Hydro Pumped Storage/
Lessons Learned from large-scale Alpine
Pumped Storage Power Plants

The Future Role of Energy Storage in
South Eastern Europe

Dietmar Reiner
21. October 2014
VERBUND operates and owns 127 hydro power plants in Austria and in Bavaria, one in Albania and operates one in Turkey.

VERBUND operates and owns 154 wind power plants and two solar parks in Austria, Germany, Romania, Bulgaria and Spain with a total capacity of 416 MW.

Long track record in design, construction and operation of hydro power plants and wind power plants.

International reputation as hydro power specialist.

High environmental standards, high corporate social responsibility. The Sustainable Rating Agency oekom research lists VERBUND as a “Prime Investment“.

30% of area affected by hydro power plants became nature protection area.
VERBUND Hydro and Wind Power

VERBUND is by far the largest Austrian electricity producer and a significant European producer of electricity from renewable sources of energy.

VERBUND Hydro Power is the competence centre for hydropower and windpower at VERBUND.

The management of the company is based on efficiency, market conformity, social responsibility, environmental compatibility and sustainability.

The continuous extension of our capacities ensures the success of the company.

VERBUND actively responds to the challenges posed by the market.

The commitment and specialist skills of our staff play a decisive role in our corporate success.
Generation Portfolio Hydro Power

<table>
<thead>
<tr>
<th>Country</th>
<th>Capacity</th>
<th>Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>8,420 MW</td>
<td>30,259 GWh</td>
</tr>
<tr>
<td>Austria</td>
<td>7,040 MW</td>
<td>24,515 GWh</td>
</tr>
<tr>
<td>Germany</td>
<td>656 MW</td>
<td>3,374 GWh</td>
</tr>
<tr>
<td>Albania</td>
<td>52 MW</td>
<td>241 GWh</td>
</tr>
<tr>
<td>Turkey</td>
<td>672 MW</td>
<td>2,129 GWh</td>
</tr>
</tbody>
</table>

*gross yearly average generation
** Assets according to IFRS without assets under construction,
*** without Ennskraft

Germany 656 MW in operation
Austria 7,040 MW in operation
430 MW under construction
Albania 52 MW in operation
Turkey 672 MW in operation (until 2016)
Power plants in Austria and Germany
Run of river powerplant: HPP Freudenau (Danube river)

Type run-of-river
Annual prod. 1.052 GWh
Nominal cap. 172 MW
Turbines 6 Kaplan bulb
Mean gross head 8.6 m
Maximum flow 3,000 m³/s
Spillway system 4 weirs (24 m)
Navigation locks 2 (275 m x 24 m)
Backwater area 28 km

Favourable Impacts: Infrastructure
- Flood protection
- Improvement of navigation
- Infrastructure measures
- New recreational areas
- Groundwater management
Pump storage powerplant: HPP Malta (Main Stage)

<table>
<thead>
<tr>
<th>Type</th>
<th>pump storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual prod.</td>
<td>715 GWh</td>
</tr>
<tr>
<td>Nominal cap.</td>
<td>730 MW (pump: 290 MW)</td>
</tr>
<tr>
<td>Turbines</td>
<td>4 Pelton</td>
</tr>
<tr>
<td>Mean gross head</td>
<td>1.106 m</td>
</tr>
<tr>
<td>Maximum flow</td>
<td>20 m³/s</td>
</tr>
</tbody>
</table>

![Diagram of HPP Malta](image)
Advantages of (high-)alpine pumped storage power plants

The topography of the Alps enables:

• the usage of large reservoir volumes for seasonal and day-ahead energy reallocation

• the usage of natural inflows and natural valleys in the alpine and high alpine regions

• high pressure heads

• a variety of different products for future, spot and intraday markets as well as ancillary services

