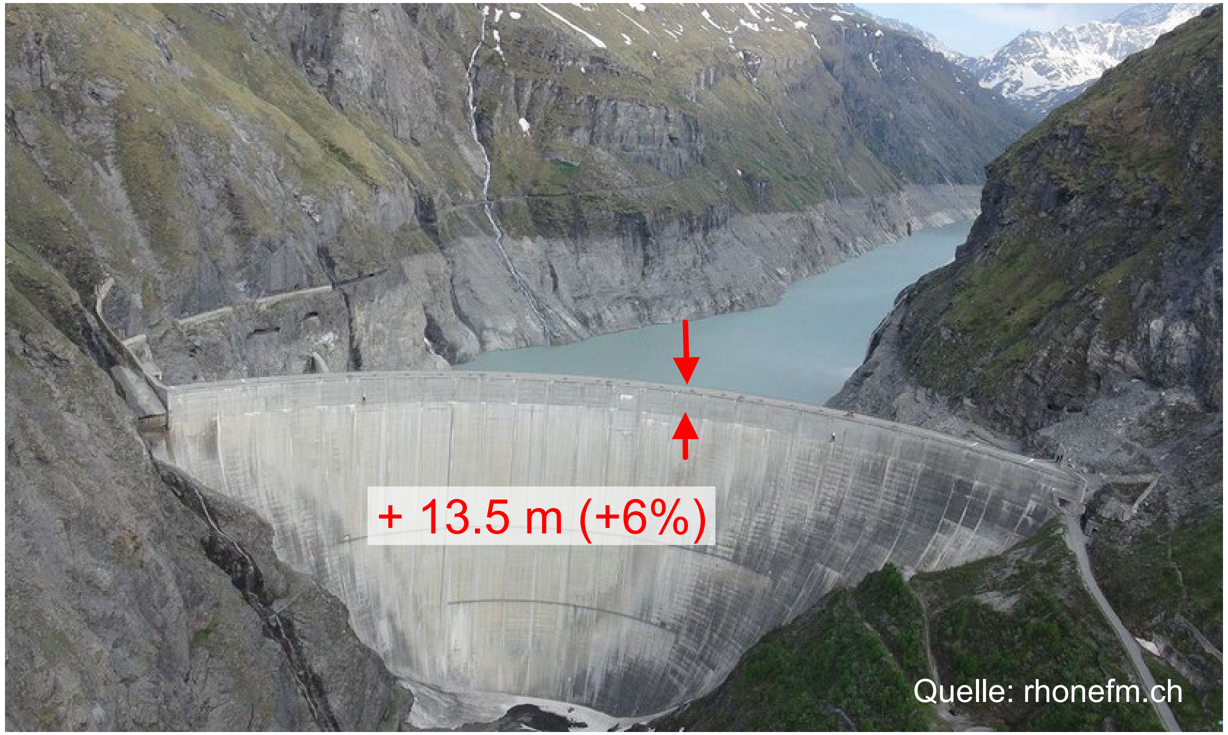
Need for increased transfer of electricity from summer to winter

Main advantages of dam heightening

- Many dams, especially arch dams, have unused reserves in bearing capacity
- Experience with the behaviour of existing dams over many decades is available
- Considerable increase of storage capacities are possible with relatively low impact on environment and landscape

Example Mauvoisin
(built 1951-1957, heightened 1989-1991)

Storage volume 182 → 212 Mio. m^3 (+17%)



Add. energy transfer summer → winter = 0.1 TWh

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Increasing the electricity production in winter by dam heightening

Method for a Swiss-wide potential study of reservoir extensions

(1) Formulation of **assessment criteria**

(2) **Systematic assessment (rating)** of 38 hydropower reservoirs (> 20 Mio. m^3) for three relative extents of heightening $\Delta h / h$ = 5%, 10% und 20%

(3) Identification of **heightening options** with the best ratings and grouping in 4 scenarios

(4) Estimations of **additional storage volumes** and how much **electric energy** could be additionally transferred from summer to **winter**

