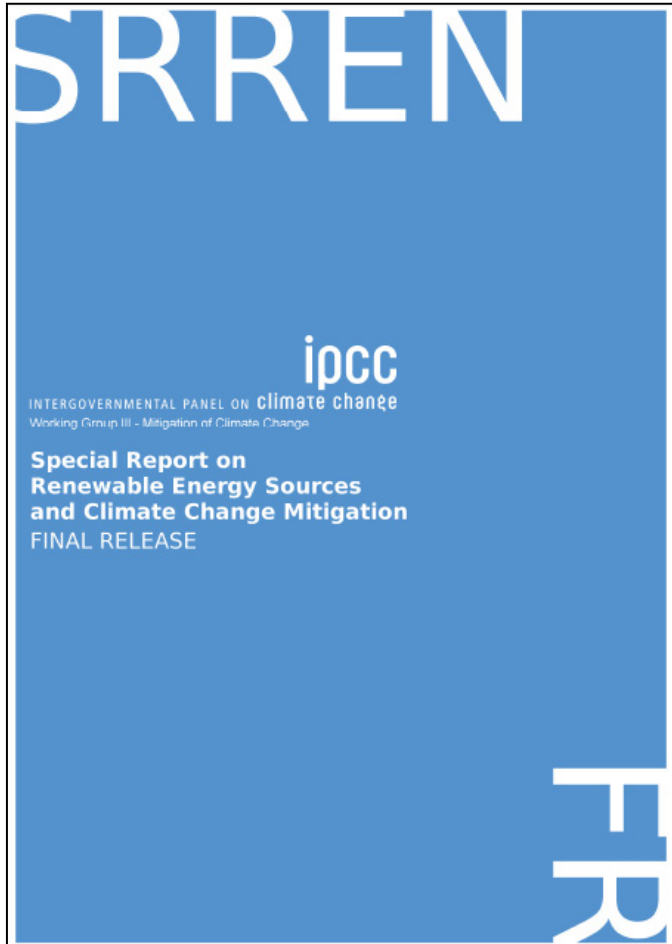


EcoManage WP3: Water consumption/footprint for hydropower

Ånund Killingtveit @NVE 21 Jan 2015



What raised the attention?