• an important support for the integration of wind and solar power

• security of supply and grid stabilisation

VERBUND Zemm-Ziller storage power plants as an example for high alpine PHS

VERBUND Seasonal Storage Reservoirs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Storage Capacity Energy MWh</th>
<th>Water Capacity Mio. m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kölnbrein</td>
<td>588,300</td>
<td>200.2</td>
</tr>
<tr>
<td>Schlegeis</td>
<td>331,094</td>
<td>126.5</td>
</tr>
<tr>
<td>Zillergründl</td>
<td>244,255</td>
<td>86.7</td>
</tr>
<tr>
<td>Mooserboden</td>
<td>237,004</td>
<td>84.9</td>
</tr>
<tr>
<td>Wasserfallboden</td>
<td>159,864</td>
<td>81.2</td>
</tr>
<tr>
<td>Durlaßboden</td>
<td>84,516</td>
<td>50.7</td>
</tr>
</tbody>
</table>

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Products delivered by Pumped storage powerplants

Flexibility
- Future market (yearly, quarterly and monthly products)
- Spot market (hours day-ahead)
- Intraday market (intraday)
- Balancing energy

Ancillary Services
- Primary control
- Secondary control
- Tertiary control
- Operating reserve
- Congestion management capabilities
- Reactive power
- Black start capability
- Energy and power in emergency situations
Europe / EEX Price trends – Future and Spot market

- Decreasing prices and change of profile
  - Since 2008, there are clearly decreasing spreads between peak (turbining) and off-peak (pumping) → decreasing revenue possibilities for PHS
  - Low increase of demand AND increasing capacities of wind and solar energy
  - Displacement of conventional power plants by RES capacities (highly supported and priority grid access)
  - At noon, demand-decrease instead of demand-peak (due to solar production)

EEX-spot prices for the second week of July 2008 until 2013

Source: EEX
Europe / Strong fluctuations of RES-generation in Germany

Day-ahead price determination

- **strong fluctuations** (daily and seasonal)
- load changes up to 10,000 MW within 1.5 h or up to 26,000 MW within 6 h
- forecasting errors up to 10,000 MW

Winter: → high wind generation → low solar generation

Summer: → moderate wind generation → high solar generation

Source: Amprion, 50Hz, TenneT TSO GmbH, EnBW Transportnetze AG
Pumped storage projects in Germany, Austria and Switzerland

Projects of the “Alpine countries Energy Initiative” (implementation depending on regulatory framework):

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>Austria</th>
<th>Switzerland</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped storage capacity installed (MW)</td>
<td>6.500</td>
<td>4.300</td>
<td>1.700</td>
<td>12.500</td>
</tr>
<tr>
<td>Pumped storage projects until 2020 (MW)</td>
<td>4.000</td>
<td>3.500</td>
<td>3.500</td>
<td>11.000</td>
</tr>
<tr>
<td>Share of pumped storage capacity in [EU-15 + CH(%)]</td>
<td>24</td>
<td>12</td>
<td>7</td>
<td>43</td>
</tr>
<tr>
<td>Share of total electricity production [EU-27 + CH(%)]</td>
<td>18,8</td>
<td>2,1</td>
<td>2,0</td>
<td>22,9</td>
</tr>
<tr>
<td>Total electricity production 2010 (TWh)</td>
<td>628,0</td>
<td>71,1</td>
<td>68,5</td>
<td>767,6</td>
</tr>
</tbody>
</table>
Importance of PHS as backup-capacity for Austria

- Yearly Generation: 72.2 TWh
  - 31.5 TWh
  - 16.1 TWh
  - 22.1 TWh

- Capacity: 23.2 GW
  - 7.8 GW
  - 5.5 GW
  - 8.3 GW
  - 1.6 GW

Pumped Storage Capacity

- Maximum Load
  - 10.1 GW
  - 5.7 GW

- Minimum Load
  - 6.8 GW
  - 3.9 GW

Source: E-Control, 2012

→ Current capacity of PHS amounts to 77% of the maximum load of the months December, January and February 2012 and up to 93% of the remaining months of 2012
Actual Impacts on further Hydropower Development in Europe