Criteria for assessment of heightening options

0 - 4 points for each criterion, with the following weights

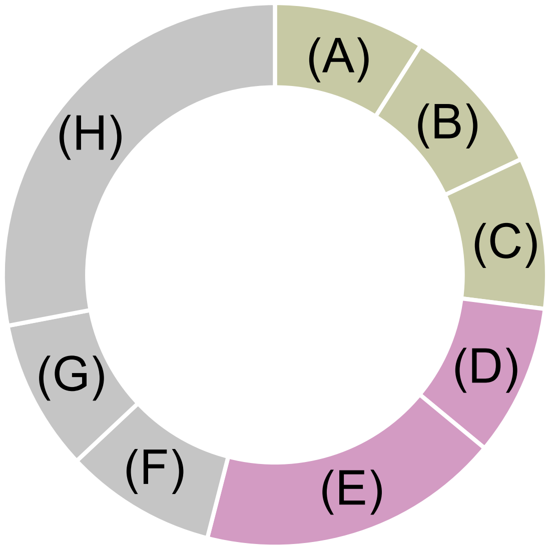
0 points = “impossible”, e.g. if several houses would need to be relocated, or moors would be affected

ADDITIONAL RESERVOIR AREA (27%)

(A) Nature and landscape reserves (9%)
(B) Land use and buildings (9%)
(C) Adaptations on third-party infrastructures (9%)

HPP SYSTEM (46%)

(F) Water resources (9%)
(G) Adaptations of existing HPP structures (9%)
(H) Additional shift of electricity generation to winter (28%)



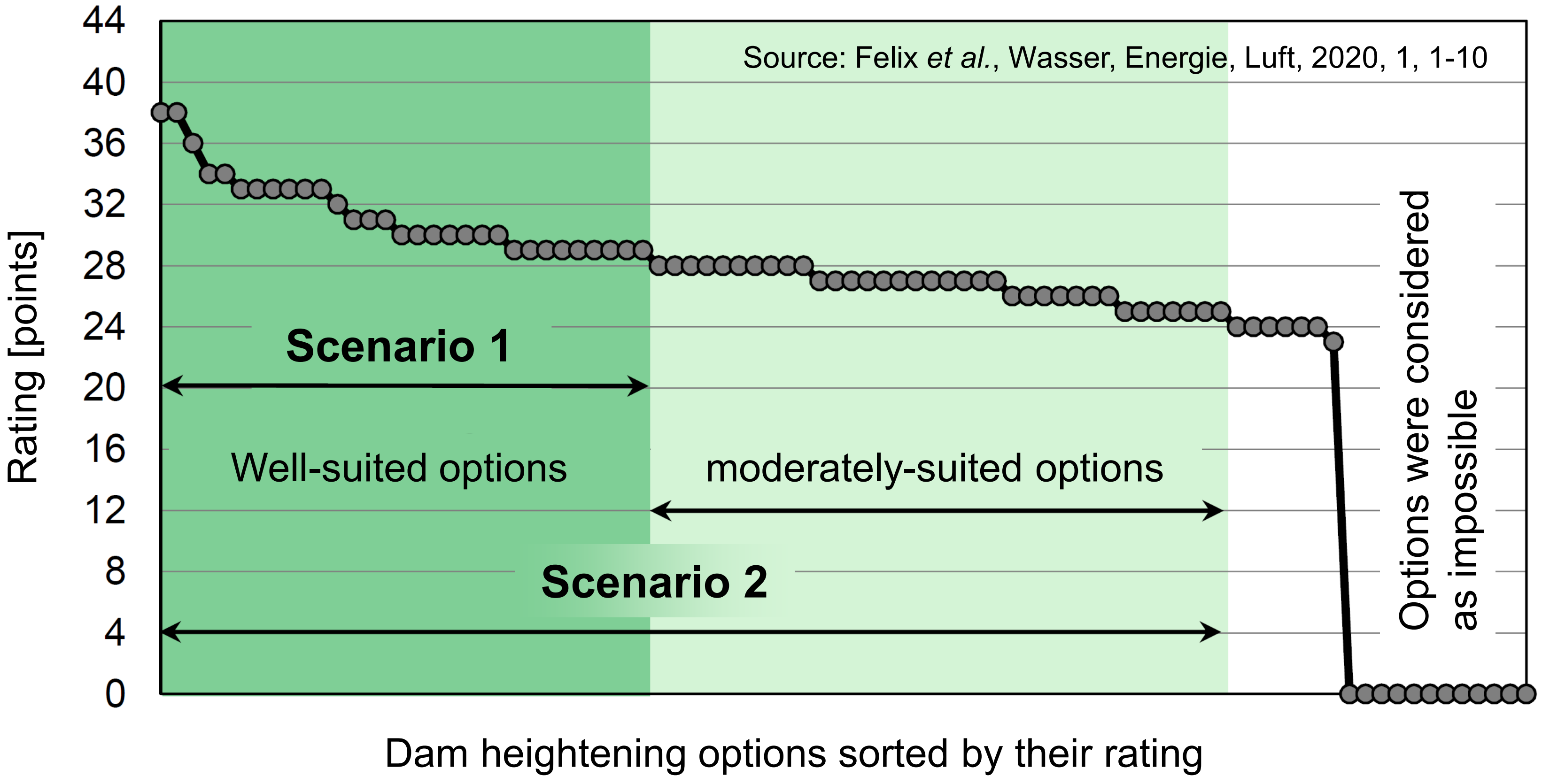
DAM (27%)