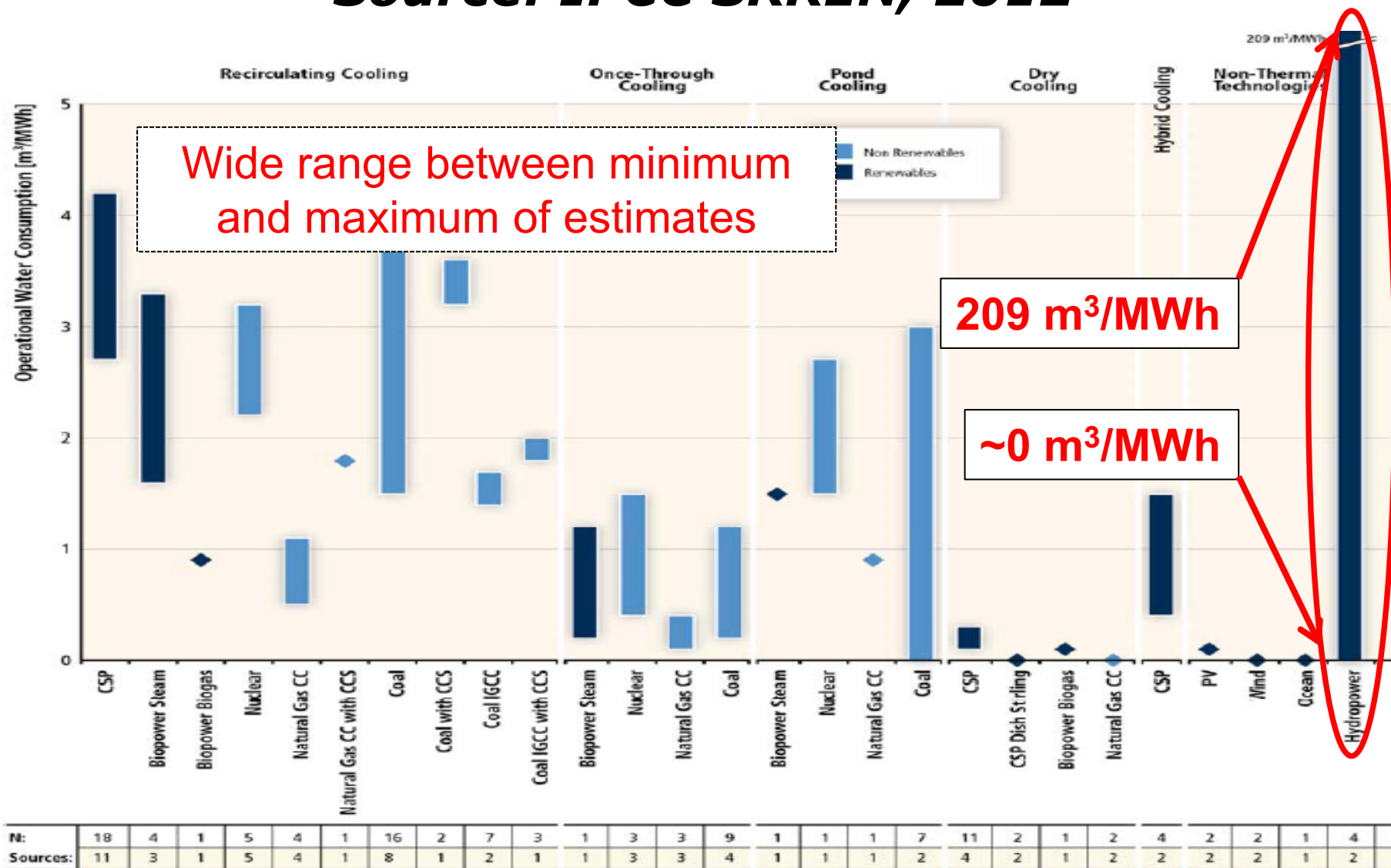


IPCC Special Report on Renewable Energy (2012):

- 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*)'

