A GIS tool for mapping of pump storage potential in Norway

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Background

- Large interest in Norway's potential for pumped storage hydropower (PSH) to develop renewable energy sources
- Pre-study from 2011 for southern Norway: selection of potential PSH connections based on expert knowledge
- GIS-tool: mapping for entire Norway based on documented selection criteria (first stage; no costs or reservoir interactions included)
GIS mapping of PSH potential in Europe

- Linking two existing reservoirs, or
- Transformation of one existing lake or reservoir to PHS by detecting a suitable site for a second reservoir

Schmidt et al. (2011); Mapping of potential in Thüringen (Germany)

**Norway:**
Only linking of existing reservoirs, no construction of new ones
Scheme of a pumped hydropower storage reservoir pair

Upper reservoir

Water level change rate (m/hour)

Gross pressure head (GPH)
2/3 reservoir level

Natural protection area

Penstock length (PSL)

Environmental influence point (EIP)

No change of existing regulation limits (HRW, LRW)!

Nearest distance between reservoirs (DISTpl)

Lower reservoir

HRW_L

LRW_L

CEDREN
Centre for Environmental Design of Renewable Energy
### GIS mapping of PSH potential in Europe

Table 1: Proposed values for some of the criteria described, depending on the scope of the assessment. Minimum distances are between the new reservoir under assessment and the given feature.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>National</th>
<th>Region</th>
<th>County</th>
<th>Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max distance between reservoirs (km)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Minimum head (m)</td>
<td>50 – 200</td>
<td>25 – 200</td>
<td>15 – 200</td>
<td>50 – 200</td>
</tr>
<tr>
<td>Topologies 1 &amp; 2: minimum usable volume of existing reservoir (Hm³), or hydropower installed capacity (MW)</td>
<td>1 Hm³/10 MW</td>
<td>0.1 Hm³/5 MW</td>
<td>0.05 Hm³/1 MW</td>
<td>1 Hm³/10 MW</td>
</tr>
<tr>
<td>Topology 2, assumed new reservoir size (m²)</td>
<td>1 000</td>
<td>700</td>
<td>700</td>
<td>1 000</td>
</tr>
<tr>
<td>Topology 2, assumed new reservoir average depth (m)</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Minimum distance to inhabited sites (m)</td>
<td>2 000</td>
<td>1 000</td>
<td>200</td>
<td>2 000</td>
</tr>
<tr>
<td>Minimum distance to existing transportation infrastructure (m)</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Distance to national parks</td>
<td>2 000</td>
<td>1 000</td>
<td>500</td>
<td>2 000</td>
</tr>
<tr>
<td>Distance to Natura 2000 sites</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Distance to special protection areas</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Minimum distance to a UNESCO site (m)</td>
<td>2 000</td>
<td>1 000</td>
<td>500</td>
<td>2 000</td>
</tr>
<tr>
<td>Maximum distance to suitable grid connection (km)</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>
GIS Mapping Norway

Input data (maps) from the Norwegian Mapping Authority, NVE, and Environmental Agency

Norway has 905 existing reservoirs, 886 of them with a reservoir volume of >100 000 m³

Grey: User-defined input parameters or data sets
Green: Result files

Flow chart
Python script tools, included into ArcGIS 10 geoprocessing toolbox
Tool 1: Topographical analysis

Terrain criterion
Prevents the occurrence of "perched tunnels"

Distance criterion
Limits the distance between suitable reservoir pairs (Default: 50 km)

Power plant criterion
Pump storage power related to existing power plants (not mandatory)

Brutto fallhøyde (2/3 mag.nivå)

Kraftverk

45°
Tool 1, Step 1
(Distance cr.)

Tool 1, Step 2
(Terrain cr.)
Tool 2 & 3: Production- and environmental related selection criteria

- There must be transmission capacities for the produced electricity.
- The water level changes (m/hour) in the upper reservoir and lower reservoir are limited because of environmental considerations (fish stranding etc.) and erosion issues.
- Protected areas (e.g. INON) should not be affected.
Tool 2: Calculation of production and restriction parameters
### User-defined parameters (can be varied in sensitivity tests)

**Table 3: User-defined criteria and default values used in the present study**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Unit</th>
<th>Default</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum distance between reservoirs</td>
<td>km</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Minimum head</td>
<td>m</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Minimum hydropower installed capacity</td>
<td>MW</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Maximum distance to roads</td>
<td>km</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Maximum distance to suitable grid connection</td>
<td>km</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Maximum rate of water level change in reservoirs</td>
<td>m/hour</td>
<td>0.13</td>
<td>Based on river data</td>
</tr>
<tr>
<td>Minimum distance to INON areas (not affected by heavy technical installations or constructions)</td>
<td>m</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Minimum distance to cultural landscape areas of high priority with biological and historical values</td>
<td>m</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Minimum distance to wild reindeer areas</td>
<td>m</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Minimum distance to existing and suggested natural protection areas</td>
<td>m</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

Distances with respect to EIP. Update and expert assessment necessary!

**Tool 3: Screening**
Some screening results

P-Screening-Mode

PSH potential for power production of 400, 700 and 1400 MW, minimum storage duration one day, maximum water level change rate in reservoir 0.13 m/hour
PSH connections for three and 30 days storage

Power production >100 MW, Maximum water level change rate in reservoir 0.13 m/hour

Red PSH lines: Environmental restrictions violated

Legend
- Reservoirs
- Roads
- Power production, no ENV-R
  - 100 - 400 MW
  - 400 - 700 MW
  - 700 - 1400 MW
  - > 1400 MW
- Power production, with ENV-R
  - 100 - 400 MW
  - 400 - 700 MW
  - 700 - 1400 MW
  - > 1400 MW

Td- Screening- Mode

Three Days Storage

30 Days Storage
Performance test example: Tinnsjø (C1)

Figure 6: The Møsvatn-Tinnsjø-Kallhovd/Mår area with the PSH cases suggested by Solvang et al. (2012, left) and the GIS-screening results obtained using the P-Mode for 400, 700 and 1400 MW. Dashed lines: PSH lines which are in conflict with the environmental restriction zones.

Table 8: Net inflow from the reservoirs for Case C1

<table>
<thead>
<tr>
<th></th>
<th>Upper Reservoir: Møsvatn</th>
<th></th>
<th>Lower Reservoir: Tinnsjø</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other inflow</td>
<td>m³/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other discharge</td>
<td>m³/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net inflow</td>
<td>m³/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other inflow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other discharge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net inflow</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Different net inflow rates, depending on assumptions

Multiple PSH lines
Testing and suggestions for improvements/development

Master thesis C. Cortinez (2013):
- Suggestions for improvements of some algorithms (e.g. terrain criterion)
- Inclusion of a simplified cost estimation as additional selection criterion for a test region in Telemark
Cost estimation

NVE Guidelines for cost estimates; with some simplifications
Establish a minimum $E$ to clip out lines with very low energy storage potential.

$E = \rho g \eta \cdot GPH \cdot V$

$E$ = total potential energy storage (GWh)

$GPH$ = gross pressure height

$V$ = volume

Choose the best GWh/NOK for each reservoir

C. Cortinez (2013)
Conclusions

- The GIS tool showed high PSH potential in the mountains in the southern part of Norway, some relevant sites in Central Norway, few in North-Norway.
- Results are highly depending on net inflow due to existing power plants and reservoir interactions.
- Many of the PSH connections are in conflict with environmental restrictions. Further investigations of environmental restrictions are needed (expert assessment)!
- Suggested improvements and new routines for cost calculation and selection in case of multiple reservoir connections need to be implemented into the GIS tool.
Thank you!

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