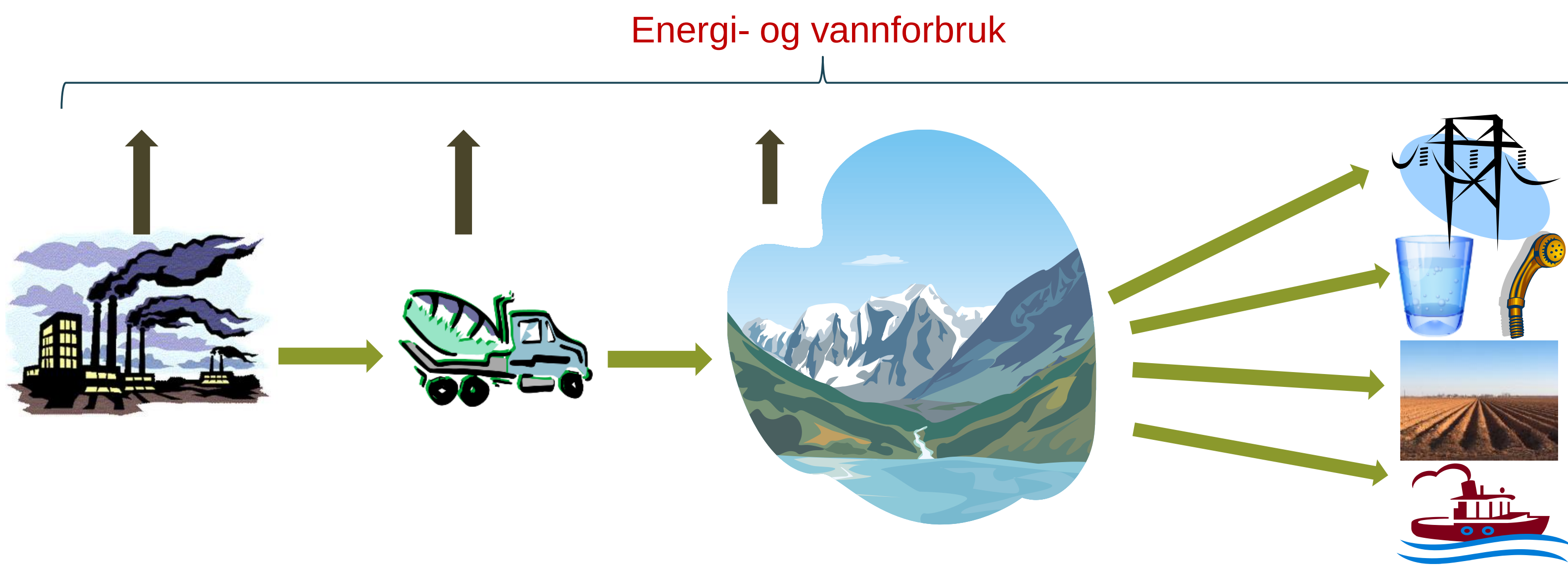
Østfoldforskning

SUSTAINABLEINNOVATION

Miljøvurdering av vasskraft i eit livsløpsperspektiv: bruk av ulike indikatorar for energi- og vannforbruk

Energy Payback Ratio og Cumulative energy Demand (EPR og CED)
Water footprint og water scarcity
Systemgrenser, allokering og regionalisering



EcoManage brukermøte torsdag 12. november 2014 – WP 2: Energiindikatorar

Ingunn Saur Modahl og Hanne Lerche Raadal

Innhald

1. Energiindikatorar (EPR og CED) brukt på elproduksjon

- Resultat for ulike teknologiar, fokus på systemgrenser.
- Rapport + artikkel i Energy Policy (2013): «How methodological issues affect the energy indicator results for different electricity generation technologies».
- Forfattarar: Ingunn Saur Modahl, Hanne Lerche Raadal, Luc Gagnon og Tor Haakon Bakken.

2. Allokering i fleirbruksmagasin

- Systemgrenser = aktuelt for alle indikatorar.
- Innsendt artikkel til Water Policy (2015): «Allocation recommendations for multipurpose reservoirs - results for water consumption».
- Forfattarar: T. H. Bakken, I. S. Modahl, H. L. Raadal, A. A. Bustos og S. Arnøy.

