Review of water consumption estimates and the importance of evaporation

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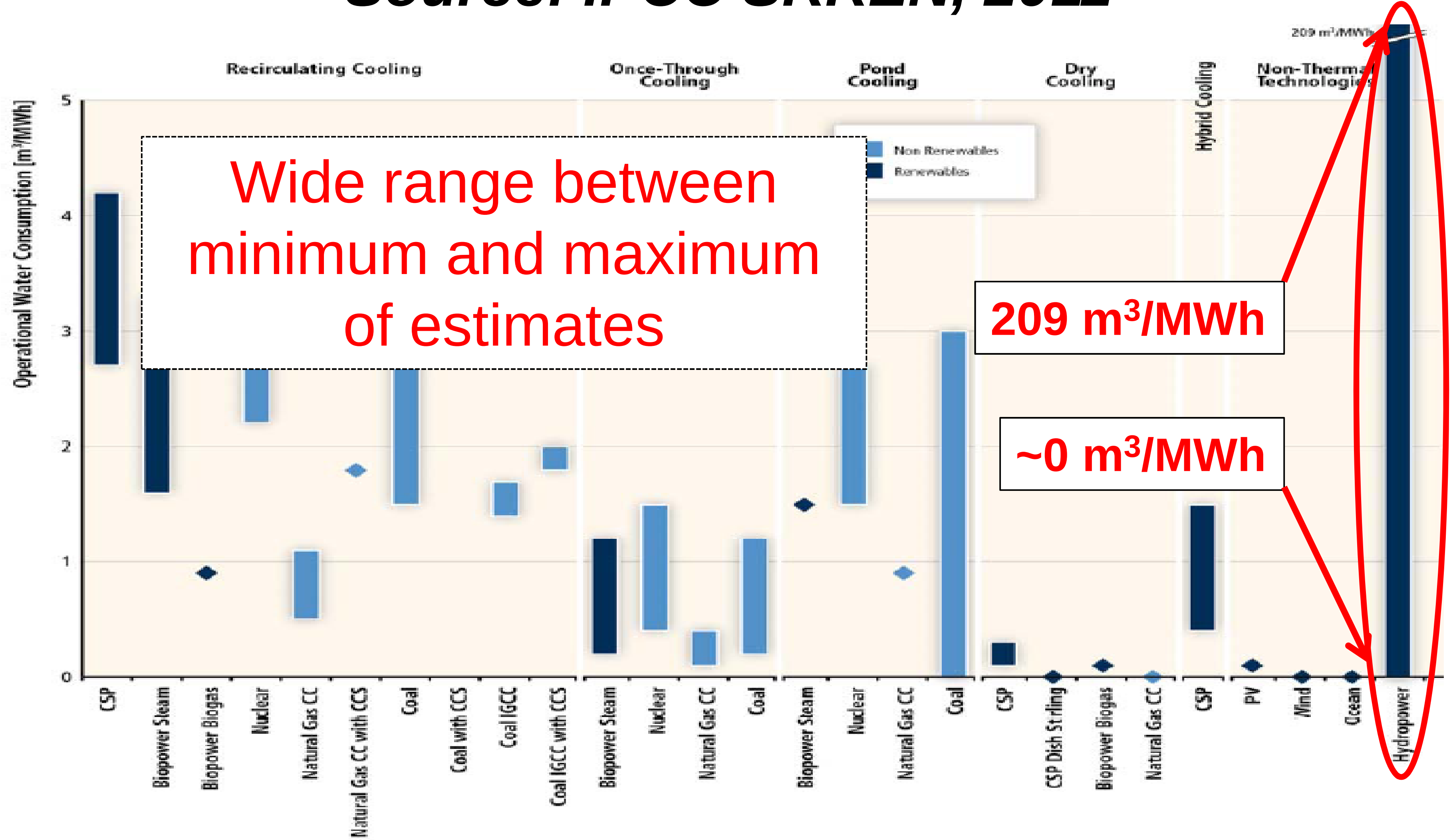
Structure of talk

