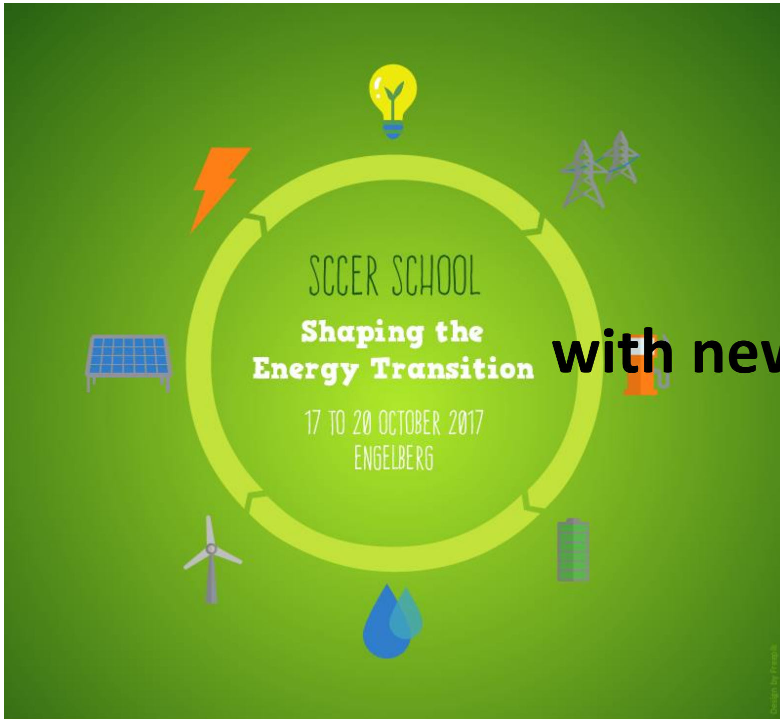


SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

with new large Hydropower!

Lukas Schmocker, ETH Zürich
Pedro Manso, EPF Lausanne
SCCER School 2007, 19.10.2017

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Outline

- Why hydropower?
- Swiss HP infrastructure
- Selected challenges
- How to increase HPP storage?
- Conclusions

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Why Hydropower?

In cooperation with the CTI

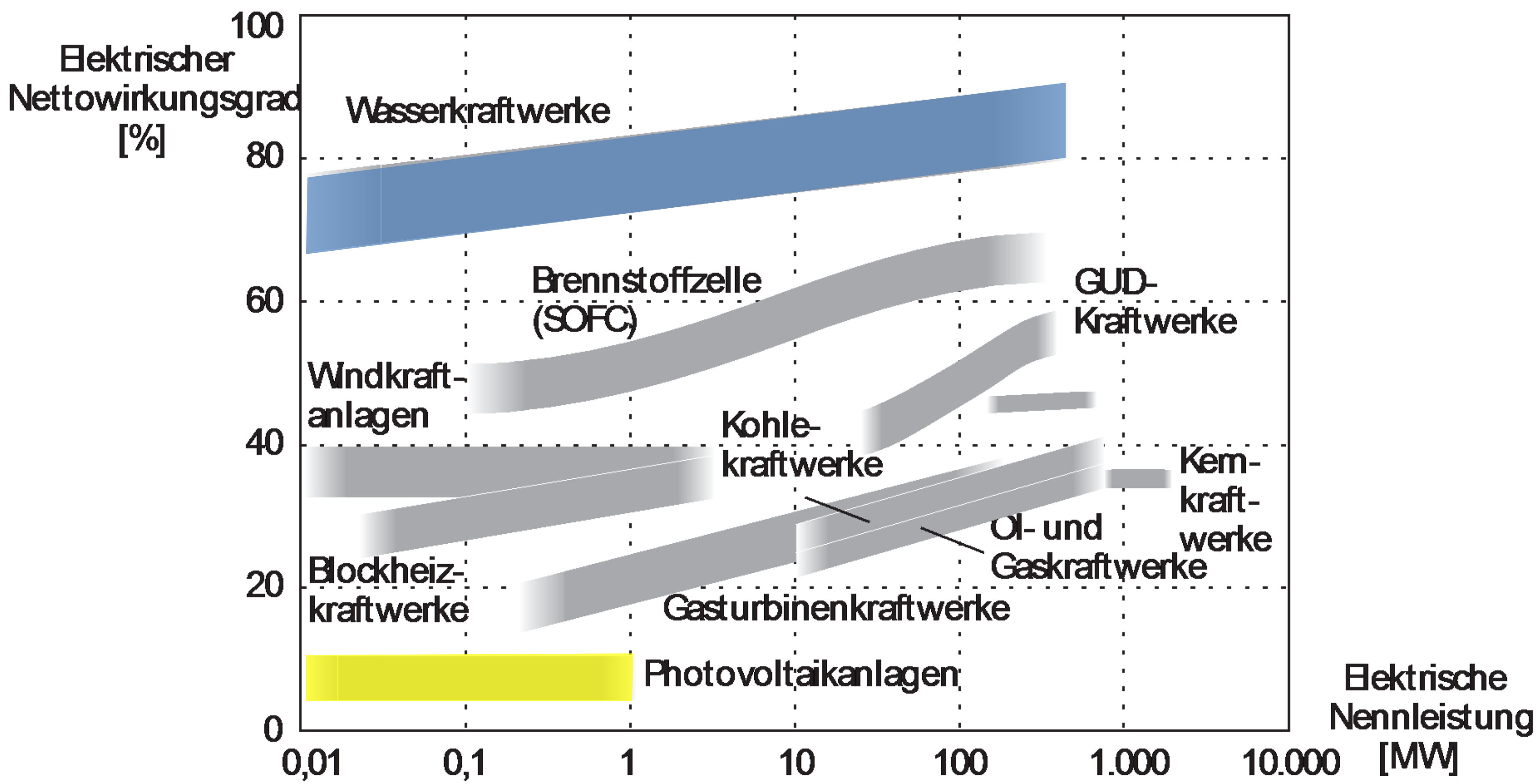
Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

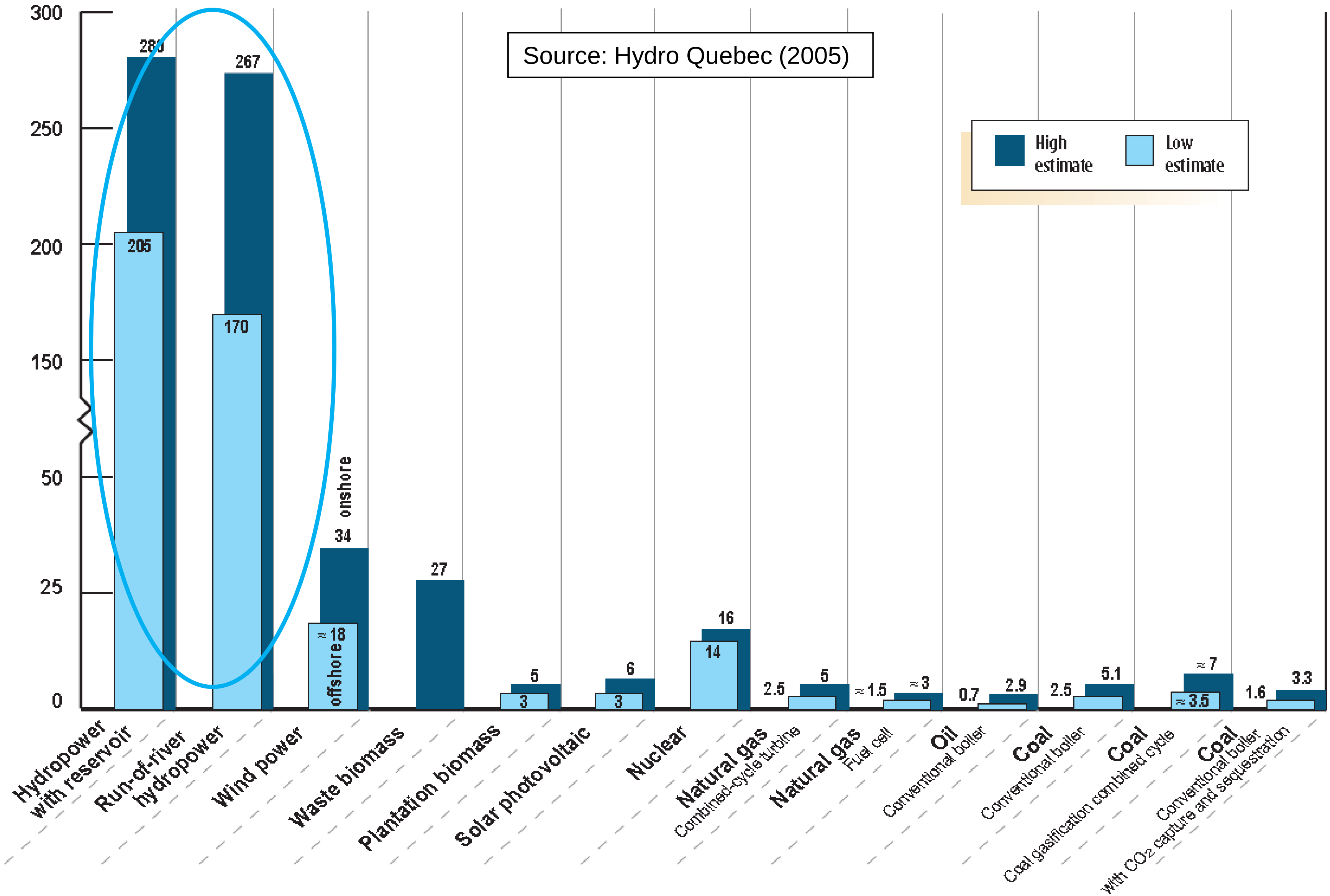
Commission for Technology and Innovation CTI