(D) Technical suitability (9%)
(E) Relative effort (18%)

Source: Felix *et al.*, Wasser, Energie, Luft, 2020, 1, 1-10

Ranking of heightening options

38 reservoirs (V ≥ 20 Mio. m³) with $\Delta h/h$ = 5, 10 or 20%



12 reservoirs excluded because of:

Existing settlements and constructions (6):
Lac de Gruyere, Schiffenensee, Sihlsee, Wägitalersee, Lago di Livigno, Lago di Vogorno

Moors (federal proction) (2):
Räterichsbodensee und Göscheneralpsee

Topography/technical (1):
Zeuzier

Already heightened (3):
Mauvoisin, Luzzone, Vieux Emosson

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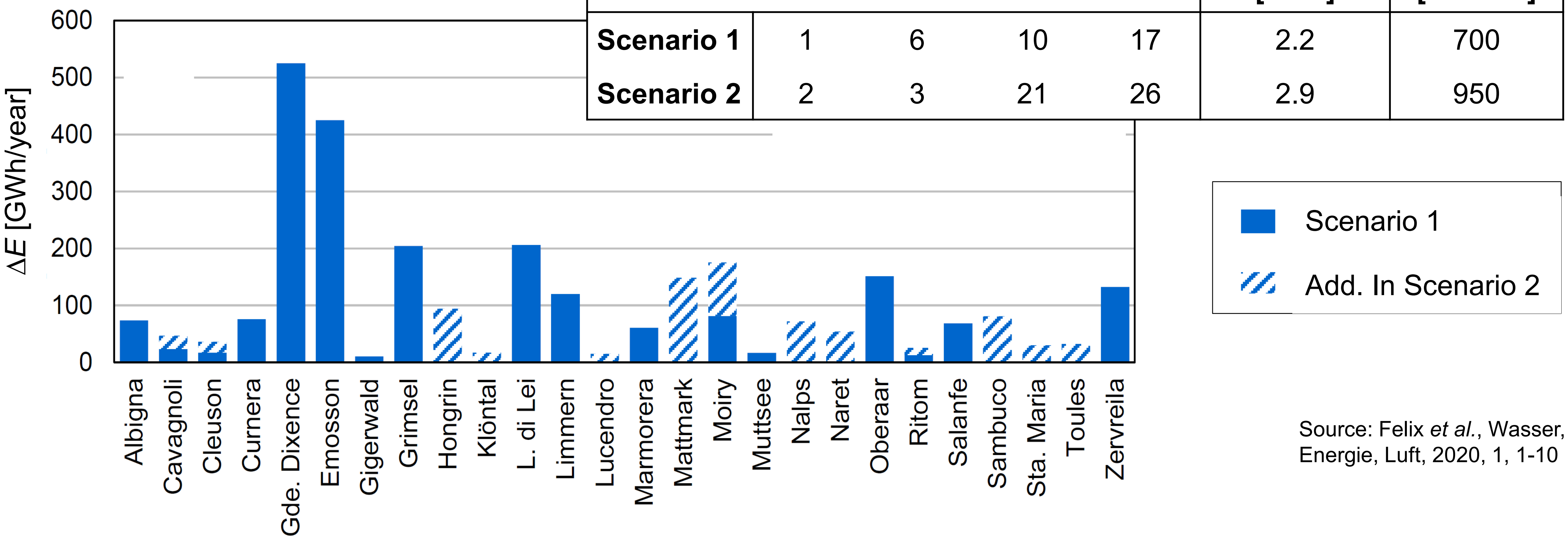
Potentials for add. electric energy transfer from summer to winter