1. Review of published estimates of water consumption from hydropower plants

2. Evaporation datasets and calculations

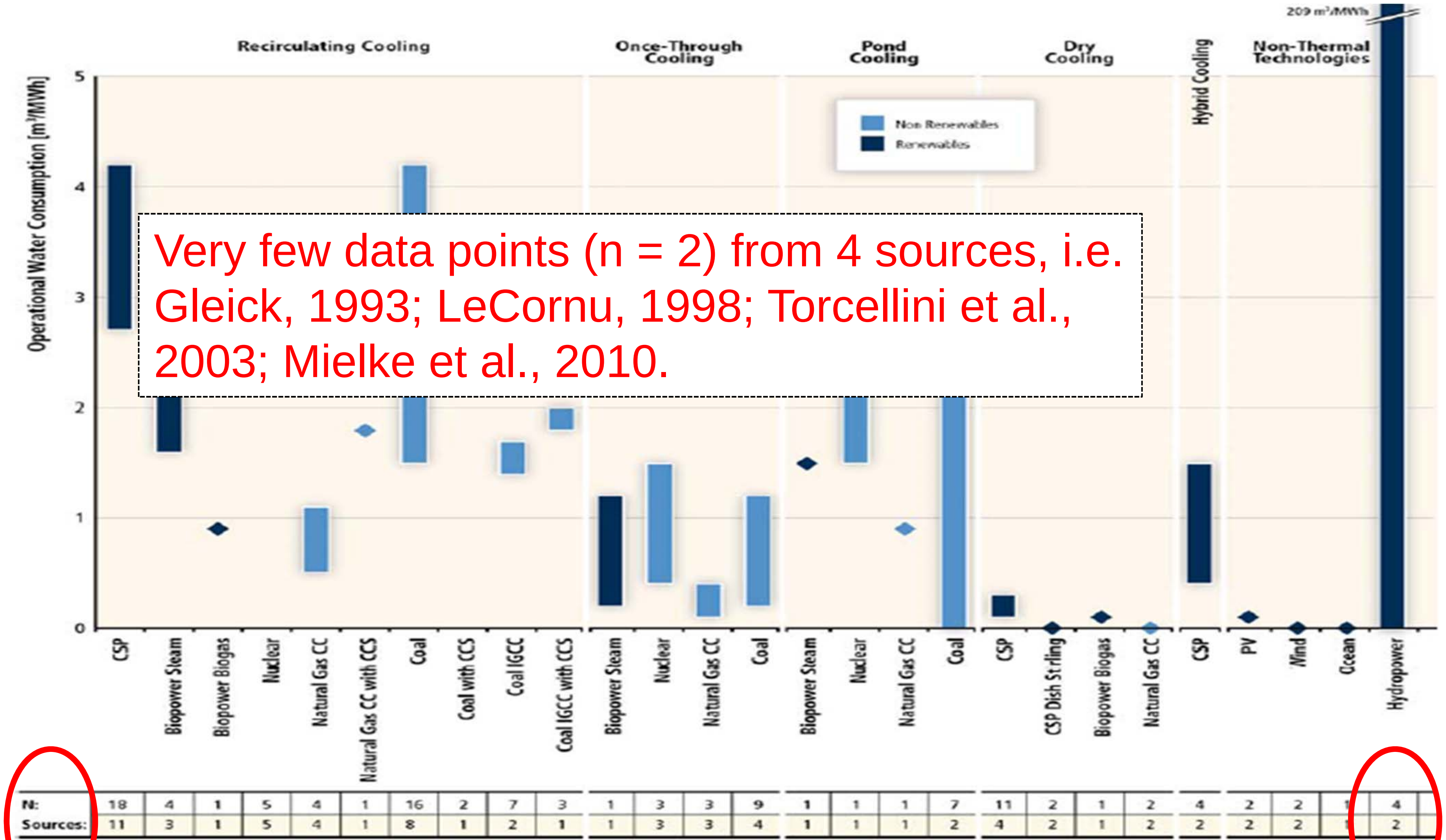
3. Case studies high-lighting methodological challenges

Water consumption for energy generation*:*
Source: IPCC SRREN, 2011



N:	18	4	1	5	4	1	16	2	7	3	1	3	3	9	1	1	1	7	11	2	1	2	4	2	2	1	4
Sources:	11	3	1	5	4	1	8	1	2	1	1	3	3	4	1	1	1	2	4	2	1	2	2	2	2	1	2

