Water consumption from hydropower production: review of published estimates

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Structure of talk

1. Background
2. Review of published estimates
3. Critique of concept
4. Summed up
What raised the attention?


- What is the potential for renewable sources to replace fossil-based fuels?

- The different technologies benchmarked with respect to various criteria, including ‘water needed to produced 1 MWh electricity (water consumption)’
Water consumption from energy generation:

Source: IPCC SRREN, 2012

Wide range between minimum and maximum of estimates

- 209 m$^3$/MWh
- ~0 m$^3$/MWh
Water consumption from energy generation:

*Source: IPCC SRREN, 2012*

- **Main source of water losses:** evaporation from reservoir surfaces
- **209 m³/MWh**
- **~0 m³/MWh**
Water consumption from energy generation:  
Source: IPCC SRREN, 2012

Very few data points (n = 2) from 4 sources, i.e. Gleick, 1993; LeCornu, 1998; Torcellini et al., 2003 & Mielke et al., 2010.
IPCC SRREN (2012) states

• Upper values for hydropower result from few studies measuring gross evaporation values, and may not be representative.

• Research may be needed to determine the net effect of reservoir construction on the evaporation in the specific watershed.

• Allocation schemes for determining water consumption from various reservoir uses in the case of multipurpose reservoirs can significantly influence reported water consumption values.
Why this concern in the HP sector?

- The picture on hydropower is very inconsistent
- Very limited data/investigations and immature concept
- A fear that these numbers can be taken as ‘typical water footprint of hydropower’
- Potentially a large reputational and business risk
- Might disqualify hydropower based on an unfair methodological basis
- The water footprint methodology seems to gain an increasing foothold

Main source of water losses: evaporation from reservoir surfaces
Results from our review documented in:


2. HESS Discussion (open until August 19th, 2013):
   http://www.hydrol-earth-syst-sci-discuss.net/10/8071/2013/
Basis for calculations

1. \[ \text{Gross water consumption} = \frac{\text{Evaporation reservoir}}{\text{Annual power production}} \]

2. \[ \text{Net water consumption} = \frac{\text{Evaporation reservoir} - \text{Evaporation before inundation}}{\text{Annual power production}} \]

3. \[ \text{Water balance} = \frac{\text{Evaporation reservoir} - \text{Direct rainfall reservoir}}{\text{Annual power production}} \]
**Selected benchmarks published – Gross values**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value (m³/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low values (IPCC, 2012)</td>
<td>0.04</td>
</tr>
<tr>
<td>High value (IPCC, 2012)</td>
<td>209</td>
</tr>
<tr>
<td>US average [Torcellini et al., 2003]</td>
<td>17</td>
</tr>
<tr>
<td>US average (US Dept. of Energy, 2006)</td>
<td>68</td>
</tr>
<tr>
<td>Arizona average (Pasqualetti &amp; Kelly, 2008)</td>
<td>113.9</td>
</tr>
<tr>
<td>World average selected large HPPs (Mekonnen &amp; Hoekstra, 2012)</td>
<td>80</td>
</tr>
<tr>
<td>World average selected large HPPs (Mekonnen &amp; Hoekstra, 2012)</td>
<td>244.8</td>
</tr>
<tr>
<td>New Zealand gross ave. (Herath et al., 2010)</td>
<td>21.8</td>
</tr>
</tbody>
</table>

- ‘IPCC-values’
- US averages, based on 2 different datasets
- World average based on 2 different datasets
- 2 regional averages (Arizona and NZ)
Single-plant studies – Gross values

Water consumption [m³/MWh]

Hydropower plant & Country of location

CEDREN
Centre for Environmental Design of Renewable Energy
Single-plant studies – **Net** values

![Graph showing water consumption and lake evaporation for various hydropower plants and countries](graph.png)