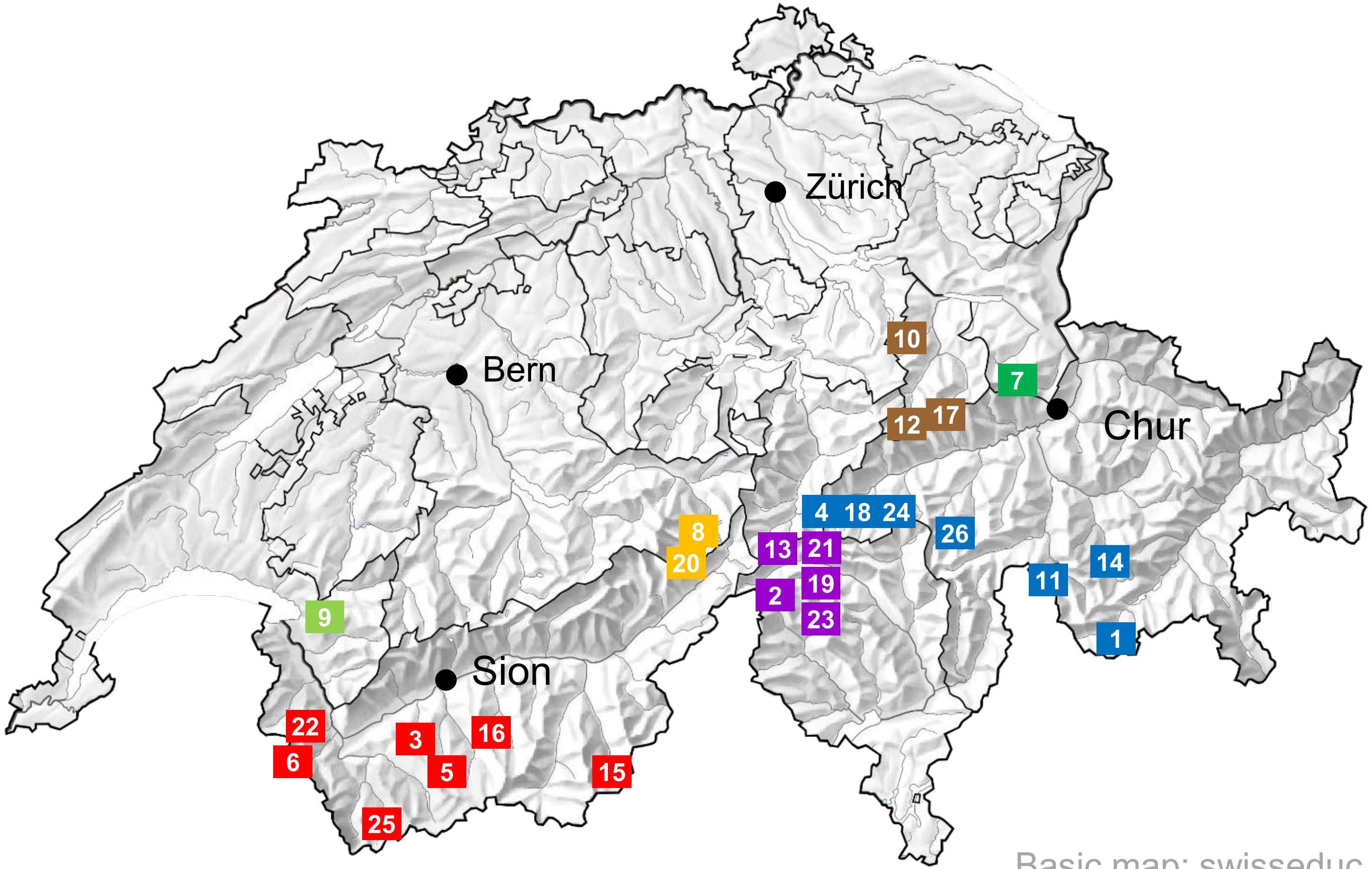
Δh/h=	Number of extended reservoirs 5%	10%	20%	total	Δ Energy [TWh]	Δ Volume [Mio. m³]
Scenario 1	1	6	10	17	2.2	700
Scenario 2	2	3	21	26	2.9	950