Water consumption for energy generation*:* *Source: IPCC SRREN, 2011*



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

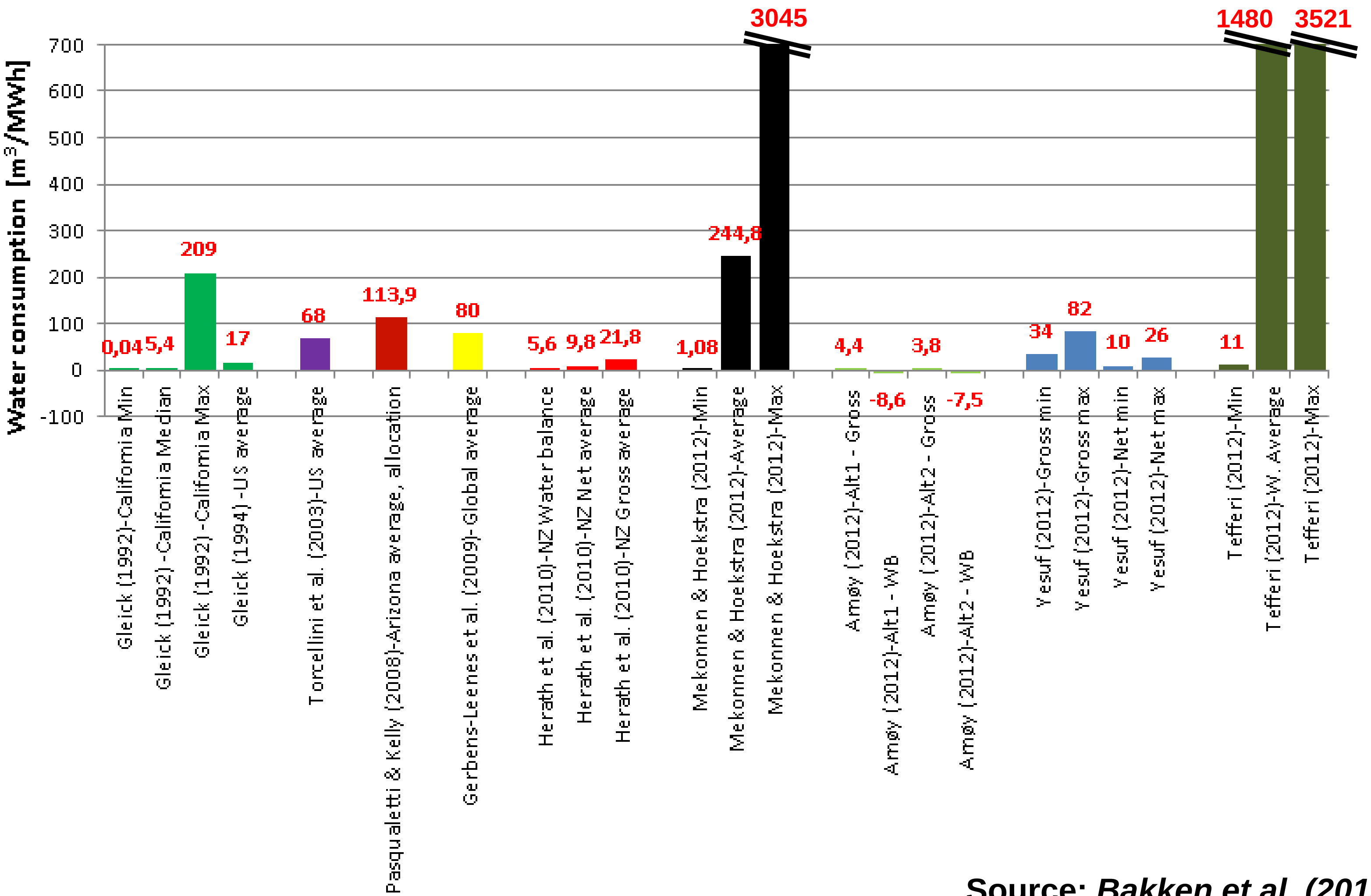
IPCC SRREN (2011) states

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.

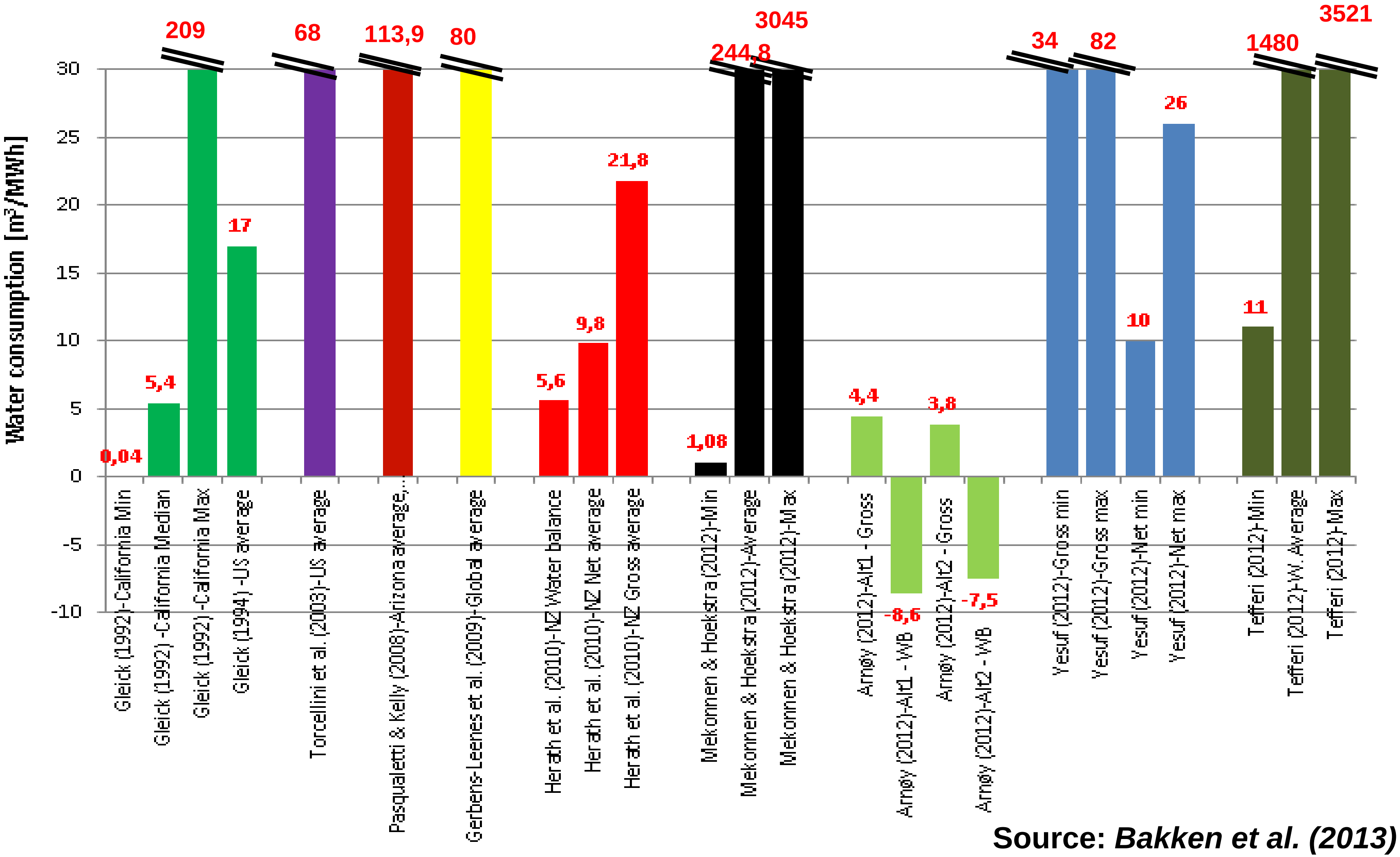
Allocation schemes for determining water consumption from various reservoir uses in the case of multipurpose reservoirs can significantly influence reported water consumption values