3. Vannfotavtrykk for vasskraft

- Vannknappheit (water scarcity) for heile verdikjeda (konstruksjon og drift) til to vasskraftanlegg.
- Innsendt artikkel til Journal of Cleaner Production (2015): «The life-cycle water footprint of two hydropower projects in Norway» (revisjon innsendt i august).
- Forfattarar: T. H. Bakken, I.S. Modahl, K. Engeland, H. L. Raadal og S. Arnøy.

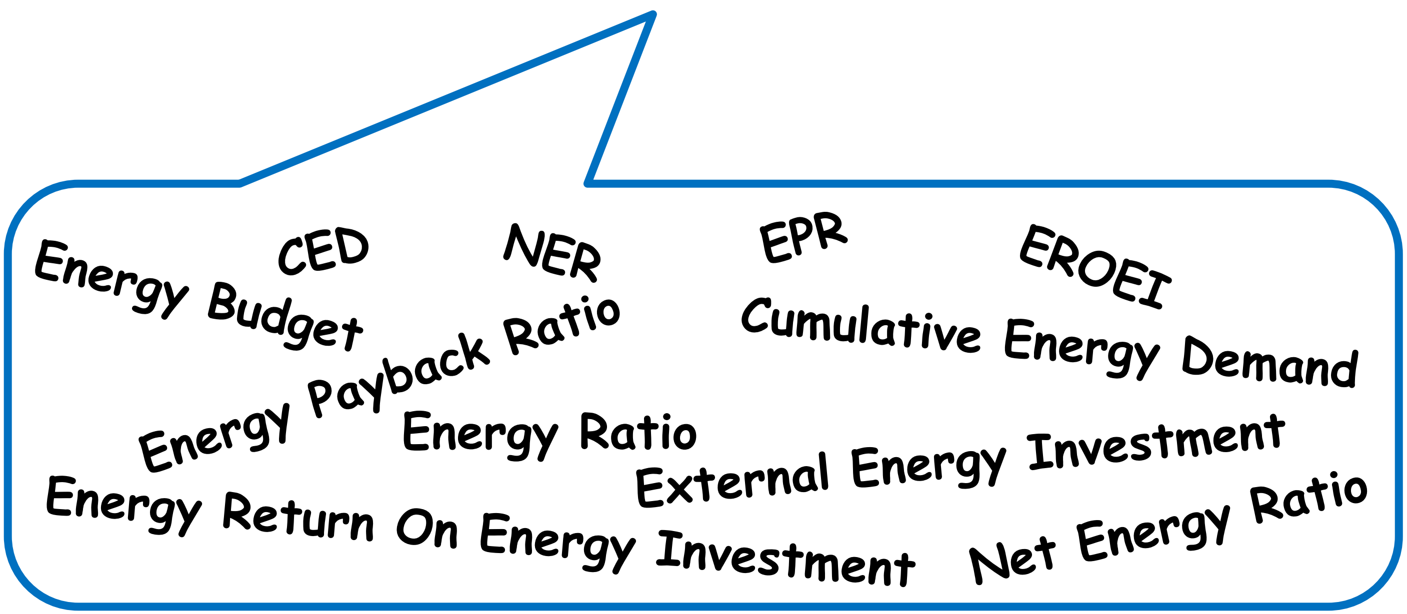
4. Regionalisering av vannfotavtrykk/water scarcity

- Gjennomførte beregningar av fordamping og water scarcity ved «flytting» av Follsjøen (Trollheim) til Canada, Kina, Etiopia, New Zealand, California og Florida.
- Planlagt artikkel til Journal of Cleaner Production.

5. Presentasjon på Life Cycle Management 2015 Bordeaux 2.september 2015

1. Energiindikatorar

"Assessment of major electricity generation technologies based on different energy indicators – the effect of system boundaries"