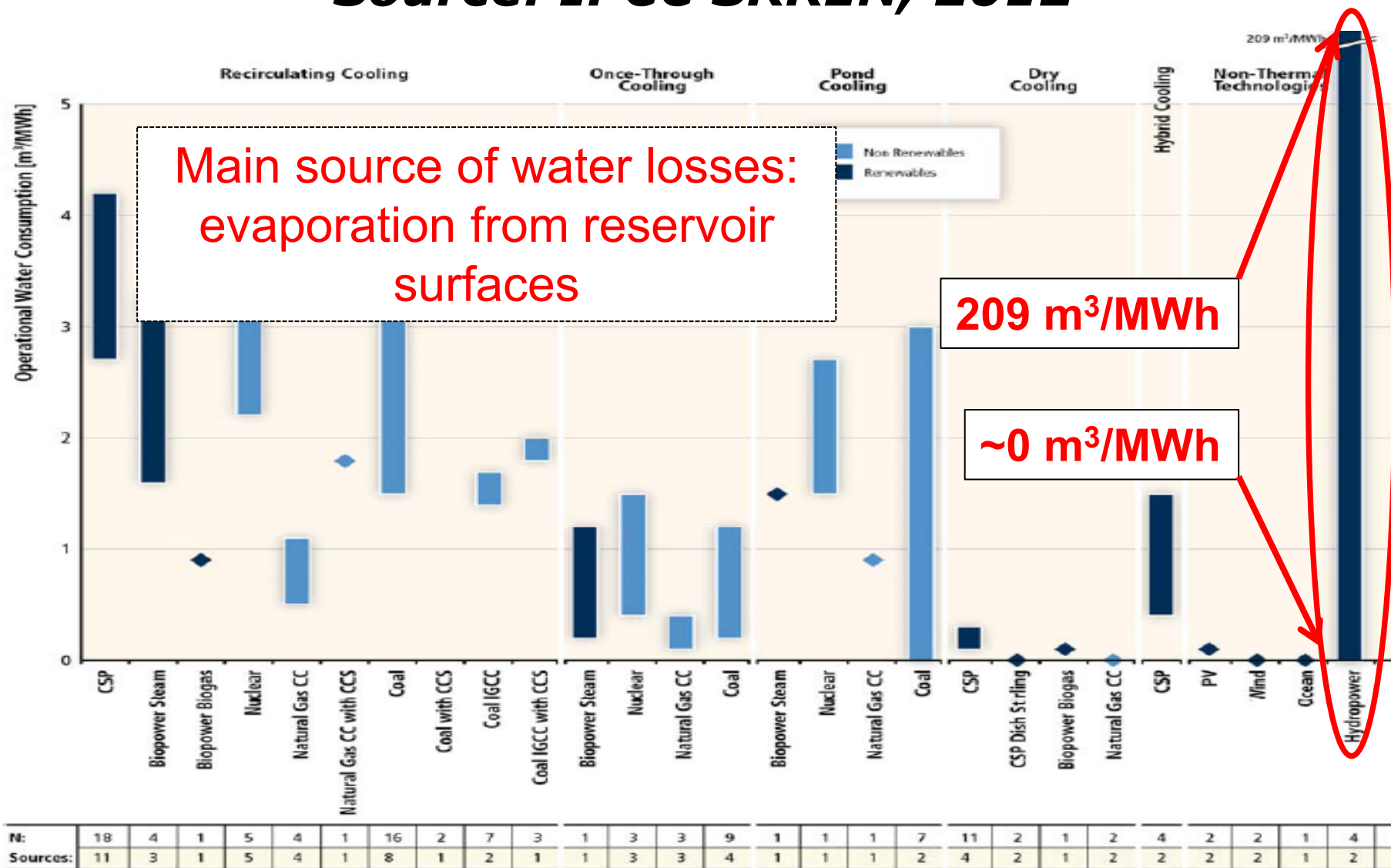
Water consumption from energy generation:

Source: IPCC SRREN, 2012



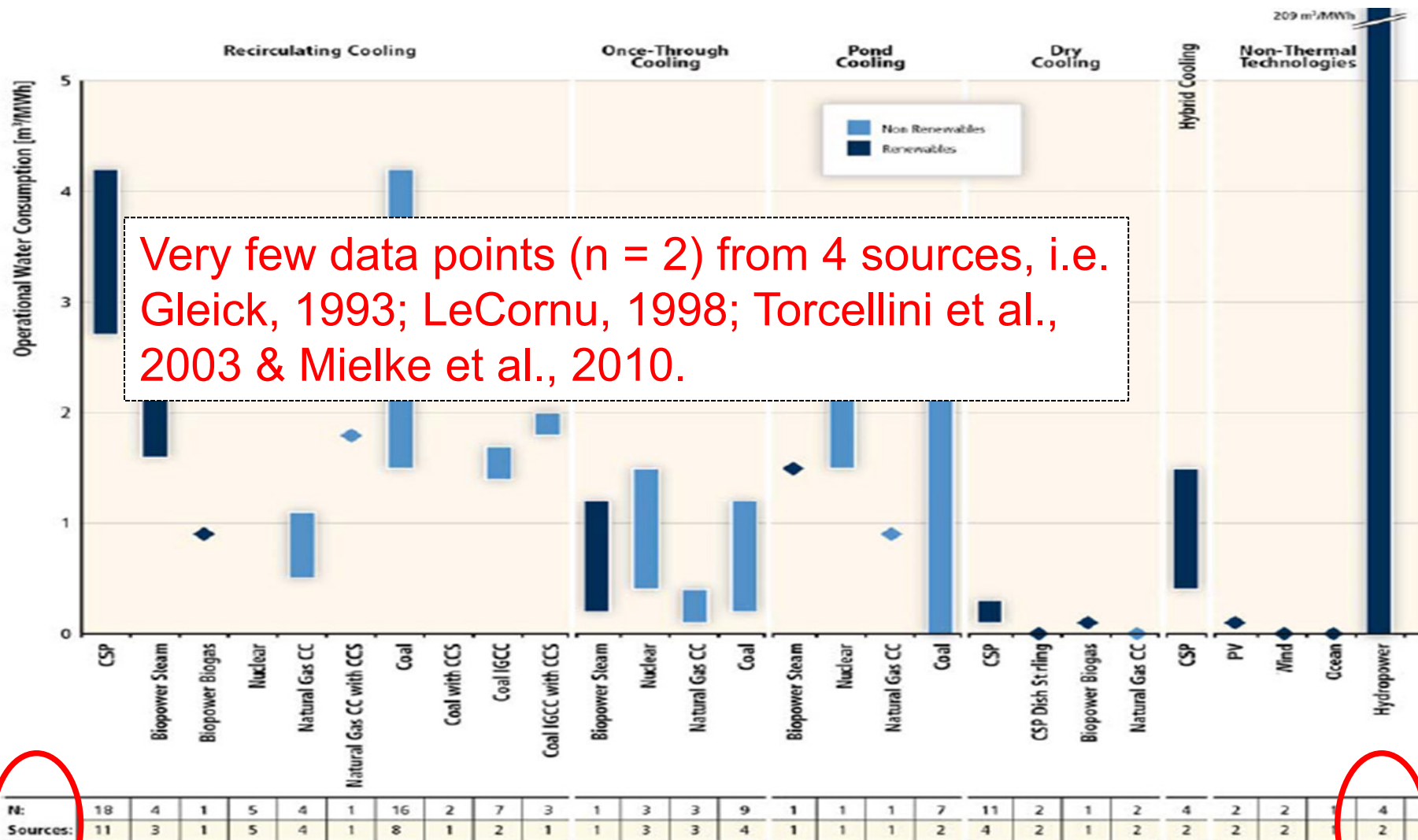
Water consumption from energy generation:

Source: IPCC SRREN, 2012



Water consumption from energy generation:

Source: IPCC SRREN, 2012



N: 18
Sources: 11

N: 4
Sources: 2

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.*

Water footprint of energy

Primary energy carriers		Global average water footprint (m ³ /GJ)
Non-renewable	Natural gas	0.11
	Coal	0.16
	Crude oil	1.06
	Uranium	0.09
Renewable	Wind energy	0.00
	Solar thermal energy	0.27
	Hydropower	22 (=80 litres/KWh)
	Biomass energy	70 (range: 10-250)

[Gerbens-Leenes, Hoekstra & Van der Meer, 2008]

Water footprints for energy: Water consumed by energy type

Energy Type	Water consumed (m ³ /MWh)
Wind	~0
Nuclear	0.3
Gas	0.4
Coal	0.6
Oil/Petrol	4
Hydropower	80
Bio-fuel (1 st gen.)	66-90

Source: UNESCO-IHE



ENERGY POLICY: Senate panel to take up hydropower, water use measures

(03/28/2011)

Katie Howell, E&E reporter

The Senate Energy and Natural Resources panel convenes Thursday to discuss three measures that address hydropower and the impact of energy development on water resources.

The committee's third legislative hearing this Congress will focus on two bills to boost hydropower in the United States and on the water section of the broad energy bill that passed out of the committee in 2009.

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

A hydropower dam and reservoir (Nyamba ya Mungu, Tanzania)

Evaporation loss from reservoir E_G (Gross evaporation)?

Evaporation loss from wetland area without the dam E_0 ?

Net evaporation loss $E_N = E_G - E_0$

Water is also used for Irrigation downstream

What is most important:
Lost water compared to regulated flow?