Publ. water consumption estimates – all
Only primary sources



Source: ***Bakken et al. (2013)***

Publ. water consumption estimates – lower range
Only primary sources



Source: ***Bakken et al. (2013)***

Notifications

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

2. Some of the high estimates are from reservoir with the irrigation as the primary purpose and limited hydropower production, and/or large (natural) lakes with limited tapping of water for HP production.

3. Some studies are single-plant studies, while others have a very large geographical extent, 'smoothening out' large spatial variations in water consumption values.

4. It is probably large uncertainties related to the quality/precision of the evaporation rates applied.

5. The studies/publications range in quality.

Findings from review

- More studies are now available than those used by IPCC (2011).
- Some of the newly published estimates are far beyond the earlier published maximum values by IPCC (2011).
- One study give negative water footprint (according to the 'water balance-method')
- It is an extensive re-use of data in publications, especially data originating from Gleick (1992) (re-used data not presented in the diagrams).
- Only two studies report both gross and net evaporation. In these cases the net evaporation was 40-50% of gross evaporation (water consumption).
- One study attempts to assign water losses according to the water value of the various uses (in multi-purpose reservoirs).

Findings from review

- "No way" around the fact that HP has a large water consumption is some region with current dominating calculation approach (gross evaporation).
- 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.
- Water consumption estimates are very sensitive to evaporation estimates.

Evaporation calculations/measurements

- Recommendations on which methods and/or data sets to use for estimating lake evaporation (and possibly evapotranspiration) is useful (maybe needed).
- Uncertainties – seasonal - annual

- Factors controlling lake evaporation
  - Net radiation
  - Air humidity

- Many methods available for lake evaporation
  - Pan evaporation
    - Pan coefficients
  - Mass balance
  - Energy Budget models
  - Bulk transfer models
  - Combination models
    - Penman
    - Priestly-Taylor
  - Equilibrium temperature methods
  - Empirical approaches

Evapotranspiration datasets

- Direct point measurement of water vapor flux.
- Evaporation pans
- Simulated values from based on meteorological and environmental measurements; the latter focusing on vegetation indices (LAI, height, aerodynamic roughness, albedo, etc.)
- Reanalysis data
- Remote sensing data in different combinations with modelling
- Water balance residual studies

