Dam Heightening Options in Switzerland to increase Hydro Storage Capacity and Winter Production

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Swiss Energy Strategy 2050 – Power supply and demand

- "No measures"
- "Political measures"
- "New energy policy"

Approximately 30 TWh/a lack
Swiss Energy Strategy 2050 – Alternative power production

Increasing alternative power production → Growing need for power storage capacity

ETH Zürich (2011), values in Piot (2014)

≈ 30 TWh/a
Electricity supply and demand

**Annual electricity (2009-2018)**
Oversupply $\approx 1.3$ TWh/a

**Deficit in winter (2009-2018)**
$\approx 4.7$ TWh/winter

BFE, Schweizerische Elektrizitätsstatistik 2018
Dam heightening of Mauvoisin (1989 - 1991)

Height $H$: 236.5 m → 250 m
\[ \Delta H/H = 6\% \]

Volume $V$: 180 hm$^3$ → 210 hm$^3$
\[ \Delta V/V = 17\% \]
Methodology

(1) Establishing an evaluation matrix

(2) Evaluation of 80 Swiss storage hydropower plants for 3 dam heightening options: \( \Delta H/H = 5\% \), \( \Delta H/H = 10\% \), \( \Delta H/H = 20\% \)

(3) Selection of preferable heightening degree

(4) Estimation of additional storage capacity and shifted electricity production (summer → winter)
Evaluation matrix for dam heightening

POWER GENERATION SYSTEM (46%)
(F) Hydrology (9%)
(G) Modification of hydraulic systems (9%)
(H) Electricity production (28%)

FUTURE RESERVOIR AREA (27%)
(A) Protected areas (9%)
(B) Land use and buildings (9%)
(C) Infrastructures (9%)

DAM (27%)
(D) Structural suitability (9%)
(E) Relative effort (18%)

0 - 4 points
(0 points = knock-out-criterion)
Evaluation – Case study Marmorera

Dam type: Earth core rockfill dam
Height: 91 m
Volume: 60 hm³
Energy head: 1070 m (Cascade)
Marmorera – Evaluation: Future reservoir area (27%)

0 - 4 points (0 points = knock out criterion)

(A) Protected areas (9%)
- Reserves and areas of different protection degrees
  → Designated wildlife area slightly affected 4 P.

(B) Land use and buildings (9%)
- Settlements, forests or agriculture land
  → Restaurant affected 1 P.

(C) Infrastructures (9%)
- Embankments, traffic routes or supply and disposal lines
  → important mountain pass road affected 1 P.
Marmorera – Evaluation: Dam (27%)

0 - 4 points (0 points = knock out criterion)

(D) Structural suitability (9%)
- Rock fill dams:  \( \Delta H/H \leq 5\% \) well-suited,  \( \Delta H/H \leq 10\% \) suitable,  \( \Delta H/H > 10\% \) less suitable

\[
\begin{array}{ccc}
\Delta H/H = 5\% & \rightarrow & 3 \text{ P.} \\
\Delta H/H = 10\% & \rightarrow & 2 \text{ P.} \\
\Delta H/H = 20\% & \rightarrow & 1 \text{ P.}
\end{array}
\]

(E) Relative effort (18%)
- Effort for dam and appurtenant structures, accessibility of construction sites
- No bottom and middle outlet modifications for heightening \( \leq 10\% \)
- Effort relative to additional storage capacity

\[
\begin{array}{ccc}
\Delta H/H = 5\% & \rightarrow & 2 \text{ P.} \\
\Delta H/H = 10\% & \rightarrow & 3 \text{ P.} \\
\Delta H/H = 20\% & \rightarrow & 3 \text{ P.}
\end{array}
\]
Marmorera – Evaluation: Power generation system (46%) (I/II)

0 - 4 points (0 points = knock out criterion)

(F) Hydrology (9%)
- Capacity-inflow-ratio (CIR): CIR < 1 → sufficient inflow for summer and winter production
- No additional adductions or pumps required → 4 P.

\[ \Delta H/H = 5\%: \text{CIR}=0.33 \rightarrow 4 \text{ P.} \]  \[ \Delta H/H = 10\%: \text{CIR}=0.36 \rightarrow 4 \text{ P.} \]  \[ \Delta H/H = 20\%: \text{CIR}=0.43 \rightarrow 4 \text{ P.} \]

(G) Modification of hydraulic system (9%)
- Whole hydraulic system incl. linked reservoirs and upstream located power houses
- Assumption: Energy head rise ≤ 10%: slight modifications at electro-mechanical equipment

- Slight modifications at adduction and intermediate water intake
- Surge tank modifications increases with heightening degree

\[ \Delta H/H = 5\% \rightarrow 3 \text{ P.} \]  \[ \Delta H/H = 10\% \rightarrow 3 \text{ P.} \]  \[ \Delta H/H = 20\% \rightarrow 2 \text{ P.} \]
Marmorera – Evaluation: Power generation system (46%)  (II/II)