Energy efficiency

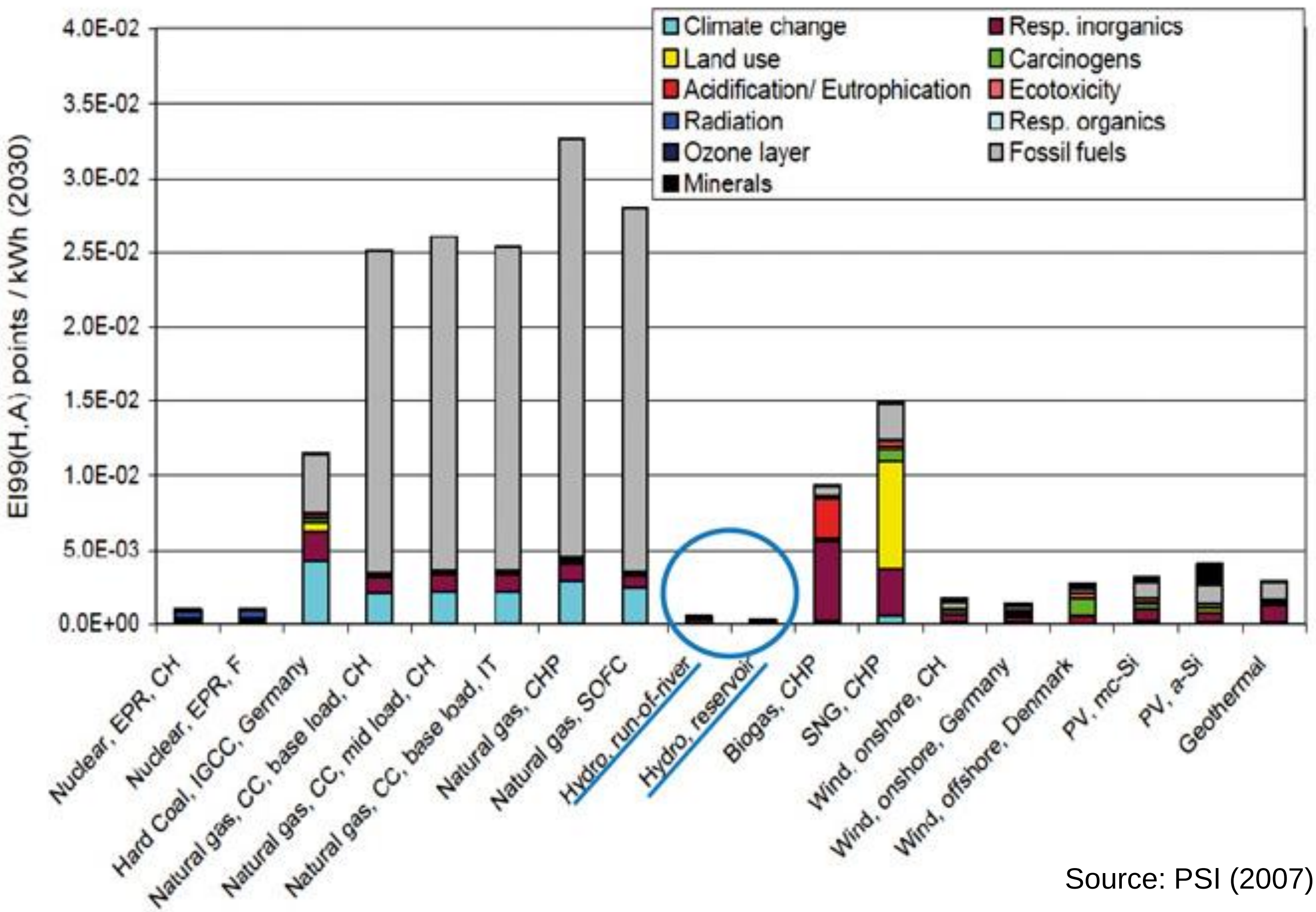


Quelle: Giesecke *et al.* (2014)

Energy payback ratio

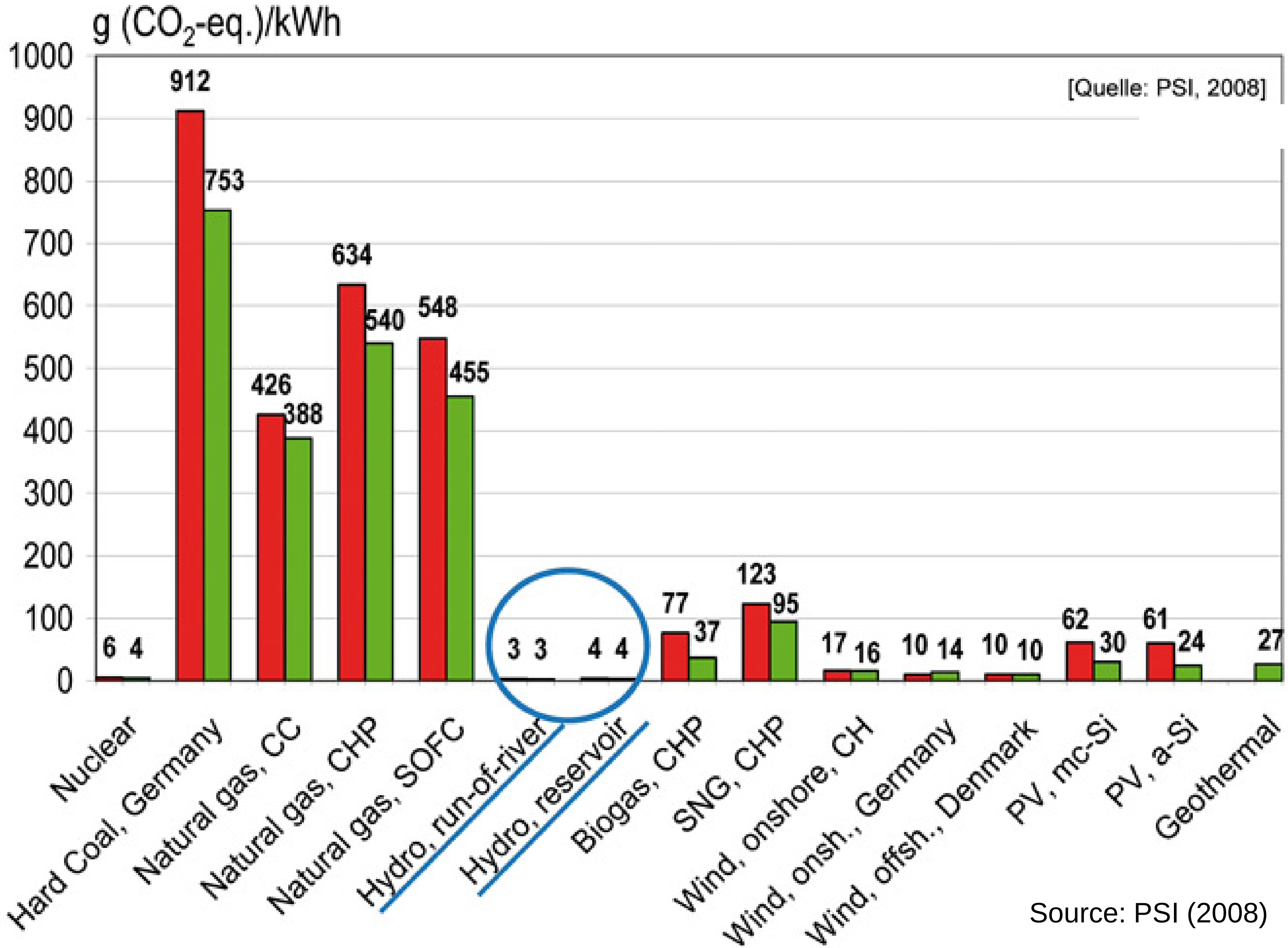


Ecological balance



Source: PSI (2007)

Balance of greenhouse gases



Source: PSI (2008)