Basis for calculations

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

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

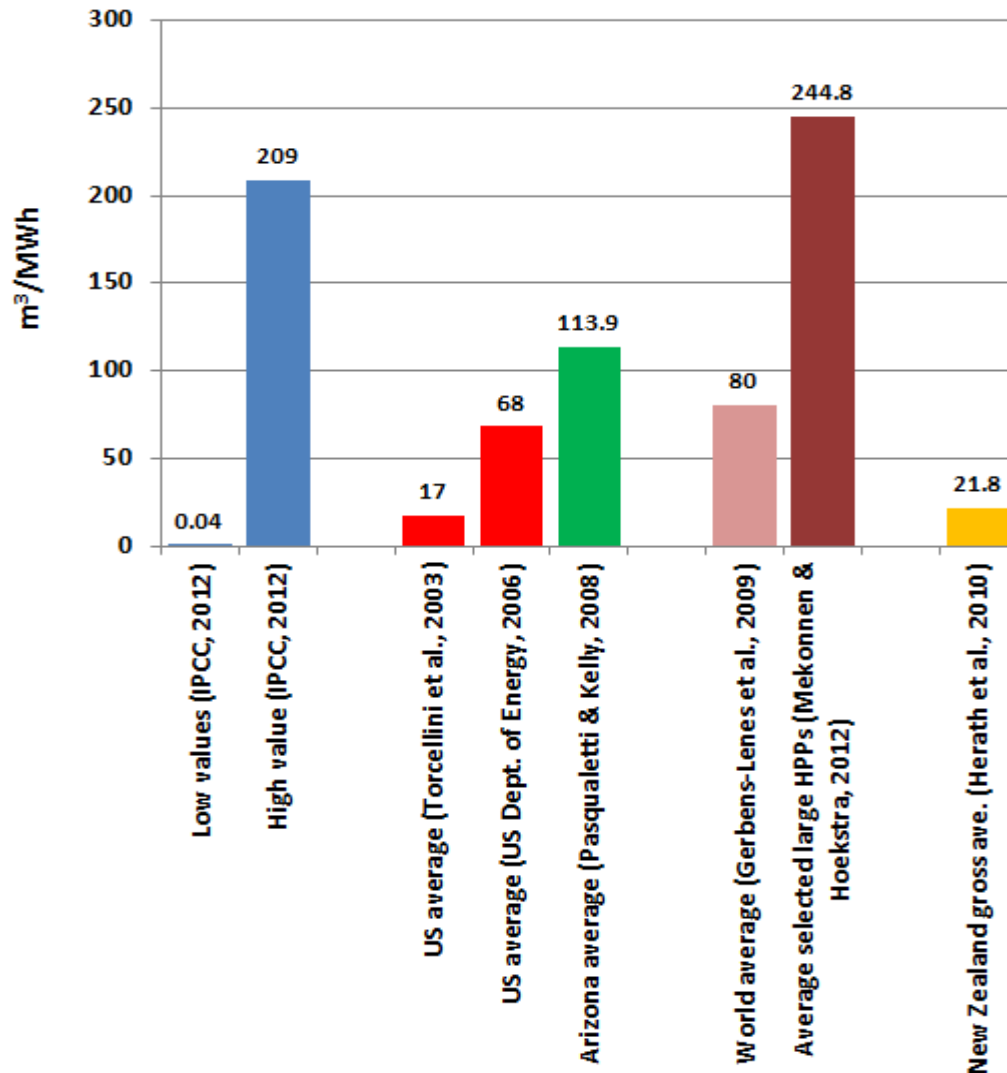
Water consumption from hydropower production: review of published estimates

Tor Haakon Bakken^{1&2}, Ånund Killingtveit¹,
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Selected benchmarks published – Gross values



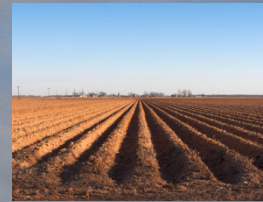
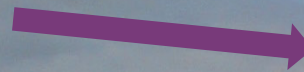
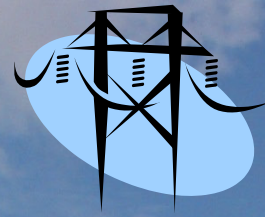
- ‘IPCC-values’
- US averages, based on 2 different datasets
- World average based on 2 different datasets
- 2 regional averages (Arizona and NZ)

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.

How to allocate the losses to the different uses of the reservoir?