0 - 4 points (0 points = knock out criterion)

(H) Electricity production (28%)
- Additional energy power production in winter semester
- Considering all power plants of cascades

\[ \frac{\Delta H}{H} = 5\%: \approx 17 \text{ GWh/a} \rightarrow 1 \text{ P.} \]
\[ \frac{\Delta H}{H} = 10\%: \approx 32 \text{ GWh/a} \rightarrow 1 \text{ P.} \]
\[ \frac{\Delta H}{H} = 20\%: \approx 62 \text{ GWh/a} \rightarrow 2 \text{ P.} \]

0 - 50 GWh/a: 1 P.  
50 - 100 GWh/a: 2 P.  
100 - 200 GWh/a: 3 P.  
> 200 GWh/a: 4 P.

TOTAL SCORE OF MARMORERA:

\[ \frac{\Delta H}{H} = 5\% \rightarrow 23 / 44 \text{ P.} \]
\[ \frac{\Delta H}{H} = 10\% \rightarrow 24 / 44 \text{ P.} \]
\[ \frac{\Delta H}{H} = 20\% \rightarrow 25 / 44 \text{ P.} \]

Preferable (?) heightening degree
### Dam heightening – Potential

- 80 Dams evaluated, whereof 33 large dams \((V \geq 20 \text{ hm}^3)\)
- 8 dams with knock out criteria

→ Additional winter production \(\approx 2.3 \text{ TWh/a}\)

(total energy equivalent of Swiss hydropower reservoirs: 8.8 TWh)

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Punkte</th>
<th>GWh</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Lac des Dix +10%</td>
<td>39</td>
<td>546</td>
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<tr>
<td>2</td>
<td>Grimselsee +20%</td>
<td>35</td>
<td>233</td>
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<tr>
<td>3</td>
<td>Lac d’Emosson +10%</td>
<td>35</td>
<td>221</td>
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<td>4</td>
<td>Oberaarsee +20%</td>
<td>34</td>
<td>154</td>
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<tr>
<td>5</td>
<td>Limmersee +20%</td>
<td>33</td>
<td>125</td>
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<tr>
<td>6</td>
<td>Zervreilasee +5%</td>
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<td>32</td>
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<tr>
<td>7</td>
<td>Lai di Curmea +20%</td>
<td>31</td>
<td>82</td>
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<td>8</td>
<td>Mattmarksee +10%</td>
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<td>68</td>
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<tr>
<td>9</td>
<td>Lac de Moiry +20%</td>
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<td>167</td>
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<tr>
<td>10</td>
<td>Lago Ritom +10%</td>
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<td>8</td>
</tr>
<tr>
<td>11</td>
<td>Lago di Lei +5%</td>
<td>28</td>
<td>101</td>
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<tr>
<td>12</td>
<td>Gigerwaldsee +5%</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>Klöntalersee +5%</td>
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<td>5</td>
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<tr>
<td>14</td>
<td>Lago da l’Albigna +20%</td>
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<td>73</td>
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<tr>
<td>15</td>
<td>Lago di Cavagnoli +10%</td>
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<td>16</td>
<td>Lai da Sta. Maria +5%</td>
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<td>17</td>
<td>Lai da Naips +5%</td>
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<td>Lac de Salanfe +10%</td>
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<td>Räterichsbodensee</td>
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<tr>
<td>31</td>
<td>Schiffernensee +5%</td>
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<tr>
<td>32</td>
<td>Sihissee +5%</td>
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<td>-</td>
</tr>
<tr>
<td>33</td>
<td>Wägitalersee +5%</td>
<td>0</td>
<td>-</td>
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</table>
Dam heightening – Shifted energy production

Existing storage power plants: 21.1 TWh/a

Values of BFE (2018): average of 2009-2018

<table>
<thead>
<tr>
<th>Season</th>
<th>Energy Production (TWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>10.9</td>
</tr>
<tr>
<td>Winter</td>
<td>10.2</td>
</tr>
</tbody>
</table>

After 25 dam heightenings: 21.1 TWh/a

Shift from summer to winter: 2.3 TWh/a

<table>
<thead>
<tr>
<th>Season</th>
<th>Energy Production (TWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>8.6</td>
</tr>
<tr>
<td>Winter</td>
<td>12.5</td>
</tr>
</tbody>
</table>

→ Winter deficit reduction ≈ 50% on average (data: 2009-2018)

BFE, Schweizerische Elektrizitätsstatistik 2018
Conclusions and Outlook

- Evaluation matrix
  - Suitable dams for heightening
  - Preferable heightening degrees
- Assessment of 80 dams in Switzerland
  - Heightening of 25 dams → 2.3 TWh additional winter production
  - Significantly higher independence of Swiss electricity supply
- Next step: analysis on feasibility of dam heightenings
Thank you for your attention

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A. Leimgruber (2018)