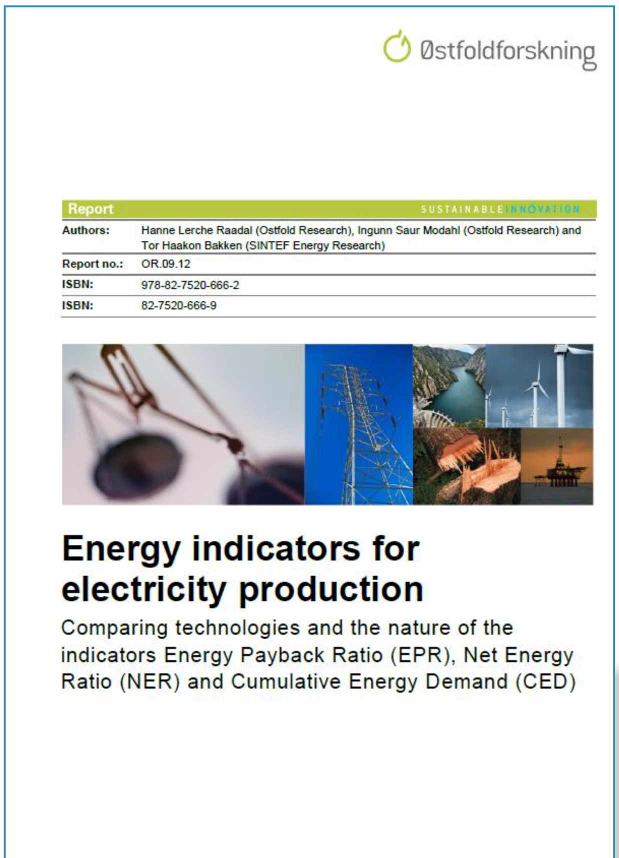


Ingunn Saur Modahl and Hanne Lerche Raadal (both Ostfold Research, Norway), Luc Gagnon (Energy and Climate Change consultant, Canada) and Tor Haakon Bakken (SINTEF Energy Research, Norway)*
** Stadion 4, 1671 Kråkerøy, Norway. E-mail: ism@ostfoldforskning.no*

Mål

- Auke forståinga av resultata ved samanlikning av energiprodukt.
- Korleis kan systemgrenser påverke resultata for dei ulike energiindikatorane? Basert på resultat for vasskraft, vindkraft og elektrisitet frå biomasse, gass og kol.

http://www.sciencedirect.com/science/article/pii/S0301421513009294



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Report SUSTAINABLEINNOVATION

Authors:	Hanne Lerche Raadal (Ostfold Research), Ingunn Saur Modahl (Ostfold Research) and Tor Haakon Bakken (SINTEF Energy Research)
Report no.:	OR.09.12
ISBN:	978-82-7520-666-2
ISBN:	82-7520-666-9

Energy indicators for electricity production

Comparing technologies and the nature of the indicators Energy Payback Ratio (EPR), Net Energy Ratio (NER) and Cumulative Energy Demand (CED)

How methodological issue... × HESS - Abstract - Water co... ×

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2. Life-cycle energy indicators: Their de...
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4. Discussion
5. Conclusions
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ELSEVIER

Energy Policy

Volume 63, December 2013, Pages 283–299

How methodological issues affect the energy indicator results for different electricity generation technologies

Ingunn Saur Modahl[a], Hanne Lerche Raadal[a], Luc Gagnon[b], Tor Haakon Bakken[c]

Show more

DOI: 10.1016/j.enpol.2013.09.005

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Highlights

- There is a need for stricter standardisation of energy performance assessments.
- System boundaries for renewable sources should be harmonised.
- One should focus on a smaller set of indicators. CED should be included.

Abstract

The aim of this paper is to improve the basis for the comparison of energy products. The paper will discuss important methodological issues with regard to various energy indicators and it will, by means of a few selected energy indicators, show examples of results for hydropower, wind power and electricity from biomass, gas and coal. Lastly it will suggest methods to achieve results which are more consistent when comparing electricity production technologies.

In general, methodological issues can affect the results of life cycle assessments. In this paper, the authors have focused on the effect of system boundaries for energy indicators and found that the internal ranking of cases within one electricity generation technology is dependent on the indicator used. These variations do not, however, alter the general ranking of the major technologies studied.