Source: Felix *et al.*, Wasser, Energie, Luft, 2020, 1, 1-10

Potentials for add. electric energy transfer from summer to winter

	Reservoir (alphab., colours = Cantons)		Scenario 1 (in GWh)	Scenario 2 (in GWh)
1	Albigna (+20%)	GR	74	74
2	Cavagnoli (+10%/+20%)	TI	24	47
3	Cleuson (+10%/+20%)	VS	17	37
4	Curnera (+20%)	GR	76	76
5	Gde. Dixence (+10%)	VS	525	525
6	Emosson (+20%)	VS	425	425
7	Gigerwald (+5%)	SG	11	11
8	Grimsel (+20%)	BE	204	204
9	Hongrin (20%)	VD		94
10	Klöntal (20%)	GL		17
11	Lago di Lei (+10%)	GR/I	206	206
12	Limmern (+20%)	GL	120	120
13	Lucendro (+10%)	TI		15
14	Marmorera (+20%)	GR	61	61
15	Mattmark (+20%)	VS		149
16	Moiry (+10% / +20%)	VS	82	175
17	Muttsee (+20%)	GL	17	17
18	Nalps (+20%)	GR		72
19	Naret (+20%)	TI		54
20	Oberaar (+20%)	BE	152	152
21	Ritom (+10%/+20%)	TI	13	26
22	Salanfe (+20%)	VS	69	69
23	Sambuco (+20%)	TI		81
24	Sta. Maria (+5%)	GR		30
25	Toules (+20%)	VS		33
26	Zervreila (+20%)	GR	133	133
	Total		**2210**	**2905**