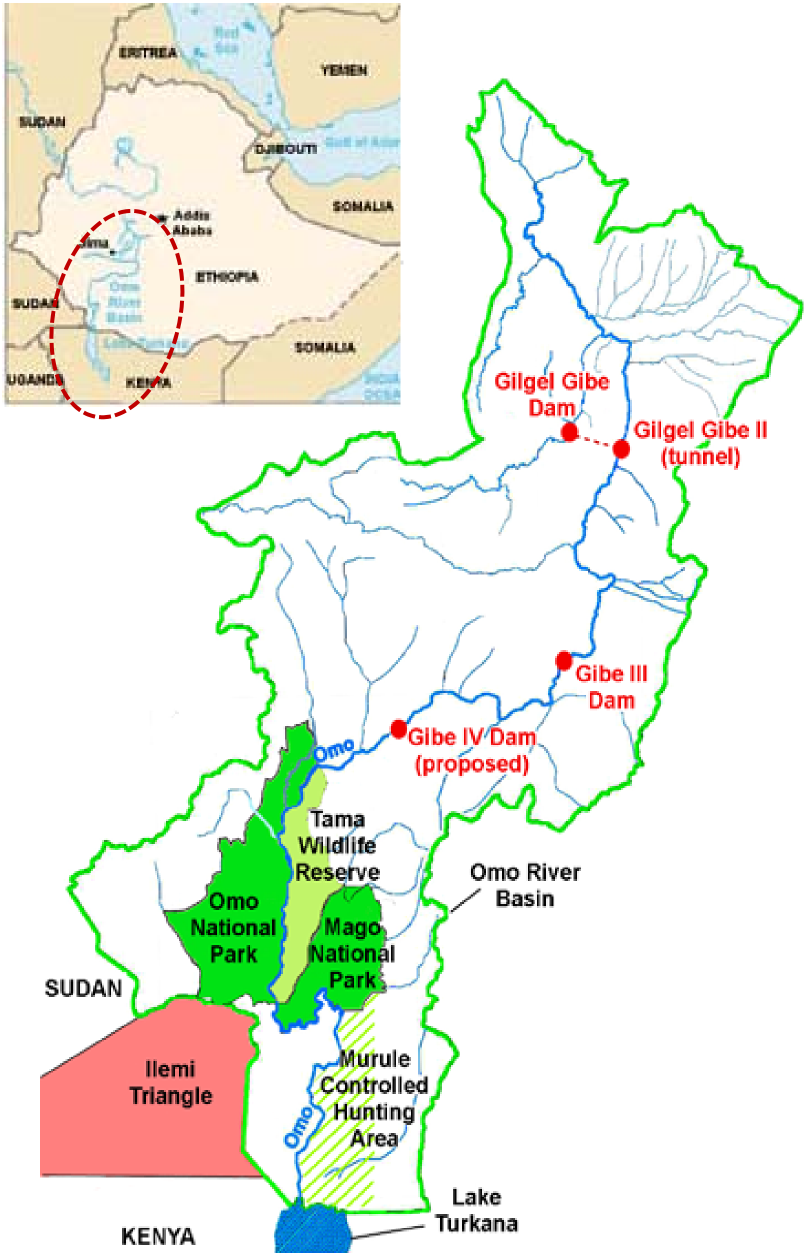
Omo-Ghibe River study:
(MSc Thesis 2012, NTNU)

Hydropower Plant in Omo-Ghibe River basin
Gilgel Ghibe I(producing power)
Gilgel Ghibe II(producing power)
Ghibe III (Construction on going)
Ghibe IV (Proposed)

Dams/Reservoirs
Gilgel Ghibe Dam
Ghibe III Dam (Construction on-going)
Ghibe IV Dam (Proposed)

Main data
Catchment area 79 000 km^2
Elevation range: 350 m.a.s.l to 4200 m.a.s.l
Rainfall: 400mm to 1900 mm (Average 1140 mm)

Second largest hydropower potential in Ethiopia (36500 GWh/yr)



Water consumption in reservoirs in Omo-Ghibe

Gross evaporation:
From 34 to 82 l/kWh

Net evaporation
From 10 to 26 l/kWh

Evaporation computation
- -Empirical (observed)
- -Water balance
- -Thorntwaite
- -Blaney-Criddle
- -Penman-Monteith
- -FAO Modified Penman

Net evaporation ca 30% of gross evaporation

Water footprint = Net evaporation = 10 to 26 l/kWh

Abay River (Blue Nile) study: *(MSc Thesis , Tefferi, 2012, NTNU)*

Three different type of reservoirs:

Irrigation reservoirs with hydro
Roseires dam 316 km^2 (1960/1980)
Sennar 158 km^2 (1925/1962)
Built for Gezira irrigation scheme

Hydropower reservoirs
Karadobi 445 km^2 (Planned)
Beko-Abo 45 km^2 (Planned)
Mandaya 515 km^2 (Proposed)
Border Dam 1066 km^2) (Under construction)

Natural Lake with hydro
Lake Tana (3150 km^2)