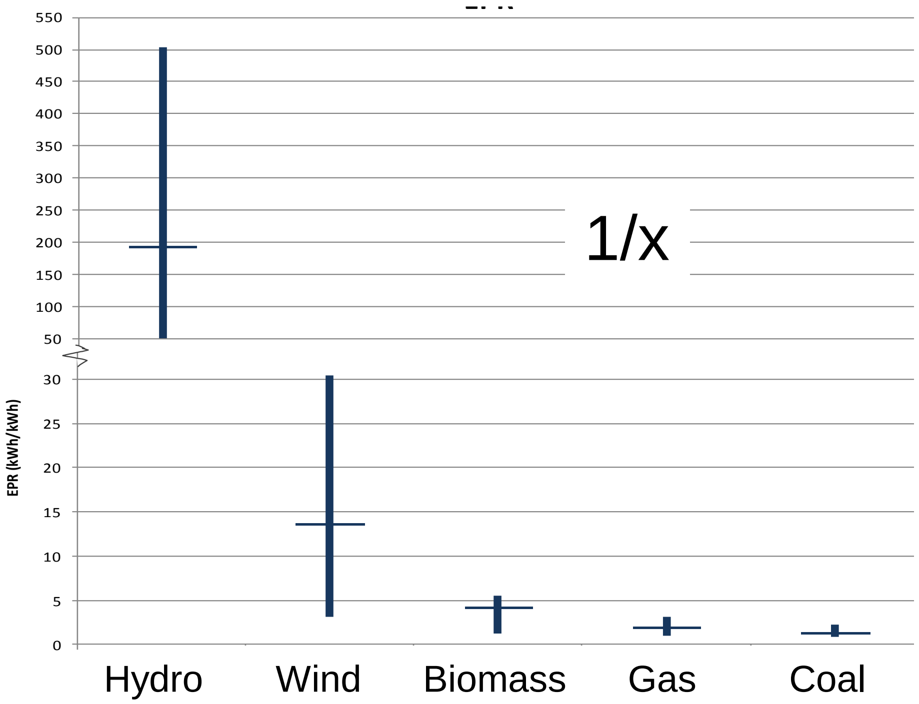
The authors suggest that future assessments should focus on a smaller set of indicators: the Cumulative Energy Demand (CED), which is the most "universal" indicator, Energy Payback Ratio (EPR) for assessment of upstream activities, and a suggested "Cumulative Fossil Energy Demand" (CFED) for resource depletion assessments. There is also a need for stricter standardisation and increased transparency in the assessment of energy products.

Keywords

Resultat for elektrisitet produsert av ulike teknologiar

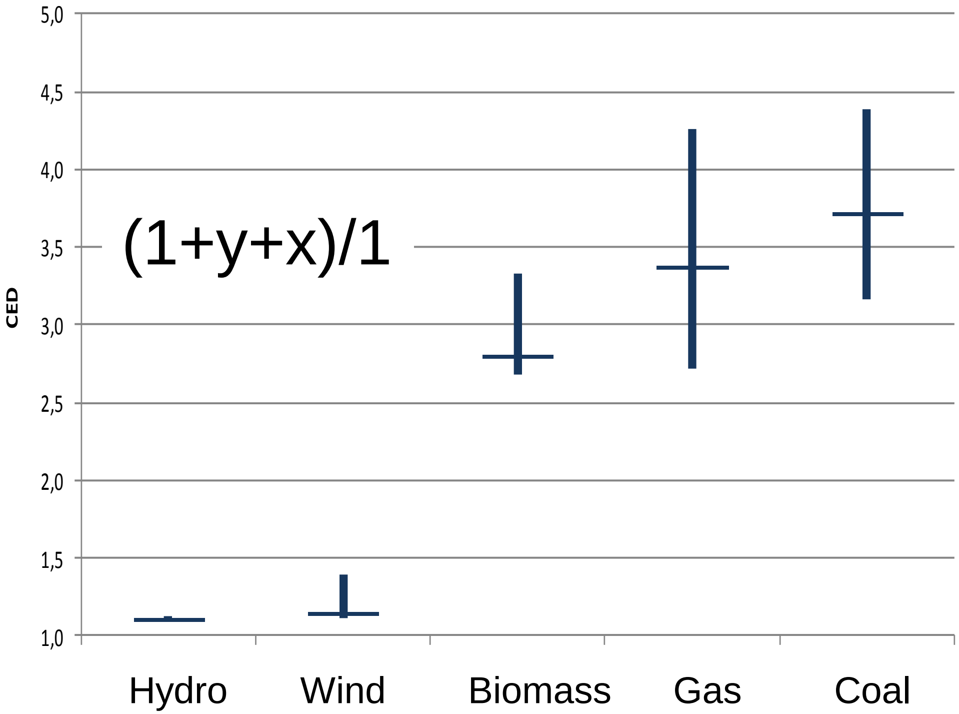
EPR=Energy Payback Ratio

Høg verdi = høg energieffektivitet



CED=Cumulative Energy Demand

Låg verdi = høg energieffektivitet



EPR = mengde energiprodukt/investert energi (inkluderer ikkje iboande energi i brenslet)

CED = brukt energi/mengde energiprodukt (inkluderer iboande energi i brenslet)

Kostnadsanalogi:

Kapitalkostnad per km eller totalkostnad per km?