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Swiss HP infrastructure

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

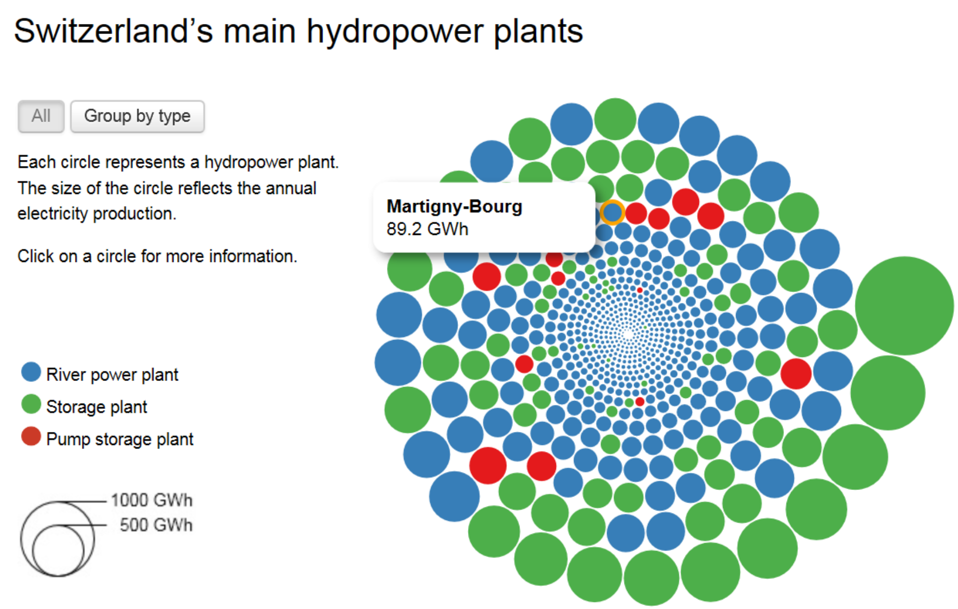
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

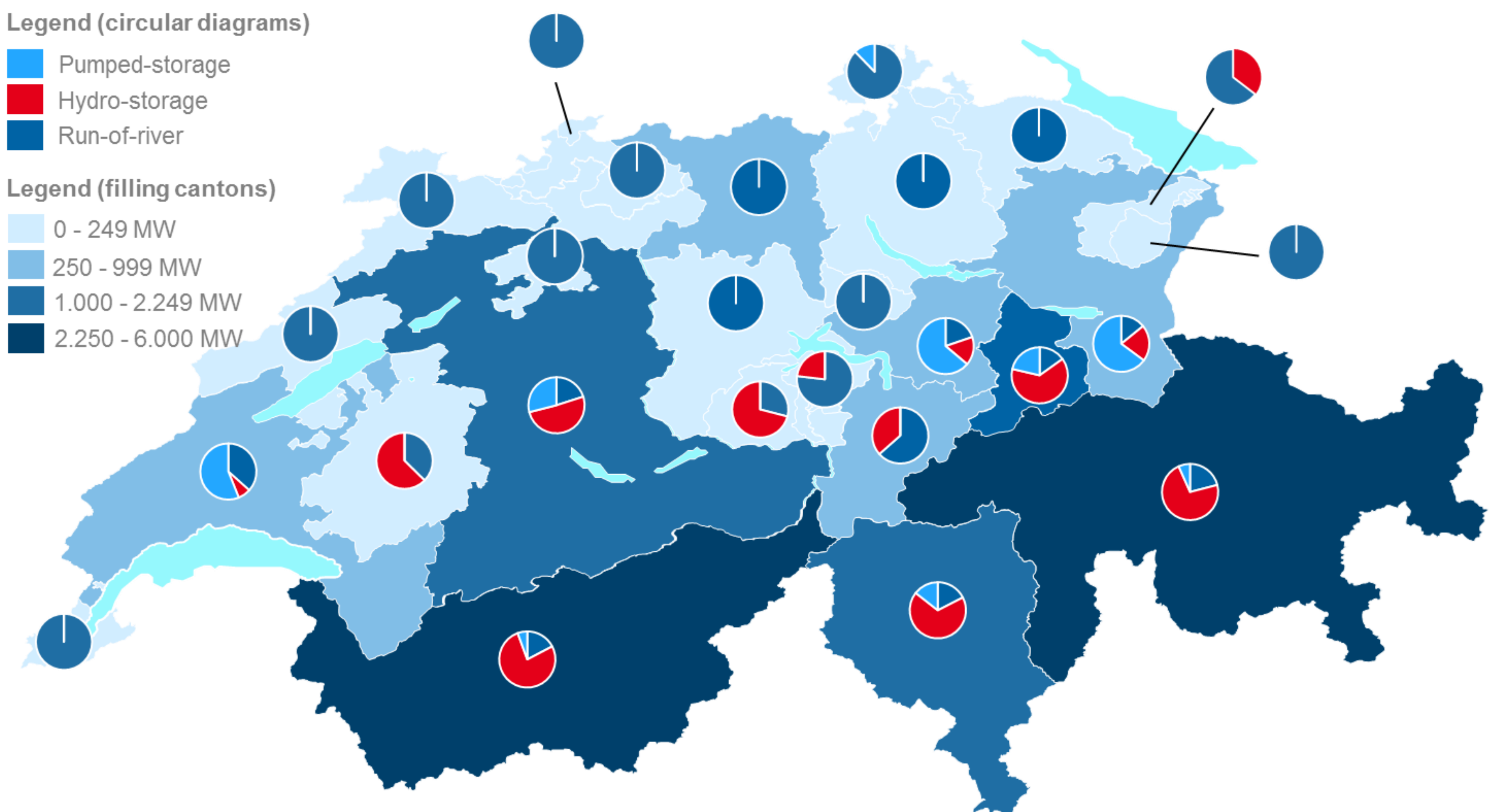
Infrastructure typology

- Per installed capacity
- Per production
- Per ownership
- Per hydraulic-economic role



http://www.bfe-gis.admin.ch/storymaps/WK_WASTA/index.php?lang=en

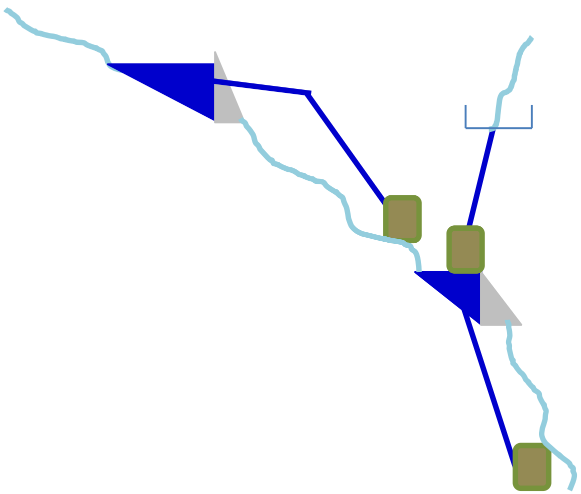
Swiss Hydropower Infrastructure

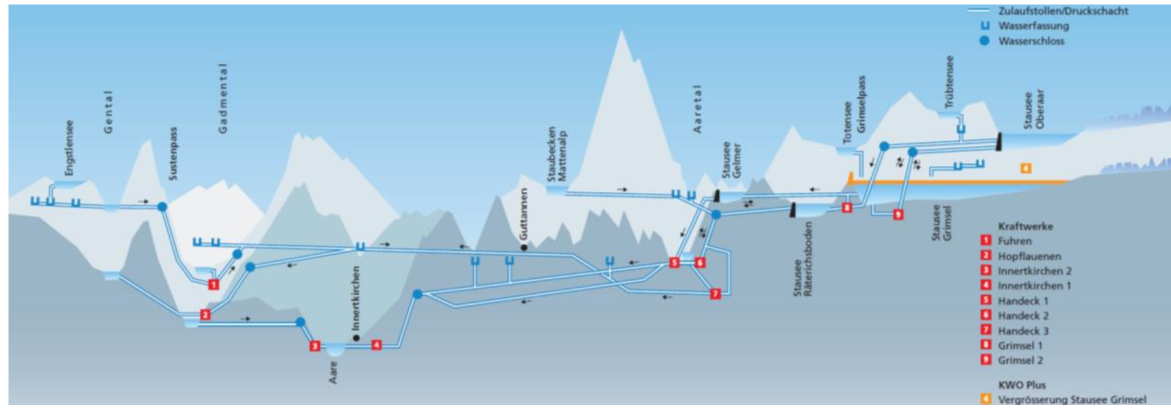


Source: Prognos 2012, based on SFOE 2011

Infrastructure typology (I)