• **Potential**
  • EU Europe app. 250 TWh/a but favourable locations already developed
  • Additional potential from refurbishment and upgrading of existing HPP and pumped storage projects

• **Political Environment – Energy Politics**
  • Positive impacts due to general energy strategy (development of RES and security of supply)

• **Political Environment – Environmental Politics**
  • Negative impacts due to environmental legislation (EU and national), water framework directive, NATURA 2000,…
  • Duration of permitting procedures (EIA)

• **Market Environment**
  • Negative outlook due to development of energy prices
  • Potentials based on flexibility and storage potentials

At present difficult environment for development of new build hydro in Europe
Hydropower – Worldwide Potentials

Gross theoretical potential: ~ 43,400 TWh/y
Technically feasible potential: ~ 15,800 TWh/y
Economically feasible potential: ~ 9,400 TWh/y
Hydro Production 2011: ~ 3,700 TWh/y

Four countries – China, Brazil, Canada and the United States – together produce half of the world hydropower generation.

Ten countries produce 70%.

More than 35 countries obtained more than half of their total electricity from hydropower in 2009.

<table>
<thead>
<tr>
<th>Country</th>
<th>Hydro electricity (TWh)</th>
<th>Share of electricity generation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>694</td>
<td>14.8</td>
</tr>
<tr>
<td>Brazil</td>
<td>403</td>
<td>80.2</td>
</tr>
<tr>
<td>Canada</td>
<td>376</td>
<td>62.0</td>
</tr>
<tr>
<td>United States</td>
<td>328</td>
<td>7.6</td>
</tr>
<tr>
<td>Russia</td>
<td>165</td>
<td>15.7</td>
</tr>
<tr>
<td>India</td>
<td>132</td>
<td>13.1</td>
</tr>
<tr>
<td>Norway</td>
<td>122</td>
<td>95.3</td>
</tr>
<tr>
<td>Japan</td>
<td>85</td>
<td>7.8</td>
</tr>
<tr>
<td>Venezuela</td>
<td>84</td>
<td>68</td>
</tr>
<tr>
<td>Sweden</td>
<td>67</td>
<td>42.2</td>
</tr>
</tbody>
</table>

Note: These numbers do not include electricity imports such as those from the Itaipu hydropower plant side of Paraguay to Brazil, which represent almost half of this hydropower plant generation (36 TWh).

<table>
<thead>
<tr>
<th>Share of hydropower</th>
<th>Countries</th>
<th>Hydropower Generation (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;100%</td>
<td>Albania, DR of Congo, Mozambique, Nepal, Paraguay, Tajikistan, Zambia</td>
<td>54</td>
</tr>
<tr>
<td>&gt;90%</td>
<td>Norway</td>
<td>126</td>
</tr>
<tr>
<td>&gt;80%</td>
<td>Brazil, Ethiopia, Georgia, Kyrgyzstan, Namibia</td>
<td>403</td>
</tr>
<tr>
<td>&gt;70%</td>
<td>Angola, Columbia, Costa Rica, Ghana, Myanmar, Venezuela</td>
<td>77</td>
</tr>
<tr>
<td>&gt;60%</td>
<td>Austria, Cameroon, Canada, Congo, Iceland, Latvia, Peru, Tanzania, Togo</td>
<td>38; 351</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>Croatia, Ecuador, Gabon, DPR of Korea, New Zealand, Switzerland, Uruguay, Zimbabwe</td>
<td>25; 36</td>
</tr>
</tbody>
</table>

Note: Countries in boldface those where hydropower generation exceeded 20 TWh in 2009 and is indicated in the last column on the right.