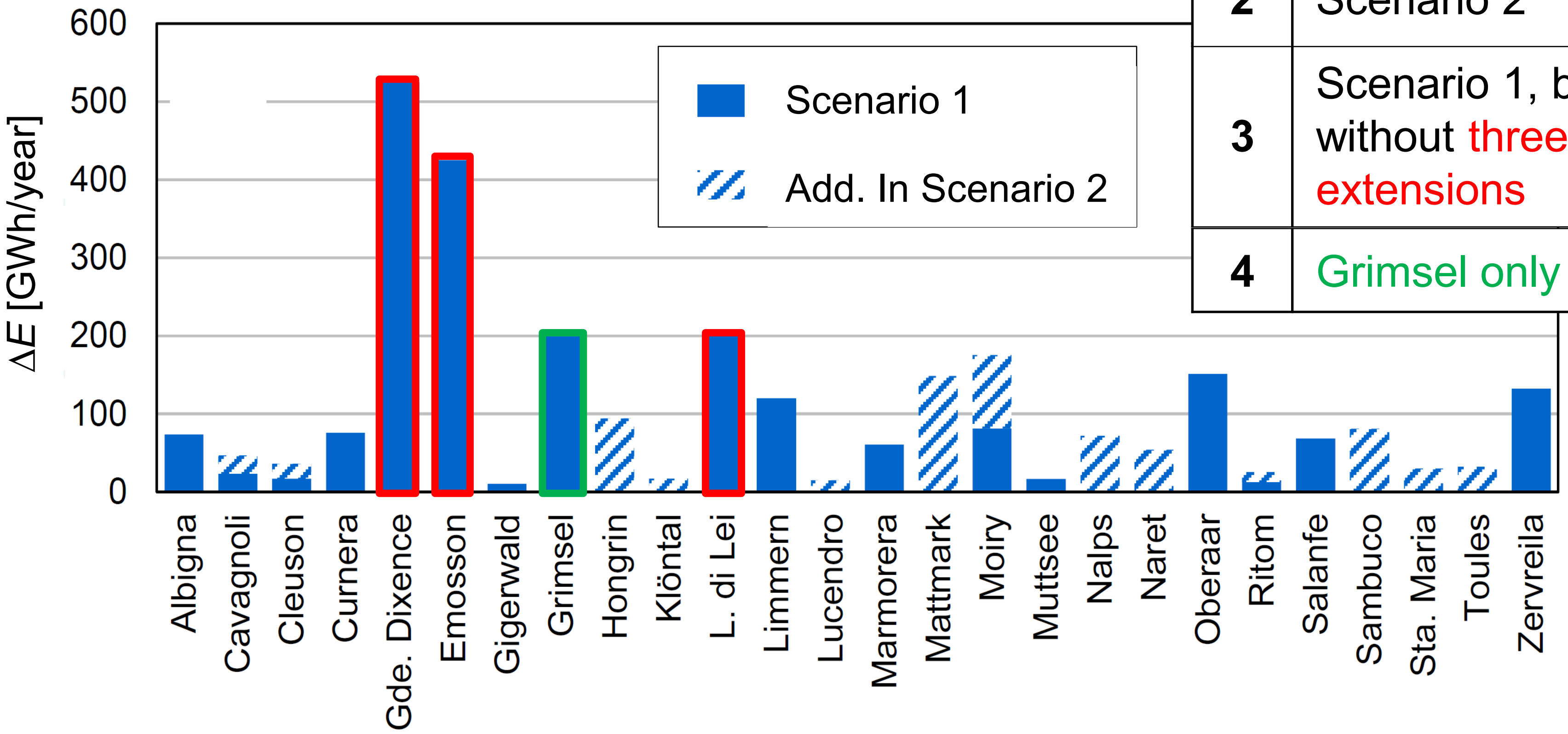


Basic map: swisseduc

Source: Felix *et al.*, Wasser, Energie, Luft, 2020, 1, 1-10

Potentials for add. electric energy transfer from summer to winter

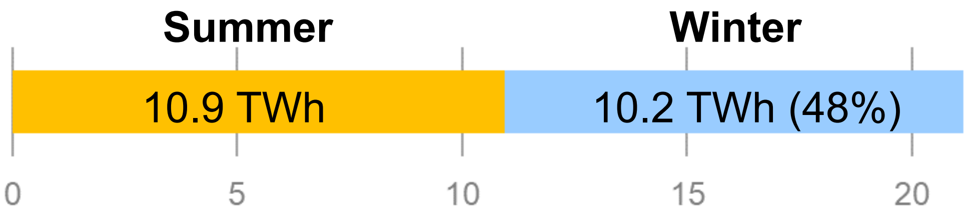
Scenario		Number of extended reservoirs	**Add. storage [TWh]**
1	Scenario 1	17	**2.2**
2	Scenario 2	26	**2.9**
3	Scenario 1, but without three largest extensions	14	**1.1**
4	Grimsel only	1	**0.2**



Source: Felix *et al.*, Wasser, Energie, Luft, 2020, 1, 1-10

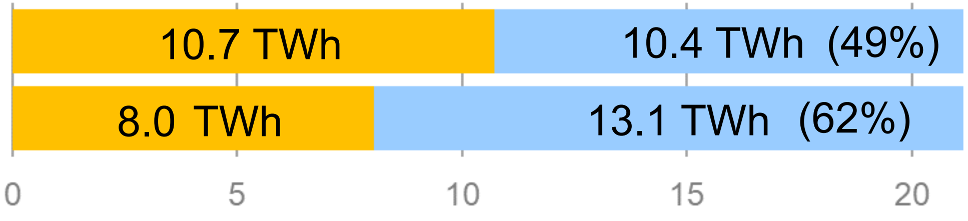
Increase of electricity generation in winter