G1
High-head storage

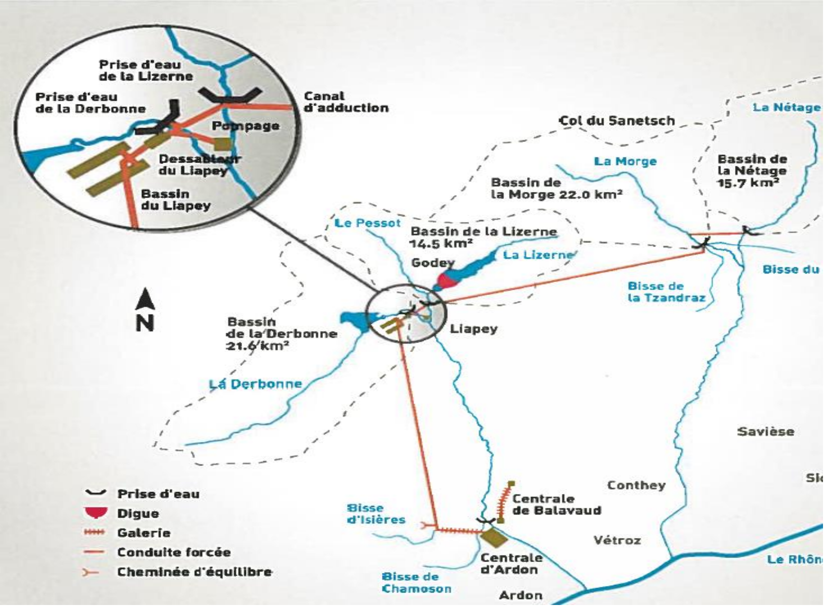




Multi-reservoir multi-HPP system of KW Oberhasli, CH

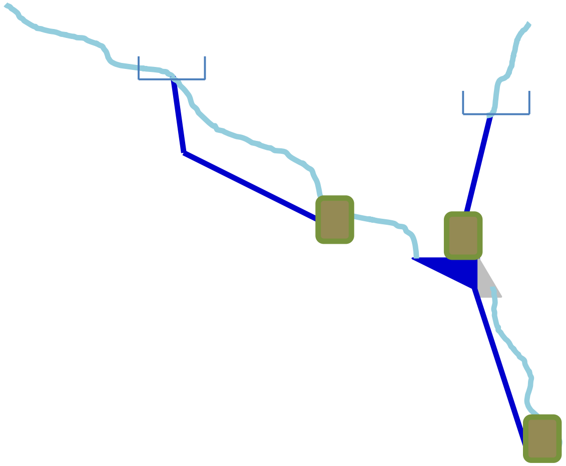
Storage reservoirs
20 TWh/a
3900 hm^3 < > 8.8 TWh
Seasonal, intra-annual
Drainage > Natural Catchment
Built > WWII, State back-up

Infrastructure typology (II)



Source: Lizerne et Morges SA, Valais

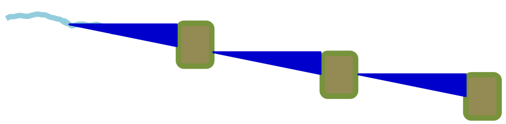
G2
High/mid-head RoR



Day/weekly small reservoirs
3 TWh/a
Built > 1850s
Private/local initiative
If P < 10 MW => FiT f/May'08

Infrastructure typology (III)

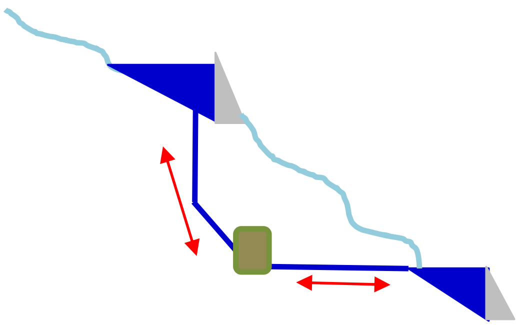
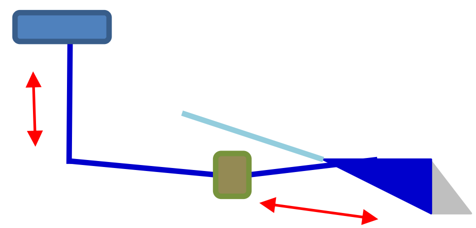
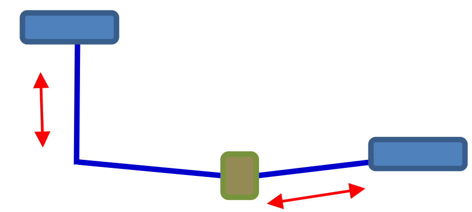
G3
Low-head RoR



Intra-day shallow reservoirs
16 TWh/a
Built > 1850s
Often power2user initiative
Concession renewals

Hydraulic model test at the LCH- EPFL (2009-2010)
Source: Erneuerung WKW Hagneck, BielerseeKW

Infrastructure typology (IV) / PSP

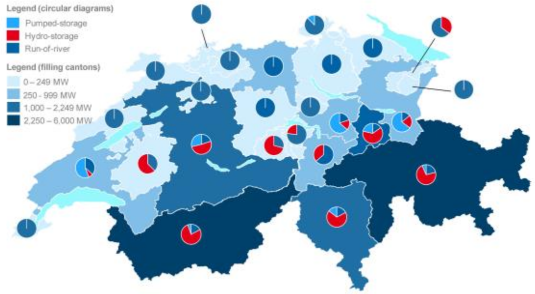
PSP1 Open-loop	PSP2 Semi open/closed-loop	PSP3 Closed PSP
		

One or two instream reservoirs
Combined natural/pump flows
Can be net producers if natural production > P/T balance
Historically base load compensation > WWII w/State back-up
Pumping = 2.5 TWh/a
Now RES compensation and privately developed if business model is feasible

Two off-stream reservoirs
Net electricity consumer
Possible worldwide
Used f/RES compensation
Privately developed if business model is feasible

Swiss Hydropower 2014

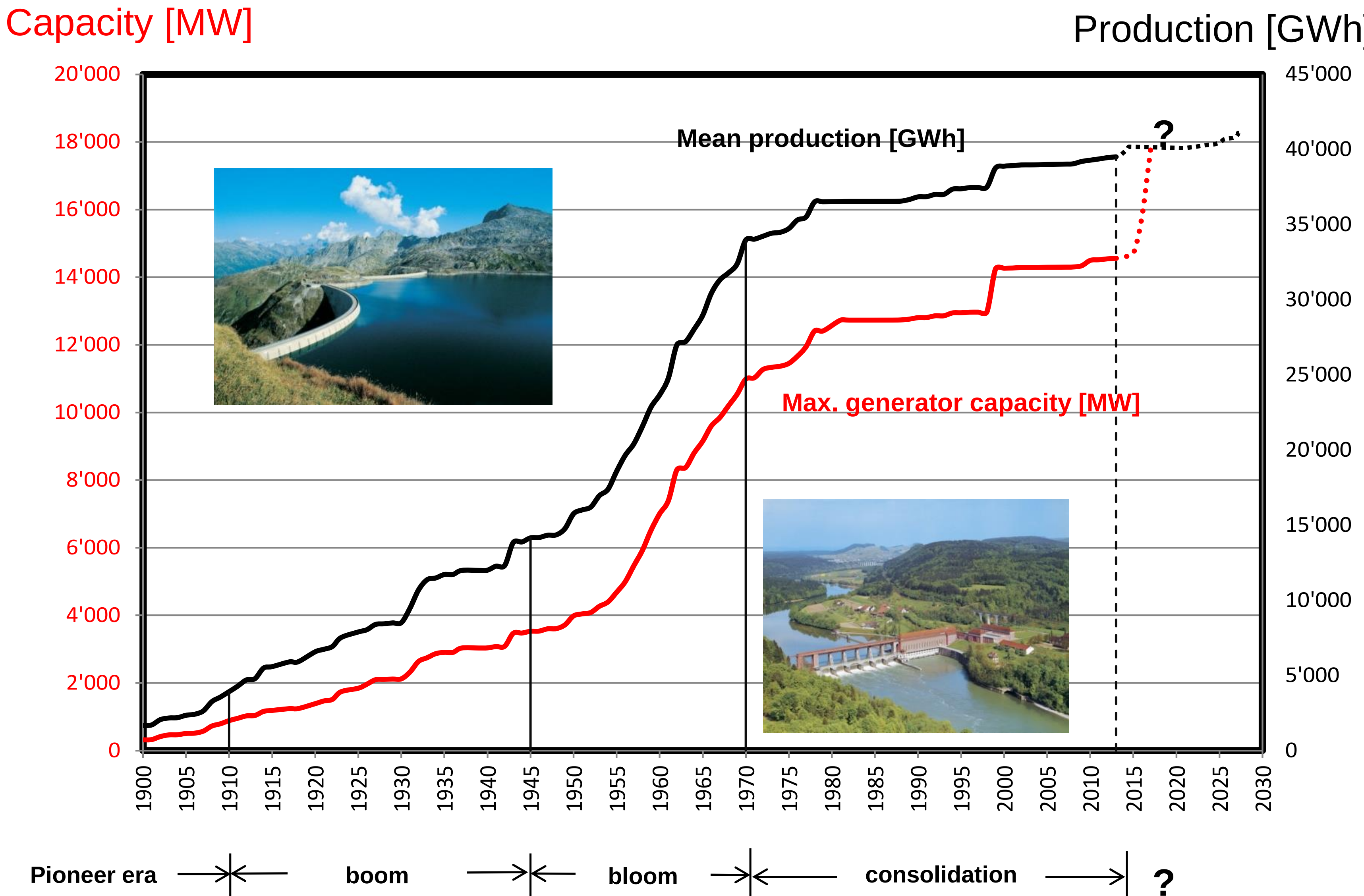
(Sources: electricity statistics FOEN + WASTA)