Source: IEA, 2012; Technology Roadmap Hydropower
Today, PHS is the most efficient storage technology

**Pumped storage**
- Retrofit in Alpine storages
- Potential for new construction on major rivers

**Compressed air storage (CAES)**
- Needs salt caverns – potential in northern Europe
- Attractive in combination with network congestion

**Hydrogen**
- Might make sense in the long-term
- Mobile, i.e. appropriate for „power-to-transport“

**Batteries**
- Potential depends on learning effects
- Might make sense decentrally
- Mobile

**Conclusion**
Different technologies for different scopes! E.g. batteries at DSO-level and (pumped) storage power plants for large-scale application

Source: Frontier Economics
Hydropowerplant Ashta

Location
• South of Shkodra/Albania
• Last Stage of the cascade on the Drin river

Main Datas
• 2 Powerplants each with 45 Hydromatrix Turbines
• Installed Capacity 52,9 MW
• Average production 242 GWh (net)
• First New Built of a large scale hydropower plant in Albania since 1980
• First Hydropowerplant in Albania with a Fishpass
• Investment: > 200 Mio €
Hydropowerplant Ashta

Project Development

- 09/2008: Signing Concession Agreement
- 12/2008: Project Company Energji Ashta Sh.p.k established
- 03/2010: Assignment of Project Agreements (e.g. Offtake-Agreement) to Energji Ashta Sh.p.k
- 08/2010: JV with EVN established

- Construction Phase March 2010 to March 2013
  - Commissioning Ashta 1: 17.11.2012
  - Commissioning Ashta 2: 20.3.2013

- Start of Energy Sales Contract with the national incumbent KESH on 1.4.2013
Operation Hydropowerplant KW Ashta

- Matrix-Technology: trouble free operation (90 Turbines)
  - Availability Kraftwerk: 100%
  - Availability Hydromatrix: > 99,2%
- Plant operation of both stages without major problems
- No schedule deviations since start of Offtake due to plant operation
- Electricity Production (RAV: 242 GWh)
  - 2013 (9-Month): 268 GWh, EK: 1,64
  - 2014 (YTD): 146 GWh EK: 0,80
- Employment
  - 23 employees:
    19x Operation, 4x Administration
Hydro power in Albania

Status Quo:

→ Albania produced ~ 4.725 GWh of electricity in the year 2012 (ERE) with 100 hydropower plants in the year 2012 and has an installed capacity of ~1.628 GW of hydro powerplants.

→ But Albania also imported ~2.500 GWh in the year 2012.

Suggestions:

→ Due to its high dependency on electricity imports Albania needs to develop its remaining hydro power potentials and other forms of electricity production.

→ Albania uses currently only ~35% of its hydro-energetic potential.

→ Albania needs both additional generation as well as additional storage capacities for gaining a higher flexibility.
Albania is a net importer!

<table>
<thead>
<tr>
<th>Emertimi</th>
<th>Viti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prodhi (GWh)</td>
<td>3,204</td>
</tr>
<tr>
<td>Import nga KESH &amp; CEZ (GWh)</td>
<td>2,072</td>
</tr>
<tr>
<td>Çmimi mesatar i importit (Euro/MWh)</td>
<td>30.18</td>
</tr>
<tr>
<td>Vlera e importit nga KESH &amp; CEZ (milion Euro)</td>
<td>62.53</td>
</tr>
<tr>
<td>Furnizimi (GWh)</td>
<td>5,430</td>
</tr>
</tbody>
</table>

Production:
- increase of Incountry production is required to high dependency on (volatile) hydropower
- no funds available for new generation assets

Trading:
- cross border capacity sales undeveloped
- increase of transparency required

Finally: The improvement of the Distribution is the key for a sustainable development!
BACK UP
TOP 10 – Europäische Wasserkraftproduzenten, 2011
(Erzeugung in Europa)