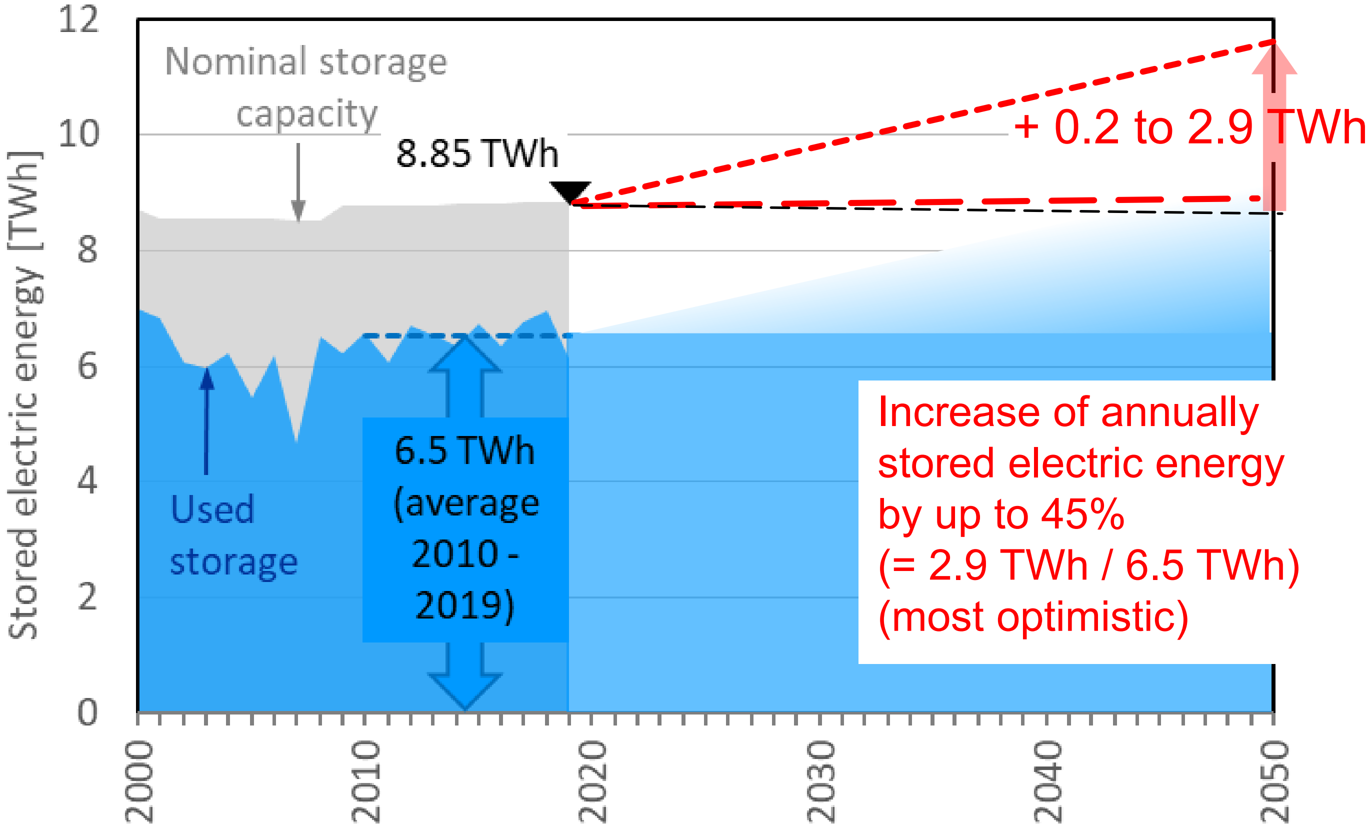
Generation of existing storage hydropower schemes in Switzerland: 21.1 TWh/year



Decadal averages 2010-2019, Source: SFOE, Electricity Statistics

With extensions of existing reservoirs: 0.2 to 2.9 TWh/a from summer → winter





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Conclusions

Extensions of up to 26 storage lakes …

- would allow to additionally shift up to 2.9 TWh/year from summer to winter, and hence reduce the need for electricity imports
- Are important for the integration of a higher share of new renewable energies
- Needs to be combined with other measures to reach the targets of the Energy Strategy 2050