(EPR tar ikkje med kor effektivt ein utnytter «brenslet»)

Kapitalkostnad →

Drivstoff →

→ Total kjørelengde

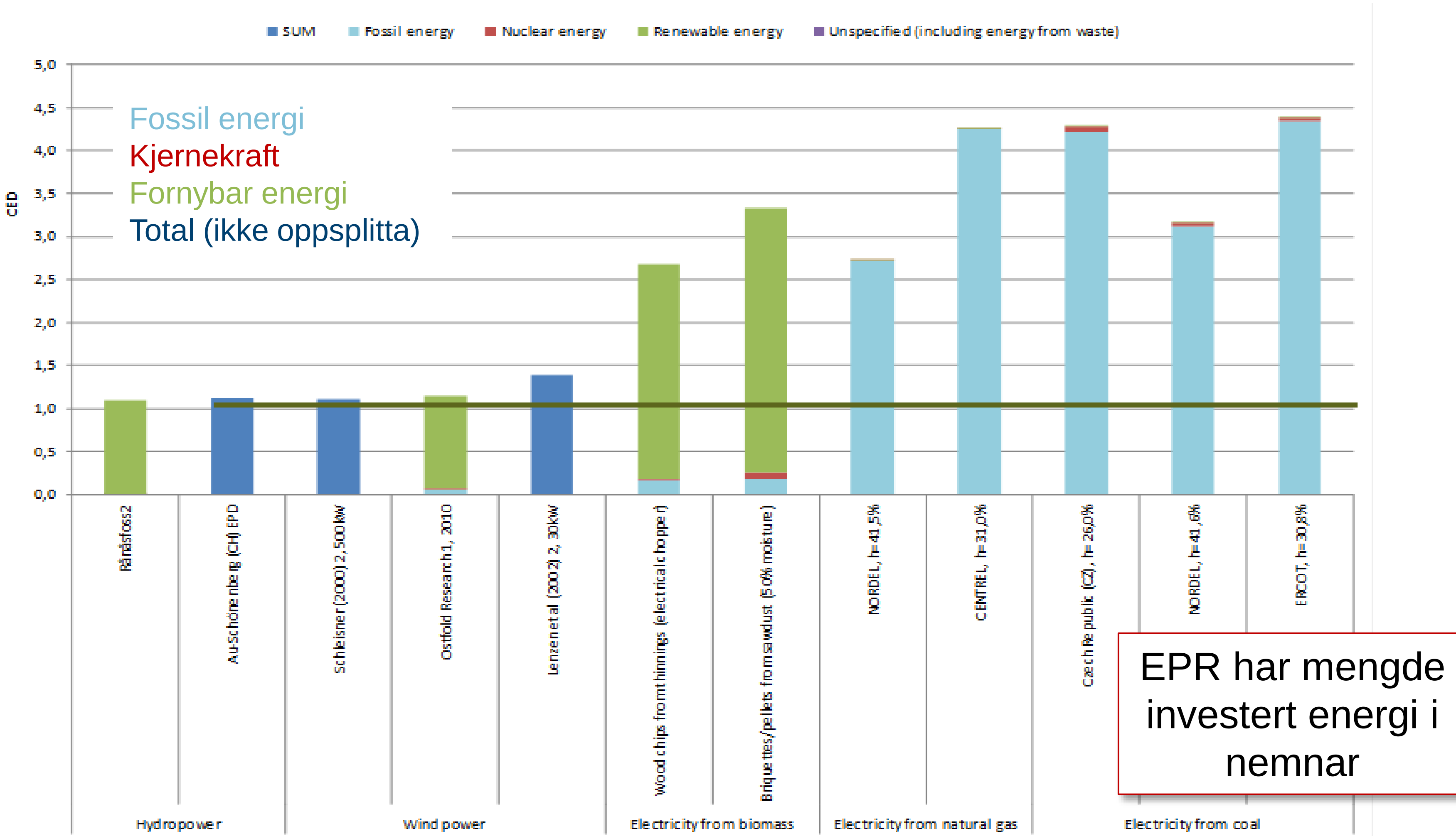
Kapitalkostnad →

Drivstoff →

→ Total kjørelengde

Resultat for ulike energiteknologiar

CED fordelt på energikjelder



”Research highlights” frå artikkelen om energiindikatorar

- Det trengs ei strengare standardisering ved vurderingar av energiytelse (energy performance assessments).
- Systemgrensene for fornybare energikjelder bør harmoniserast.