<table>
<thead>
<tr>
<th>Gesamterzeugung</th>
<th>Erzeugung aus Wasserkraft</th>
<th>Wasserkraftanteil</th>
</tr>
</thead>
<tbody>
<tr>
<td>47,2 TWh</td>
<td>Statkraft 41,7 TWh</td>
<td>88%</td>
</tr>
<tr>
<td>616,5 TWh</td>
<td>EdF 37,0 TWh</td>
<td>6%</td>
</tr>
<tr>
<td>166,7 TWh</td>
<td>Vattenfall 34,5 TWh</td>
<td>21%</td>
</tr>
<tr>
<td>182,5 TWh</td>
<td>Enel 32,2 TWh</td>
<td>18%</td>
</tr>
<tr>
<td>29,8 TWh</td>
<td>VERBUND 24,2 TWh</td>
<td>81%</td>
</tr>
<tr>
<td>179,5 TWh</td>
<td>GdF Suez 21,0 TWh</td>
<td>12%</td>
</tr>
<tr>
<td>55,3 TWh</td>
<td>Fortum 21,0 TWh</td>
<td>38%</td>
</tr>
<tr>
<td>100,0 TWh</td>
<td>Iberdrola 17,7 TWh</td>
<td>18%</td>
</tr>
<tr>
<td>208,7 TWh</td>
<td>E.ON 16,3 TWh</td>
<td>8%</td>
</tr>
<tr>
<td>21,5 TWh</td>
<td>Alpiq 5,5 TWh</td>
<td>26%</td>
</tr>
</tbody>
</table>

Quelle: Geschäftsberichte
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Hydropower – Actual Generation and Potential in Europa

<table>
<thead>
<tr>
<th></th>
<th>EU Europe</th>
<th>EURELECTRIC Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation 2009</td>
<td>340 TWh/a</td>
<td>550 TWh/a</td>
</tr>
<tr>
<td>Potential</td>
<td>250 TWh/a</td>
<td>600 TWh/a</td>
</tr>
<tr>
<td>Total</td>
<td>590 TWh/a</td>
<td>1.150 TWh/a</td>
</tr>
<tr>
<td>developed</td>
<td>App. 60 %</td>
<td>App. 50 %</td>
</tr>
</tbody>
</table>

Source: Eurelectric; Hydro in Europe Powering Renewables)

Hydropower:

- represents 20 % of installed generation capacity (17 % in EU-27)
- Annual generation app. 550 TWh/a resp. 340 TWh/a (EU-27)
- still amounts to 58 % of electricity generation from RES (2011)

Case Study Austria:

- Actual Generation: 40 TWh/a
- Technically feasible: 16 TWh/a
- Actual Projects: 4 TWh/a (50% Refurbishment and Upgrading)
### Actual Pumped Storage Projects in Central Europe

<table>
<thead>
<tr>
<th>Project</th>
<th>Data</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linthal 2015 (CH)</td>
<td>1.000 MW P/T 1.650 Mio. €</td>
<td>Under construction (2016)</td>
</tr>
<tr>
<td>Vianden (L)</td>
<td>200 MW P/T 190 Mio. €</td>
<td>Operation (2013)</td>
</tr>
<tr>
<td>Attdorf (D)</td>
<td>1.400 MW P/T &gt; 1.000 Mio. €</td>
<td>licencing procedure</td>
</tr>
<tr>
<td>Riedl (D/A)</td>
<td>300 MW P/T 365 Mio. €</td>
<td>licencing procedure</td>
</tr>
</tbody>
</table>

Potential and projects for new pumped storage in Europa is still existing, also future demand due to integration of renewables

**Actual problem: market environment**
Several surveys of future storage capacity demand

→ **DENA (8/2012):**
  - + 6.5 GW in 2050
  - daily fluctuations up to 70 GW
  - maximum reserve capacity needed 17.3 GW

→ **VDE (6/2012):**
  - current RES-share in Germany of approx. 20%: no additional demand
  - up to RES-share in Germany of approx. 40%: no additional demand
  - **goal 2050 in Germany:** RES-share of approx. 80%: further demand of
    - +14 GW i.e. 70 GWh short term storage capacities
    - +18 GW i.e. 7.5 TWh long term storage capacities

→ **DENA (2/2010):**
  - consistent network expansion
  - construction of sufficiently large storage facilities
Comparison of large-scale storage technologies

Pumped storage power plants show by far the best combination of:
- investment costs
- lifetime and
- efficiency

Capital costs (€/kW/a) depend on lifetime, size of storage, etc.

Source: Frontier Economics