- Electricity production: 60 TWh/a (34 TWh/Winter)
- 56 % from HPPs (604 powerplants, 13’689 MW)
  - 20 TWh from storage HPPs (producing 47% in Winter)
  - 19 TWh from RoR HPPs
- Storage volume: 4 km^3 = 8.8 TWh (Source: FOEN 2015)
  - Austria 3 TWh; Germany 0.03 TWh (source: Prognos 2012)
- Variability of annual production: 70 – 140 %
- Av. annual HPP production (mov.-av. 2014): **36 TWh/a**

Development of Swiss hydropower

Backbone of electricity supply system



Source: after SFOE (2014)

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Selected challenges

In cooperation with the CTI

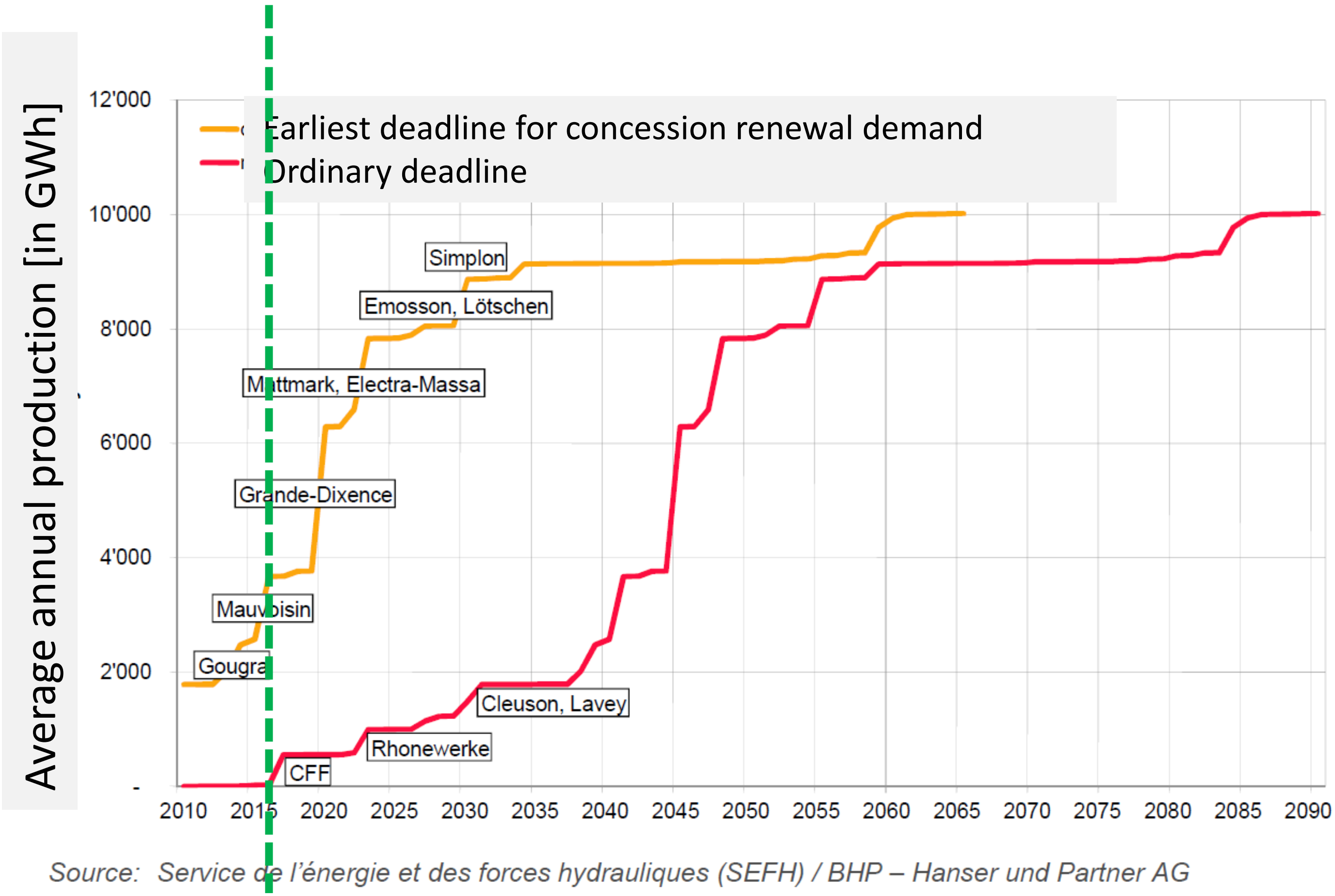
Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

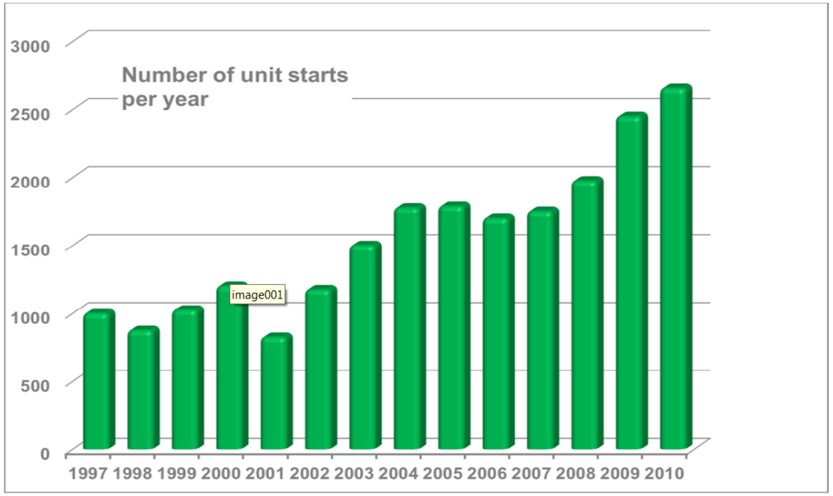
Commission for Technology and Innovation CTI

Hydropower Roadmap: motivation
Ageing & Concession renewal



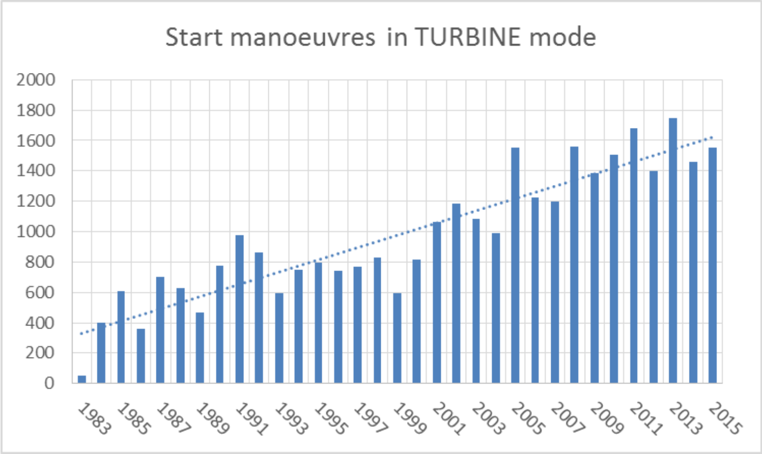
Source: Service de l'énergie et des forces hydrauliques (SEFH) / BHP – Hanser und Partner AG

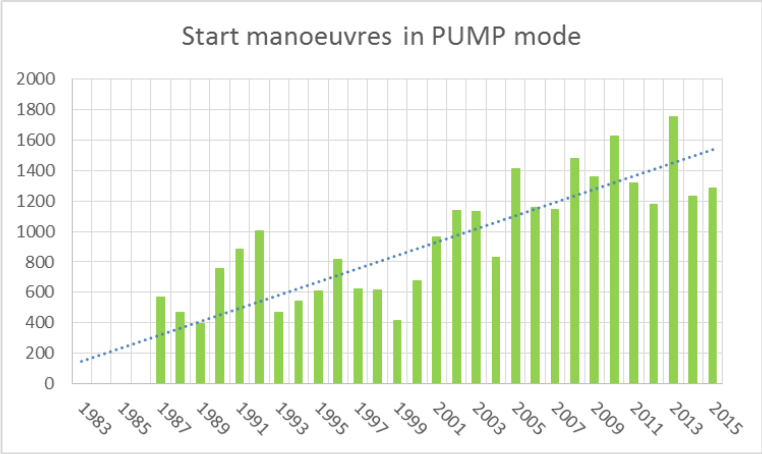
Hydropower Roadmap: motivation Pressure from markets on HPP operation