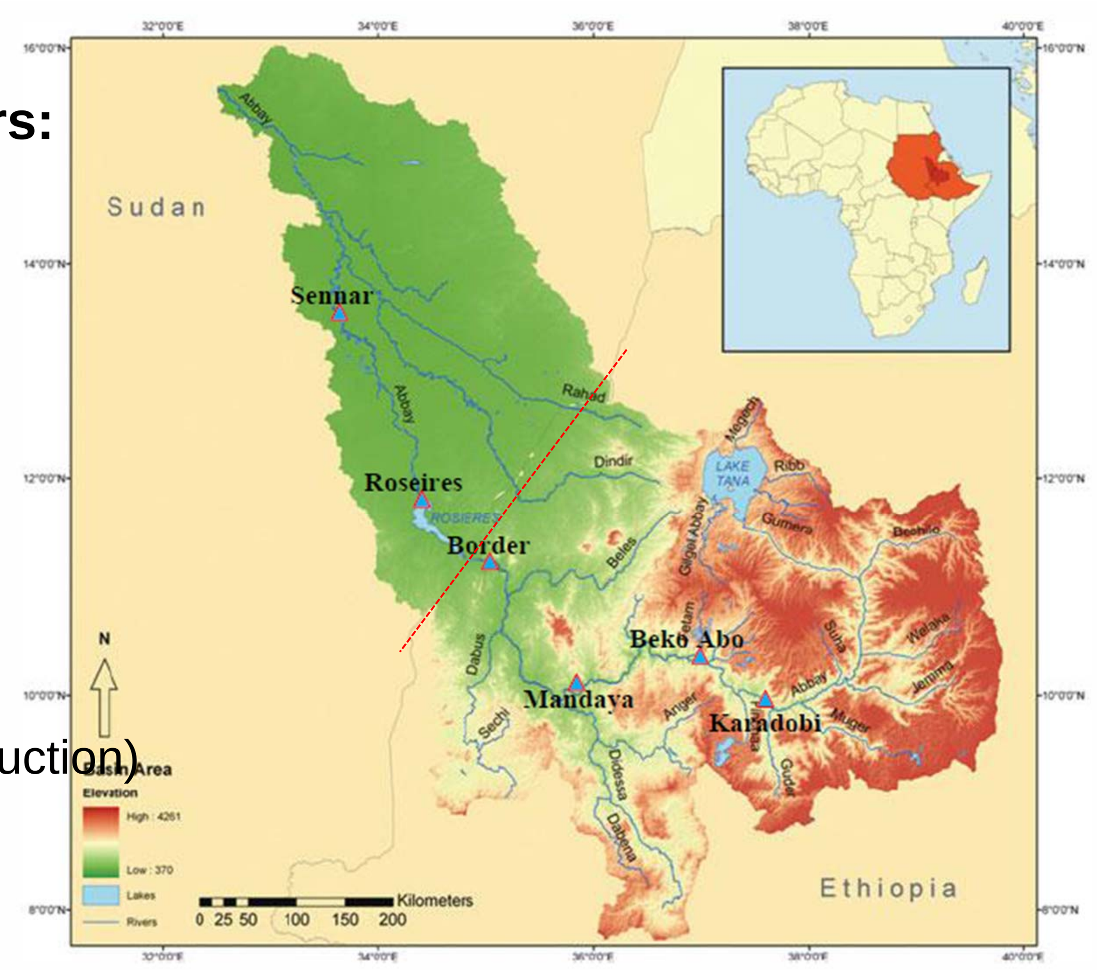
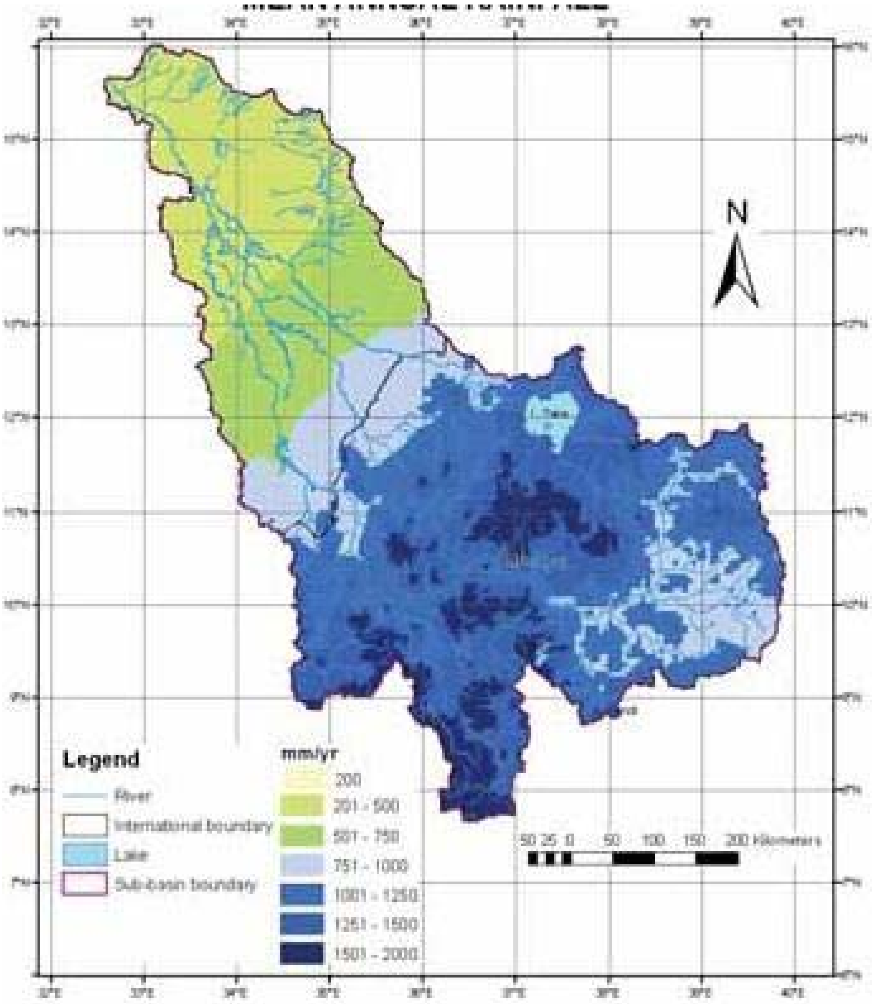