- Ein bør fokusere på færre indikatorar. CED bør alltid inkluderast som ein av indikatorane.

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2. Allokering i fleirbruksmagasin

«Allocation recommendations for multipurpose reservoirs - results for water consumption»

Tor Haakon Bakken[1&2], Ingunn Saur Modahl[3], Hanne Lerche Raadal[3],

Ana Adeva Bustos[2&4] & Silje Arnøy[3]

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Østfoldforskning

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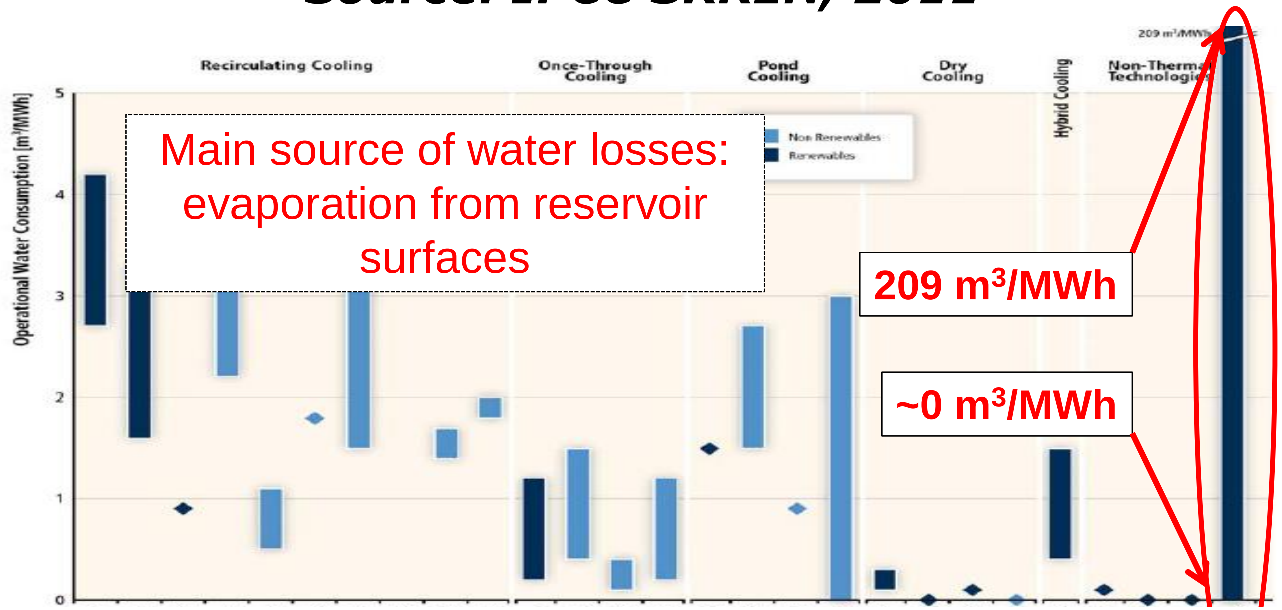
Background