Source: Alstom

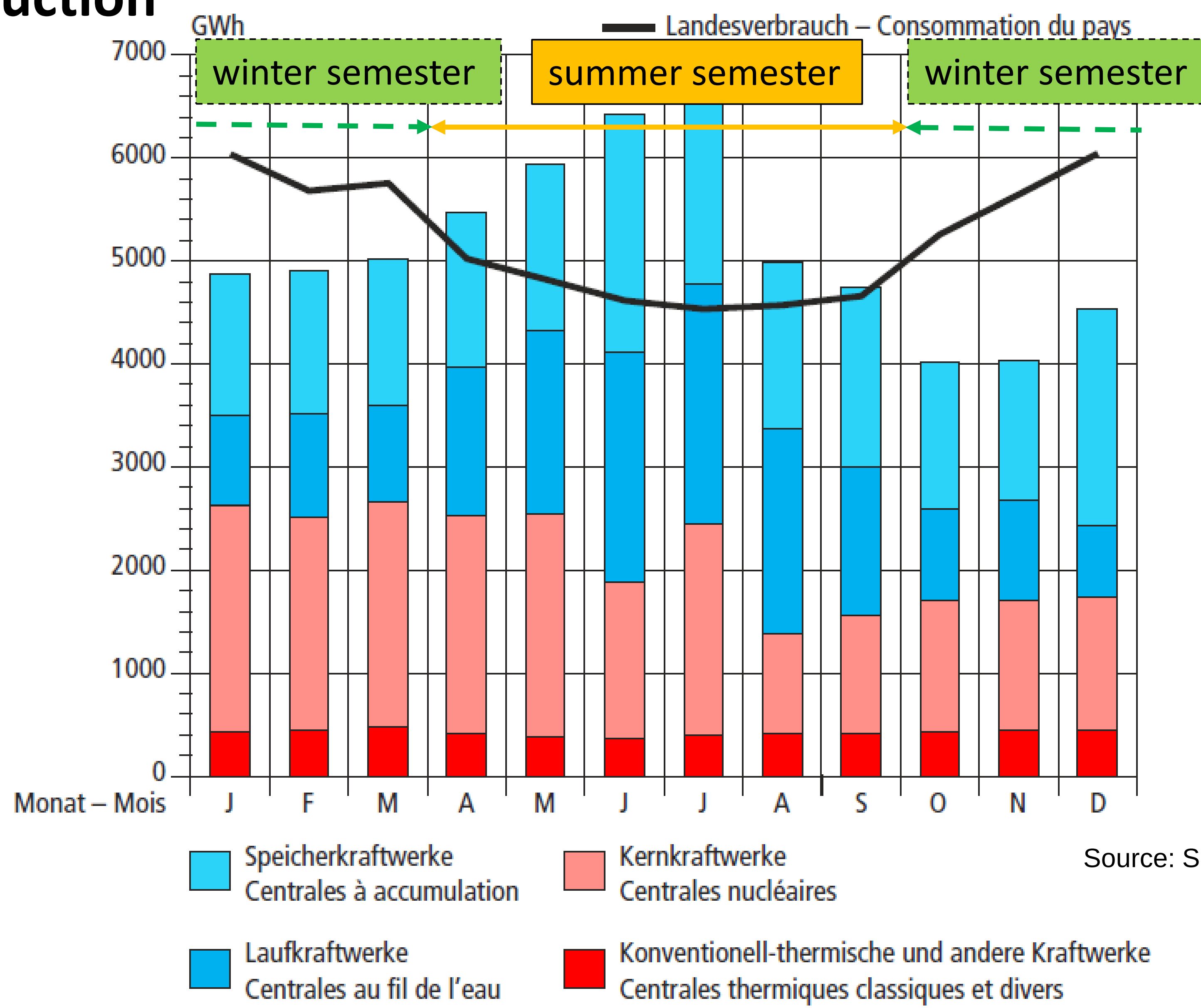
- Increase of unit starts
- Increase of partial load operation hours
- Extension of operation range





Source: Manso et al. 2016

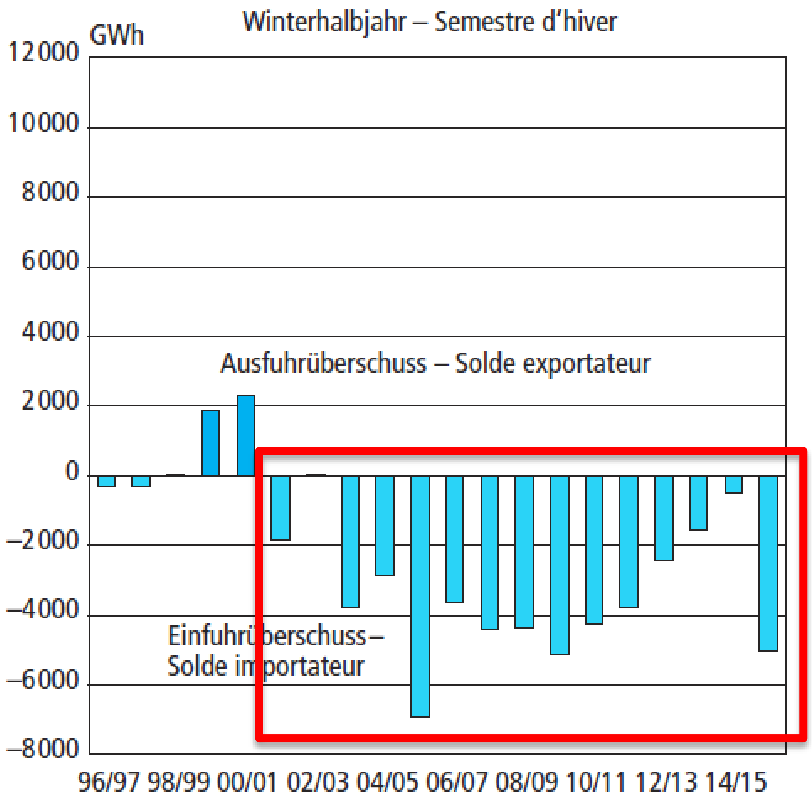
Monthly electricity consumption and production

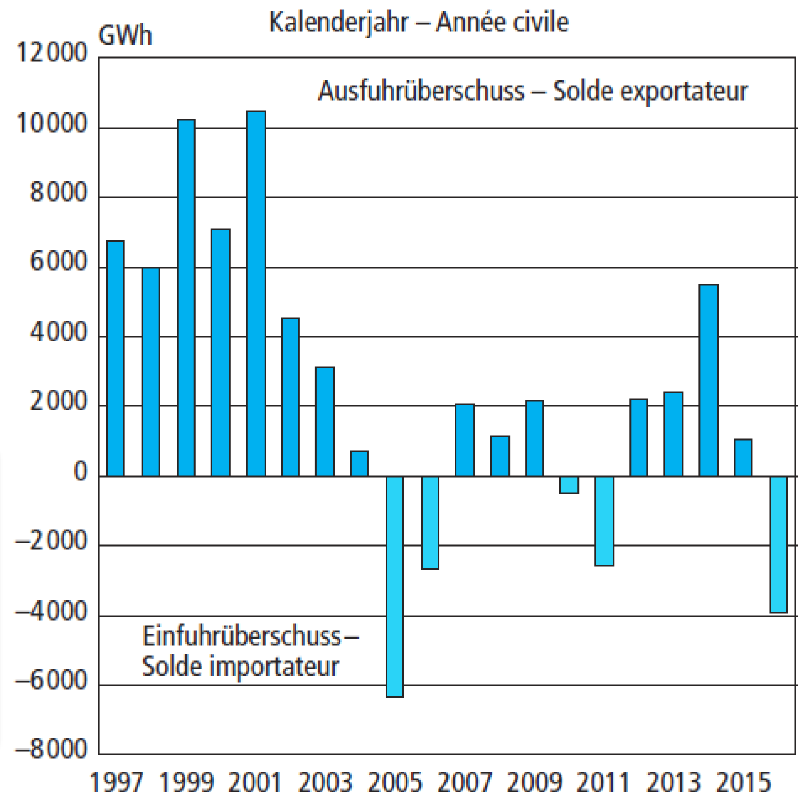


Source: SFOE (2017)

Electricity shortage in winter semester

– Surplus of electricity import in winter semester for many years
– Today nuclear PPs produce 14 TWh of base load in winter semester
– New renewables shall produce 10.5 TWh in winter semester by 2050





Source: Piot (2014), SFOE (2016)

Electricity shortage in winter semester

- Current energy equivalent of Swiss storage reservoirs: 9 TWh

- **Gap between consumption and production in winter semester** will amount to **between 3 and 7.7 TWh** (depending on scenario)

→ close gap by

  - Imports,
  - New combined cycle PPs, or
  - Additional seasonal storage reservoirs
  - Change consumption pattern

Foreseen changes

Improve → Renew → New

Goal ID	Goal Label	Operation changes (opex)	Renovation (opex/capex)	New infrastructure (capex)
1 **=E**	Maintain 2010's production level and even increase production	Increase live volume w/sediment management	Reduce friction losses Reduce transmission line losses Increase in machinery efficiency Enlarge dam drawdown range Turbine eco-flows at dams Add compensation basins	Heighten dams (add storage) New storage dams New RoR HPPs New connections between reservoirs Add diversion pumping capacity (*)
2 **+MW**	Capacity increase (MW) to avoid spilling and increase flexibility	-	EHM renewal Add compensation basins	Increase number of units New powerplants New compensation basins Add pumped-storage capacity (**)
3 **+CHF**	Revenue increase from energy sales	Concentrate production in premium hours (***)	Add compensation basin volume	All the above

*Diversion pumping consumes electricity but allows conveying water from a given valley into another one equipped with a cascade of plants, the net production output being positive since the pumping elevation difference is smaller than the cumulated production head.