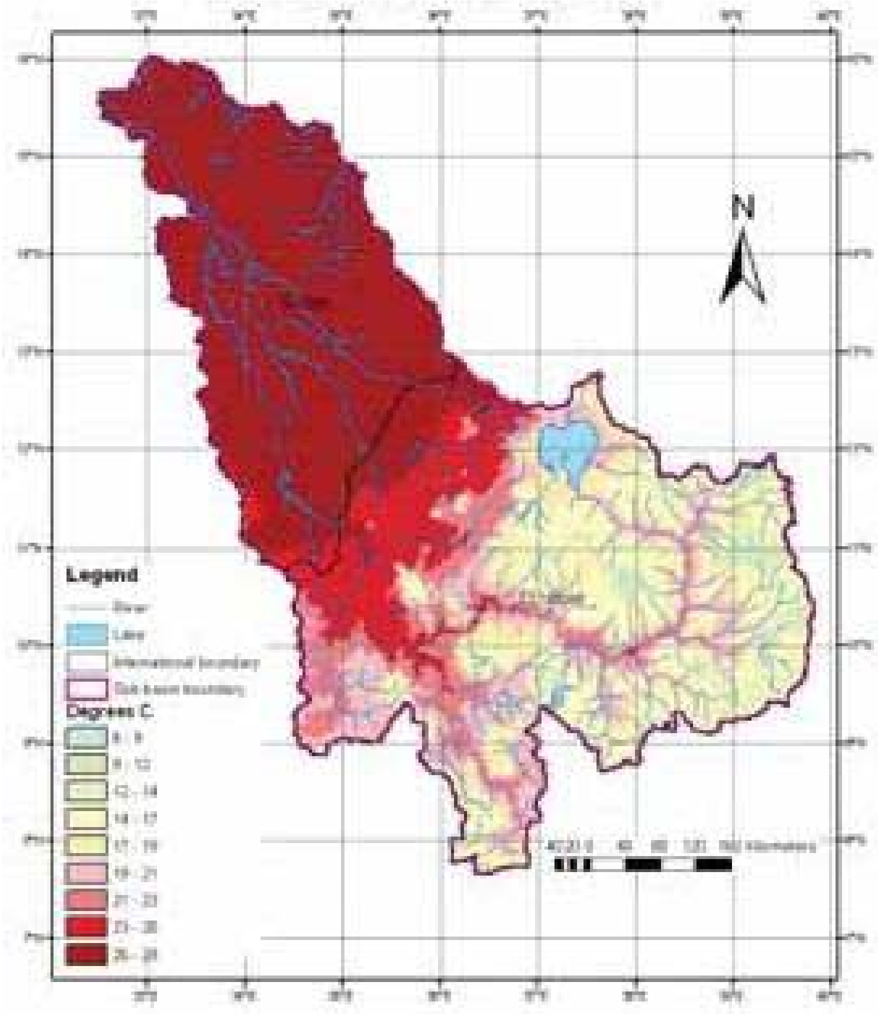