Water losses - m^3/year



Functions of the reservoir



- Case studies:
- (1) India
 - (2) Egypt
 - (3) Spain
 - (4) Ethiopia – Blue Nile
 - (5) Ethiopia – Omo River
 - (6) Turkey
 - (7) Albania

Summed up

- The recently published values vary a lot and new studies are even far beyond values published by IPCC (2011).
- 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

Documentation

Considering Hydrological Change in Reservoir Planning and Management
Proceedings of HDS, IAHS-APSD-ASPE Assembly, Götterburg, Sweden, July 2013 (IAHS Publ. 362, 2013).

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 show a large variation, from close to zero (0 MWh) to more than 1500 m³/MWh, where the maximum values are far beyond the published values by IPCC (2012). The paper also presents an assessment of the impact of the different 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, water, 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 led to a growing interest in assessing the "water footprint" of energy production, i.e. how much water is needed to produce one unit of energy (in MWh). The recently published Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN, 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 m³/MWh up to 200 m³/MWh, where the maximum values were far beyond other renewable energy sources. The high value of water consumption from hydropower is explained by the high evaporation rates from reservoirs located in subtropical and tropical regions, and that reservoir evaporation is assigned as losses of water to the hydropower plants. The report (SRREN) suffers from very few studies as the range of estimates for hydropower is based on only two sources/studies, reported in four publications. Due to the very limited number of studies, it is also very difficult to diversify the projects based on location, type of projects (reservoir versus run-of-the-river, large versus small) or other characteristics. A recent study (Macknick *et al.*, 2011, 2012a) provides an updated review of estimates of operational water withdrawal and water consumption factors for electricity generating technologies (but only including studies from the US). These studies (IPCC, 2011; Macknick *et al.*, 2011, 2012a) do acknowledge that estimates of water consumption from hydropower production faces methodological challenges.

The methodological approach of calculating the water footprint of hydropower projects has been questioned and debated (e.g. Palmer & Halverson, 2009; EIA, 2011; Mekonnen & Hoekstra, 2011). The most well-known water footprint method is presented in Mekonnen & Hoekstra (2011) and defines the water footprint from hydropower to be the gross evaporation from the reservoir. This method misses several essential aspects. Firstly it does not take into account the evaporation from the reservoir area prior to the hydropower project and provides therefore no information on net change in ambient water balance. Secondly, in the case of run-of-the-river hydropower, the water consumption is in most cases not shared between the various water uses, but is only assigned to the hydropower plant. Thirdly, the fact that reservoirs could improve the availability of water both in the reservoir area and the downstream area due to its regulating effect is not accounted for, as well as other services provided by the regulation, such as flood control, improved navigation, etc. Furthermore, Sills *et al.* (2005) emphasises the importance of reservoirs as a measures against impacts on the water resources due to climate change.

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Bakken, T.H., Killingtveit, Å., Engeland, K., Alfredsen, K., & Harby, A. (2013) Water consumption from hydropower production: review of published estimates. IAHS-AISH publication. volume 362.

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Water Allocation With Use of the Building Block Methodology (BBM) in the Godavari Basin, India

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Abstract

Access to sufficient quantities of water of acceptable quality is a basic need for human beings and a pre-requisite to sustain and develop human welfare. In cases of limited availability, the allocation of water between different sectors can result in conflicts of interests. In this study, a modified version of the Building Block Methodology (BBM) was demonstrated for allocation of waters between different sectors. The methodology is a workshop-based tool for assessing water allocation between competing sectors that requires extensive stakeholder involvement. The tool was demonstrated for allocation of water in the Sri Ravi Sagar reservoir in the Godavari Basin, Andhra Pradesh, India. In this multipurpose reservoir, water is used for irrigation, drinking water supply and hydropower production. Possible water allocation regimes were developed under present hydrological conditions (normal and dry years) and under future climate change, characterized by more rain in the rainy season, more frequent droughts in the dry season and accelerated siltation of the reservoir, thus reducing the storage capacity. The feedback from the stakeholders (mainly water managers representing the various sectors) showed that the modified version of the BBM was a practical and useful tool in water allocation, which means that it may be a viable tool for application also elsewhere.