**Pumped-storage consumes electricity but allow storing (excess) energy from wind and solar plants for later deployment, the net production output being either positive or negative depending on the ratio between production from natural inflows and production from pumped inflows.

***Premium production is only optional for storage plants, although improvements are quite dependent on the flow demodulation possibilities.

Manso, Schaefli, Schleiss (2015), Hydro, Bordeaux

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

How to increase the HPP storage?

In cooperation with the CTI

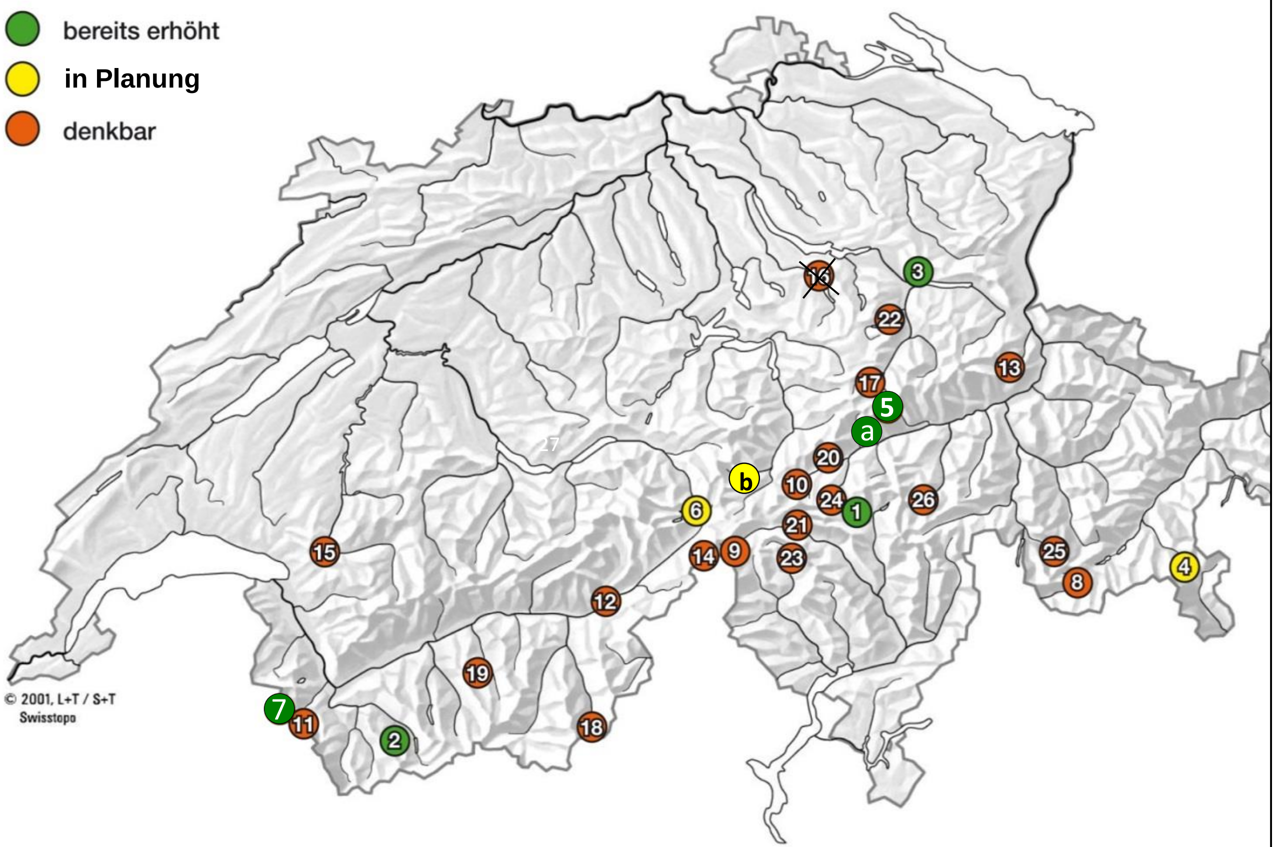
Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Dam heightening



Map: SWV; Sources: SFOE (2004), EPFL (2012), VAW (2016)

→ Additional winter semester energy of some 2 TWh

Implemented:
1 Luzzone (17 m)
2 Mauvoisin (13.5 m)
3 Muslen (5 m)
5 Muttsee (neu, 35 m)
7 Vieux-Emosson (20 m)
a Barcuns (5 m)

Design stage:
4 Lago Bianco N/S
6 Spitallamm/Seeuferegg (101 hm^3)
b Göscheneralp (76 hm^3)

Feasible:
8 Albigna (70 hm^3)
9 Cavagnoli (29 hm^3)
10 Curnera (40.8 hm^3)
11 Emosson (227 hm^3)
12 Gebidem (9.2 hm^3)
13 Gigerwald (33.4 hm^3)
14 Gries (18 hm^3)
15 Hongrin (52 hm^3)
~~16 In den Schlagen/ Hünermattdamm~~
17 Limmern (92 hm^3)
18 Mattmark (100 hm^3)
19 Moiry (77 hm^3)
20 Nalps (44.5 hm^3)
21 Piora (47.5 hm^3)
22 Rhodannenberg (39.8 hm^3)
23 Sambucco (64 Mio. m^3)
24 Santa Maria (67 hm^3)
25 Valle di Lei (197 hm^3)
26 Zervreila (100 hm^3)

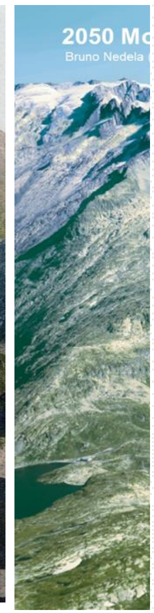
Periglacial hydro

New reservoirs and schemes due to glacier retreat

Periglacial hydro

New reservoirs and schemes due to glacier retreat

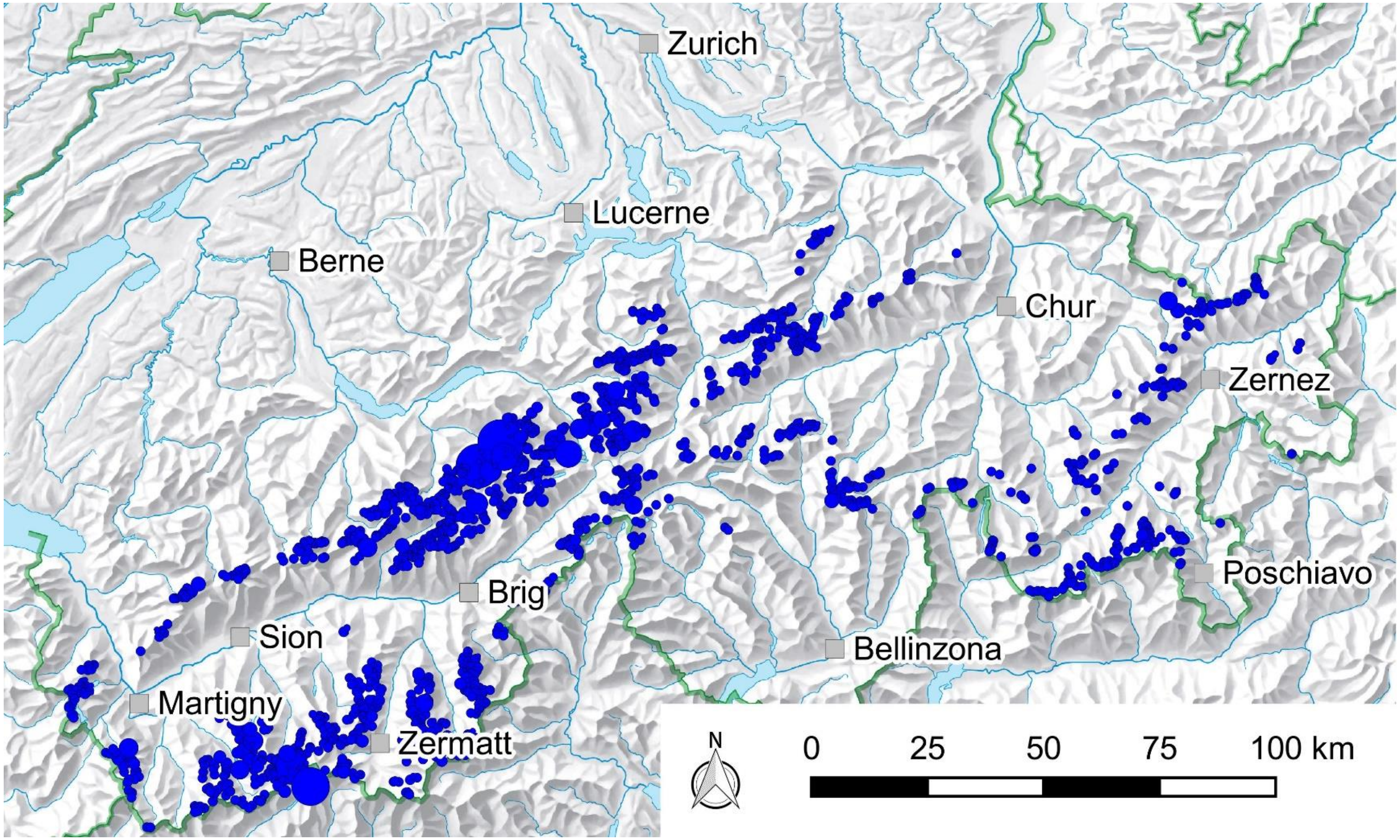
Rhone glacier ca. 1900



Rhone g

Periglacial hydro

New reservoirs and schemes due to glacier retreat



Relative glacier runoff volumes in 2035 (data from Farinotti et al. (2016)
(largest dot represents 283 hm3 annual discharge volume)