- **WC estimates**
- **Average values**
- **Lake evaporation**

**Water consumption [m³/MWh]**

**Lake evaporation [mm]**

**Hydropower plant & Country of location**

- Chibe 3 - Ethiopia
- Chibe 1 - Ethiopia
- Waipapa - New Zealand
- Maraitai - New Zealand
- Atimuri - New Zealand
- Matakina - New Zealand
- Arapuni - New Zealand
- Tongariro - New Zealand
- Whakamaru - New Zealand
- Karapiro - New Zealand
- Rotourua - New Zealand
- Ohakuri - New Zealand
- Clyde - New Zealand
- Waiaki - New Zealand
- Chaff - New Zealand
- Aviemore - New Zealand
- Benmore - New Zealand
- Tekapo - New Zealand
- Kaprun - Austria

- **23.5**
- **9.5**
Ratio Net/Gross water consumption
Findings from our review of published values

- The presented estimates are based on different methodological approach. The dominating approach is the gross evaporation divided on production.

- Some of the newly published estimates are far beyond the earlier published maximum values by IPCC (2012).

- Only three studies report both gross and net evaporation. In these cases the net evaporation was 10-60 % of gross evaporation (water consumption).

- One study give negative water footprint (according to the 'water balance-method')

- Some studies are single-plant studies, while others have a very large geographical extent, 'smoothening out' large variations in water consumption values.
Findings from our review of published values

- Some of the high estimates are from reservoir with irrigation as the primary purpose and limited hydropower production, and/or large (natural) lakes with limited withdrawal of water for HP production.
- One study attempts to assign water losses according to the water value of the various uses (in multi-purpose reservoirs).
- Water consumption estimates are very sensitive to evaporation estimates, and the qualities of these estimates are uncertain.
- The studies/publications range in quality.
Findings from our review on the concept of assessment

• "No way" around the fact that HP has a large water consumption in some regions, given the current approach (gross evaporation) of calculating water consumption/footprint.

• But, are high water consumption rates problematic?

• No solution on how to handle "impacts" on the water resources, brief sketches of concepts proposed by e.g. Ridoutt & Pfister, 2010; Pfister et al., 2011; Hoekstra et al., 2011; Zeng et al., 2012.
1. Values are given as gross evaporation from the reservoir area. For dams constructed on desert land, the net evaporation will be equal to the gross values, but in most cases evaporation will be less, especially for dams in wetland areas and areas with vegetation where the net increase may be very limited.

2. Water stored in 'hydropower' reservoirs is often used for multiple purposes; thus the evaporation losses should not all be assigned to the hydropower production.

3. Impacts from the water consumption/footprint is ‘ignored’.

4. Construction of dams is a very common way to improve the availability of/access to water.
5. How to set the right system boundaries in space and time?

- One reservoir might serve several hydropower plants
- The production might vary a lot during the year and from year to year – what is the temporal resolution and span?

[Graph: Water consumption vs Power production]
7. What about the use of existing lakes as reservoirs – should all evaporation losses be assigned to the hydropower production?
How to describe the availability of water?

Can the concept be transferred into finding the optimum water allocation in a setting of competing sectors interests?
Application of the Building Block Methodology (BBM) in India

Water needs today and in 10 years time (when introduced water saving measures)
Application of the Building Block Methodology (BBM) in India

Storage volumes in the case of ‘normal’ hydrological year and a dry year.
Summed up

• The recently published values vary a lot and new studies are even far beyond values published by IPCC (2012).

• The concept of assessment appears to be over-simplified.

• It appears as a contradiction to assign water losses to reservoirs as their main purpose is to increase the water availability for various purposes.

• The impact of the (high) water consumption/footprint values should be assessed, in a local or regional context.

• But, water losses occur and should be taken into consideration in the planning and operation of reservoirs.

• Improved quantitative descriptions of reservoirs influence on water availability needed


The effect of Ethiopian hydropower reservoirs on the Blue Nile River flow regime

Muez Araya Tefferi
‘The meat and the flesh’

The role of water losses due to evaporation in the planning and operation of reservoirs
Possible Case studies

Tydal, Norway

India ????

Africa/
Ethiopia

Turkey (Statkraft interests)