Recommendations for **further studies** on

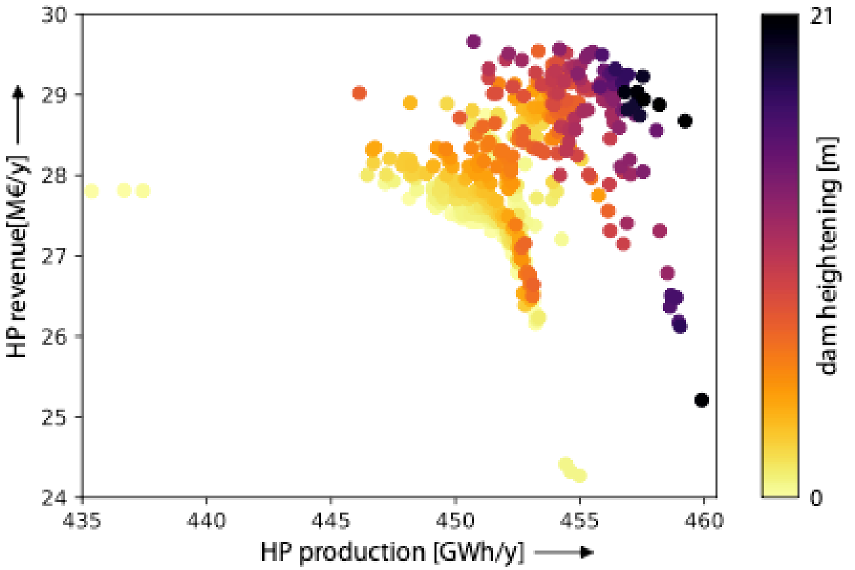
- the need for future large-scale seasonal electricity storage, alternative technologies, economic aspects and market design
- individual reservoir extension projects, including the effect on downstream river reaches, other purposes of reservoirs (e.g. protection from natural hazards)
- Swiss-wide priority list of most suitable / feasible options, and coordination with other projects and the planning of the Cantons
- on making better use of existing reservoirs (min. and max. levels every year)
- on maintaining the storage capacity of existing reservoirs (e.g. sediment management and maintenance of aging infrastructure)

Example of areas of further studies

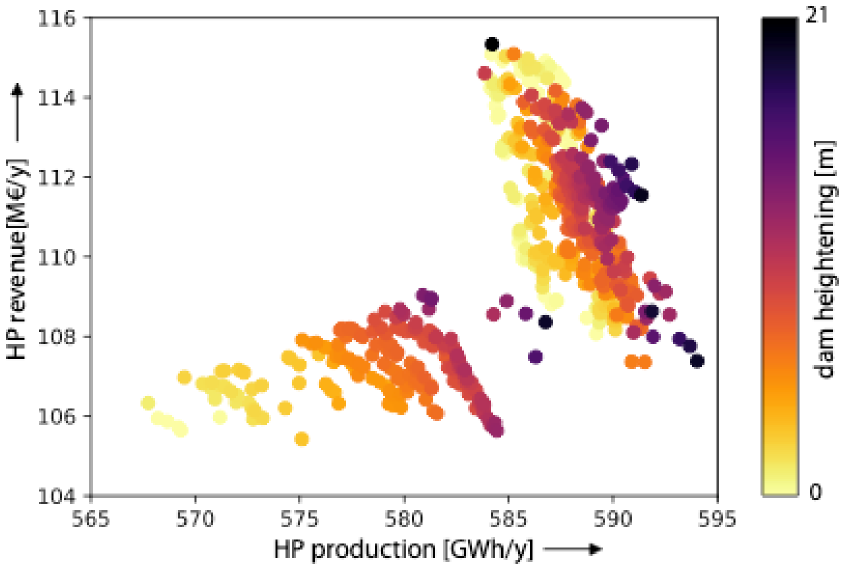
Dam heightening under climate change/market scenarios (case study Mattmark)

- Reference period 2009-2014
- Historical data of inflow and electr. price

- Climate change scenario 2070-2099
- RCP8.5 + AWE-GEN-2D + Topkapi
- Electr. price prediction (Schlecht & Weigt, 2015)



Production: +6.7 GWh/y or
Revenue: +1.3 M€/y



Production: +4.6 GWh/y or
Revenue: +0.24 M€/y

See also
Anghileri D., Castelletti A., Burlando P. (2018). "Alpine Hydropower in the Decline of the Nuclear Era: Trade-off between Revenue and Production in the Swiss Alps". *Journal of Water Resources Planning and Management* 144(8), 04018037.

Source: Prof. Burlando, IfU, ETH Zürich

Thank you for your attention

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