Figure 2-1 Location of Blue Nile Basin, its reservoirs and topography.

Climate in Abbay (Blue Nile) basin





Precipitation Distribution in basin

Temperature distribution in basin

Water consumption in reservoirs in Abbay (Blue Nile) basin

Gross evaporation:
11 to 137 l/kWh in Ethiopia
99 l/kWh weighted average

1370 to 3520 l/kWh in Sudan
(Roseires and Sennar)
1480 l/kWh weighted average

Lake Tana 2025 l/kWh
Net evaporation = 0

Evaporation computation
- Empirical (observed)
- Water balance
- Thorntwaite
- Blaney-Criddle
- Lane method
- Hargreaves
- Penman-Monteith
- FAO Modified Penman

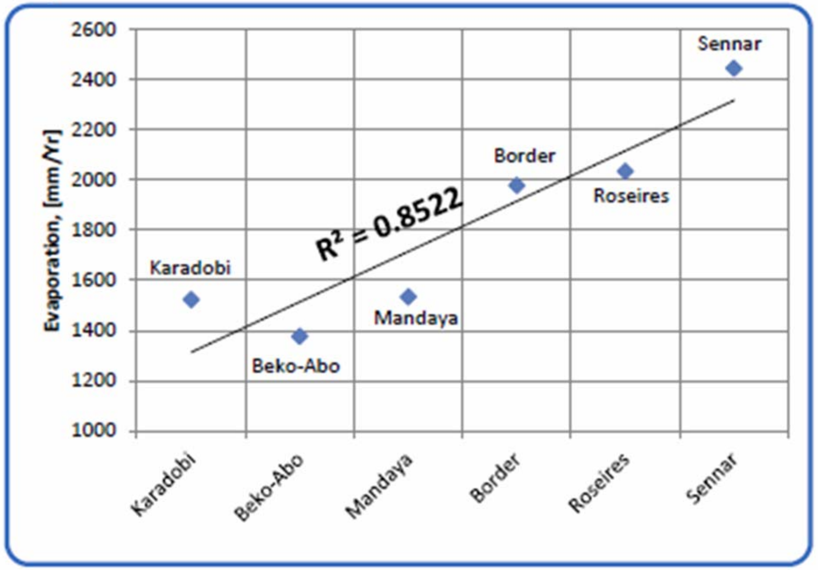
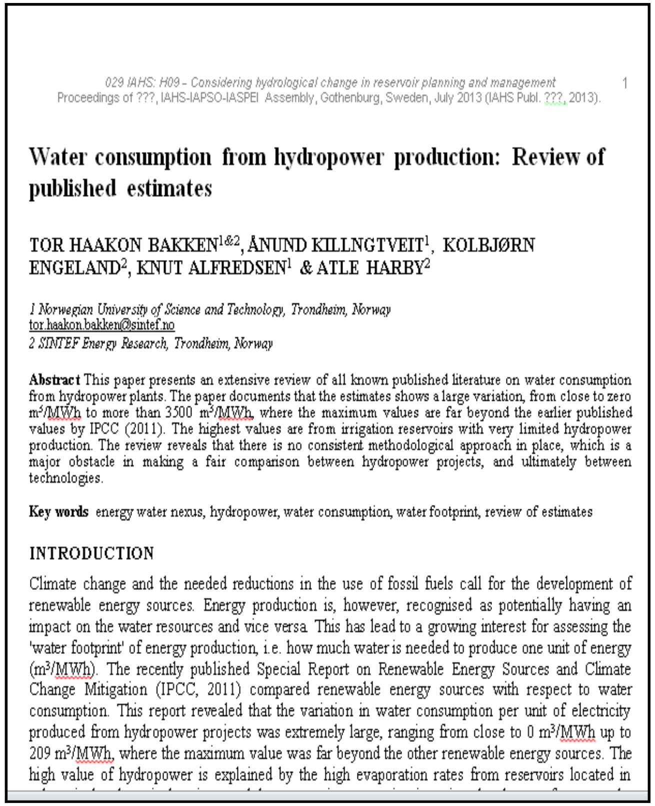


Figure 5-6 Evaporation rate (mm/Yr) of Blue Nile reservoirs.

Documentation



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Water consumption from hydropower production: Review of published estimates

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Abstract This paper presents an extensive review of all known published literature on water consumption from hydropower plants. The paper documents that the estimates shows a large variation, from close to zero m^3/MWh to more than 3500 m^3/MWh, where the maximum values are far beyond the earlier published values by IPCC (2011). The highest values are from irrigation reservoirs with very limited hydropower production. The review reveals that there is no consistent methodological approach in place, which is a major obstacle in making a fair comparison between hydropower projects, and ultimately between technologies.

Key words energy water nexus, hydropower, water consumption, water footprint, review of estimates

INTRODUCTION

Climate change and the needed reductions in the use of fossil fuels call for the development of renewable energy sources. Energy production is, however, recognised as potentially having an impact on the water resources and vice versa. This has lead to a growing interest for assessing the 'water footprint' of energy production, i.e. how much water is needed to produce one unit of energy (m^3/MWh). The recently published Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC, 2011) compared renewable energy sources with respect to water consumption. This report revealed that the variation in water consumption per unit of electricity produced from hydropower projects was extremely large, ranging from close to 0 m^3/MWh up to 209 m^3/MWh, where the maximum value was far beyond the other renewable energy sources. The high value of hydropower is explained by the high evaporation rates from reservoirs located in

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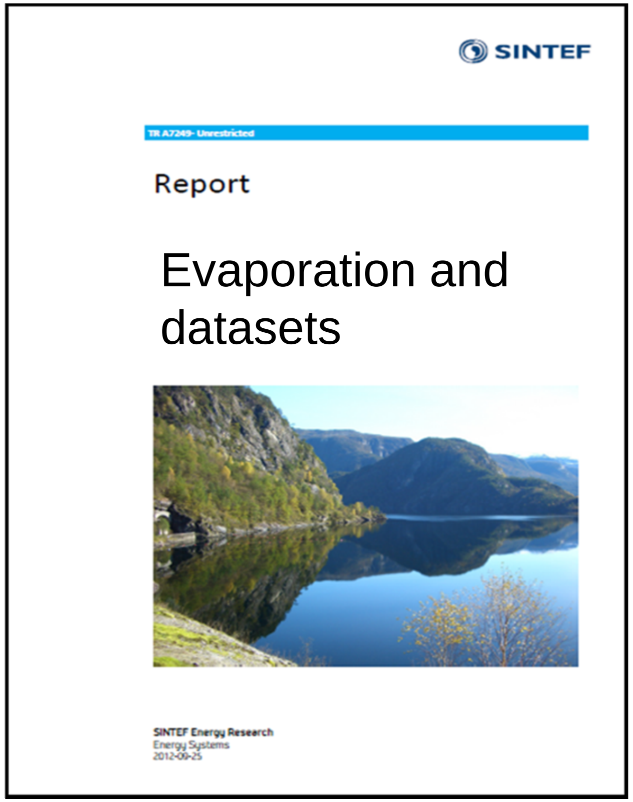

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