Keywords: optimal water allocation, building block methodology (BBM), climate change, Godavari Basin, India

1. Introduction

Water is essential for all types of basic services, such as food production, supply of drinking water, health and sanitation services, industrial production and for maintaining the earth's ecosystems. In India, investments in the water sector have primarily focused on irrigation projects with the aim to expand the area under irrigated agriculture and increase the food production. Other sectors also experience growing needs, such as drinking water supply, process-water to the industry, water for hydropower production, water to secure navigation and for recreational services (Ammersbach *et al.*, 2005; Chandra, 2002). There are also inherent dependencies between some of the water uses, exemplified by the fact that the majority of irrigation projects in India have provisions for generation of power. The availability of water is to a large extent dependent on climatological and hydrological characteristics, and the water resources in India are not evenly distributed in time and space (Gosain *et al.*, 2006; Kakumanu, 2009). One part of the country might experience floods and water logging problems, while other parts might need to cope with droughts and scarcity at the same time. In periods when the need for water is larger than the supply, practical tools to assist in the allocation of water between competing sectors can be useful. Such tools may also reduce the tension between the different interests.

Bakken, T.H., Skarbøvik, E., Gosain, A.K., Palanisami, K.; Sauterleute, J., Egeland, H., Kakumanu, K.R., Nagothu, S., Harby, A., Tirupataiah, K., & Stålnacke, P. (2013) Water Allocation With Use of the Building Block Methodology (BBM) in the Godavari Basin, India. Journal of Sustainable Development. volume 6 (8).

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Water consumption from hydropower plants – review of published estimates and an assessment of the concept

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²SINTEF Energy Research, 7465 Trondheim, Norway

Abstract. Since the report from IPCC on renewable energy (IPCC, 2012) was published; more studies on water consumption from hydropower have become available. The newly published studies do not, however, contribute to a more consistent picture on what the "true" water consumption from hydropower plants is. The dominant calculation method is the gross evaporation

Review Status
This discussion paper is under review for the Journal Hydrology and Earth System Sciences (HESS).

Bakken, T.H., Killingtveit, Å., Engeland, K., Alfredsen, K., & Harby, A. (2013). Water consumption from hydropower plants – review of published estimates and an assessment of the concept. Hydrology and Earth System Sciences. volume 17.

Master: Lake Turkana

Documentation



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Norwegian University of
Science and Technology

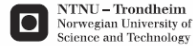
Impacts of Cascade Hydropower Plants
on the flow of the River System and
Water level in Lake Turkana in
Omo-Ghibe Catchment, Ethiopia

Mamuye Busier Yesuf

Hydropower Development
Submission date: June 2012
Supervisor: Ånund Killingtveit, IVM

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Master: Blue Nile



NTNU – Trondheim
Norwegian University of
Science and Technology

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

Muez Araya
Tefferi

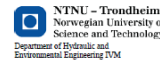
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Norwegian University of Science and Technology
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Master: Water indices



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Norwegian University of
Science and Technology
Department of Hydraulic and
Environmental Engineering IVM

Academic paper
submitted to attain the degree of

“Master of Science”

in the degree course Environmental Engineering

at the
Department of Hydraulic Engineering

of

Prof. Dr.-Ing. habil. Andreas Dittrich

Evaluation of methods measuring the water consumption
of hydropower

Handed in by:
Steen Weichert
Matr.-Nr.: 3019020

Assistant Professor:
Knut Alfredsen
Professor, IVM, NTNU

Supervisor:
Tor Håakon Bakkén
PhD Candidate, IVM, NTNU

Braunschweig, 19th November 2013

Master: Tydalen



Estimation of evaporation
from a Penman-Monteith
model, parameterized from
Eddy-Covariance
measurements

V
g

Phillip Thumser

zum
Erlangen des akademischen Grades

DIPLOMINGENIEUR
(Dipl.-Ing.)

Betreuer: Bruno Giordano