Periglacial hydro

New reservoirs and schemes due to glacier retreat

Technical potential of selected future hydropower plants

Location [name of nearest glacier]	**annual production** [GWh]	**reservoir volume** [hm^3]
Aletsch Glaciers (all)	180	106
Baltschieder Glacier	74	27
Gorner Glacier	119	34
Grindelwald Glacier	130	92
Hüfi Glacier (Maderan valley)	171	60
Rhone Glacier	98	23
Roseg Glacier	253	89
Trift Glacier	146*	85*
Total	**1'171** (+ 3.2%)	**516** (+ 35%)

* www.grimselstrom.ch/ausbauvorhaben/projekt-speichersee-und-kraftwerk-trift

Source: Ehrbar et al. (2017)

Periglacial hydro

Challenges

Climate change

– Development of water supply and sediment input

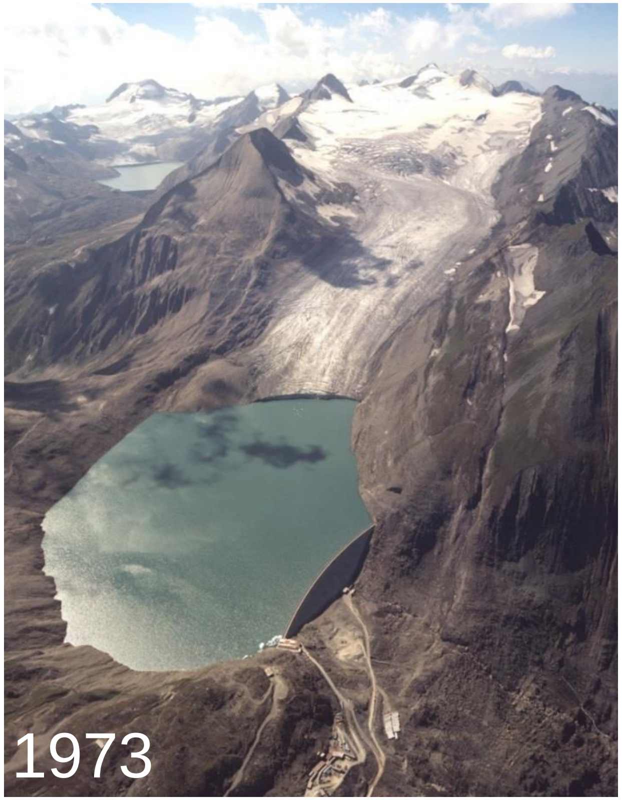


Photo: Swissair

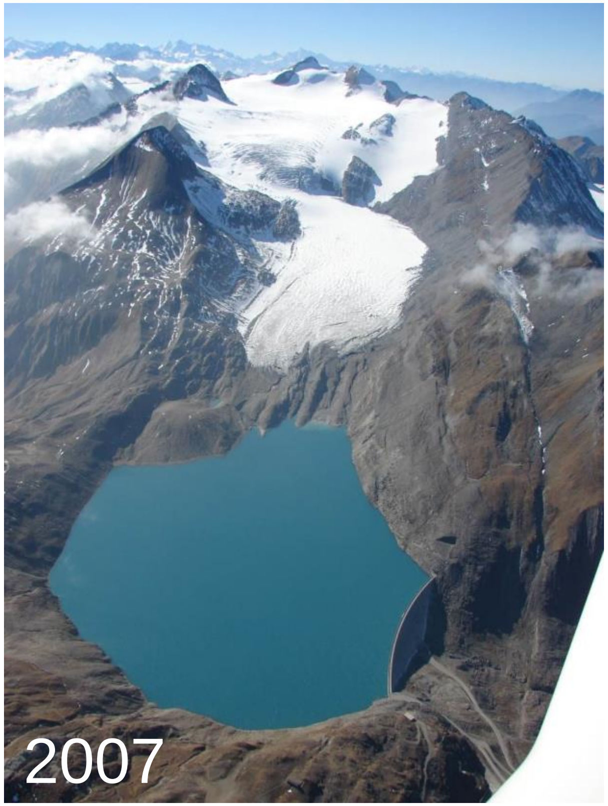


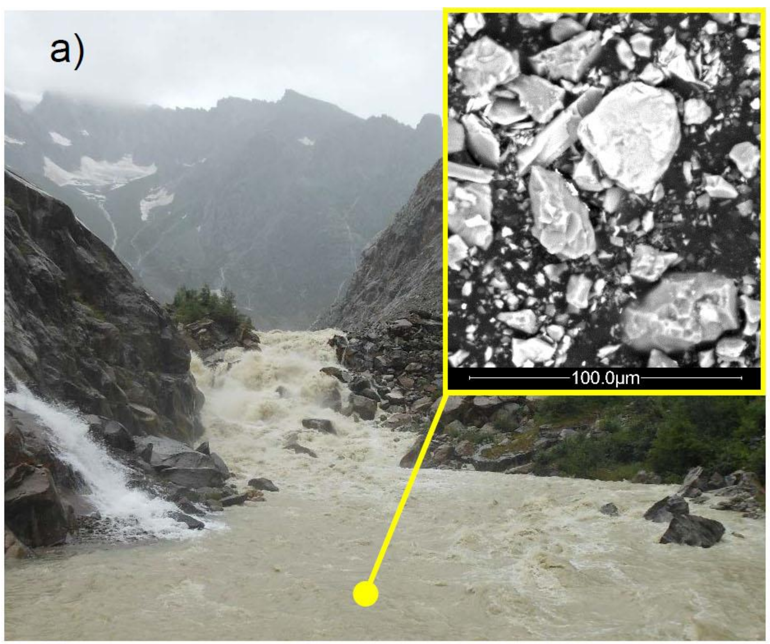
Photo: Kappenberger

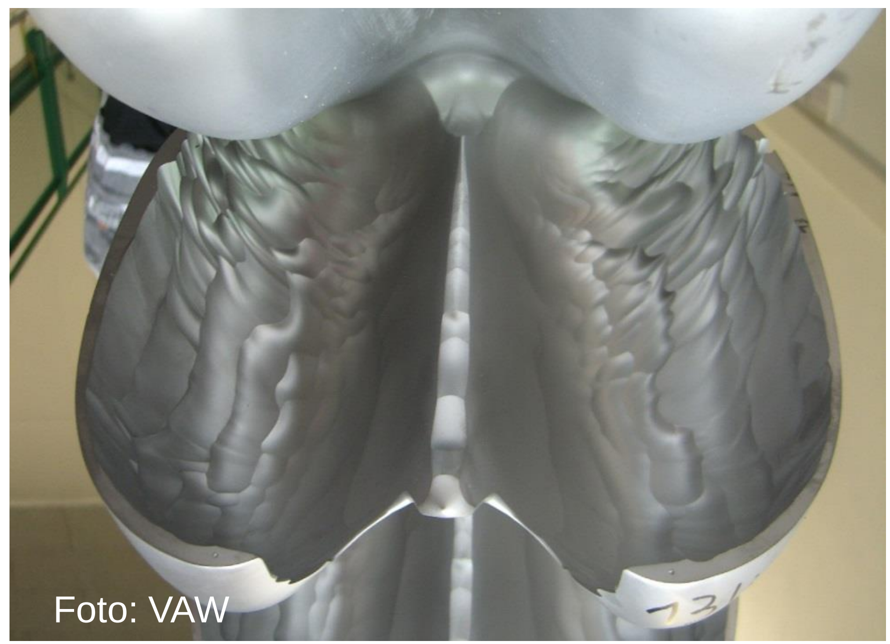
Periglacial hydro

Challenges

Sediments

- Reservoir sedimentation
- Hydro abrasion





Periglacial hydro

Challenges

Sediment evacuation under environmental constraints

Water protection act

- Fish migration
- Hydropeaking
- Residual flow

Downstream fish migration

Thermo- and Hydropeaking

Conclusions

- Swiss hydropower is and will be the backbone of our electricity supply system
- Small hydro potential still important but dispersed (numerous sites
- HPP reservoirs are practical to transfer «electricity» from summer to winter semester
- The goals of the Energy Strategy 2050 concerning electricity supply from hydropower could be achieved with **eight** new large-scale storage reservoirs in the periglacial environment by 2035.
- Major challenges ahead
- New business models (e.g. reservoir interconnections, hybrid / multiple uses, pluriannual reserve)

schmocker@vaw.ethz.ch
pedro.manso@epfl.ch