Water consumption from energy generation:
Source: IPCC SRREN, 2011



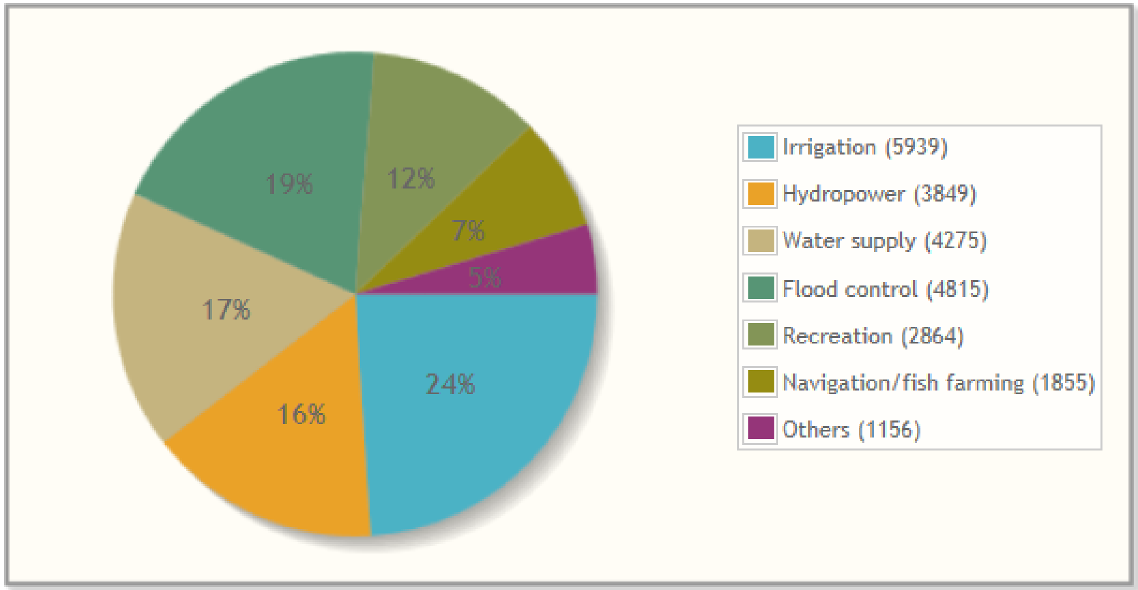
Weak methodology

- Limited number of cases
- Unclear definition of spatial and temporal boundaries of the study area
  - Only the operational phase is included
  - HP: calculations based on gross evaporation rates

Inga allokering bak IPCC-resultata

Kva er hovedformålet med fleirbruksmagasin?

ICOLD: Blant 9423 registrerte store dammar med kraftproduksjon, har meir enn 40% fleire funksjonar.

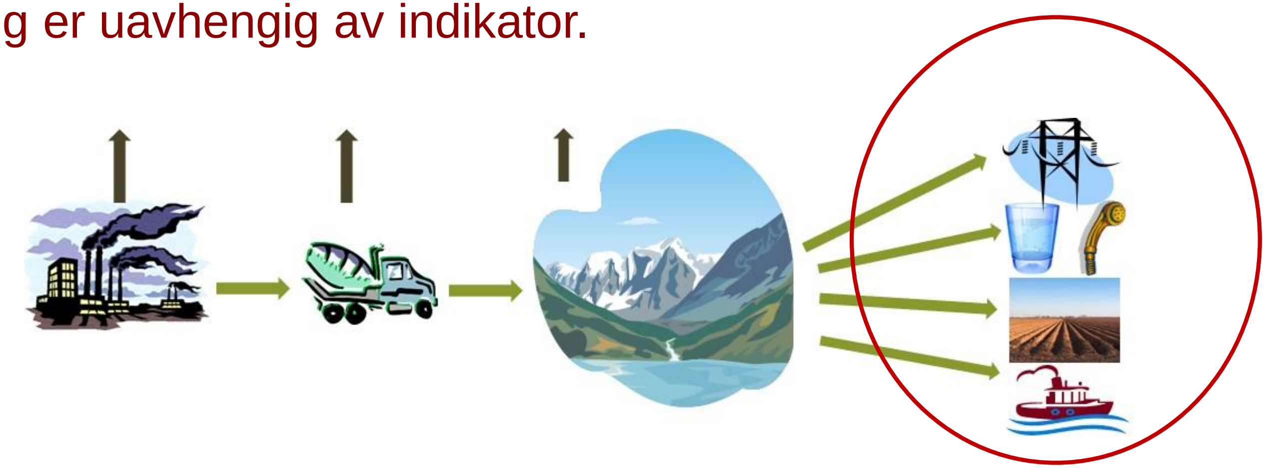


Source: ICOLD

Recommendations

- We consider <u>volume allocation</u> to be the most robust approach for allocating water consumption between competing functions in multipurpose reservoirs.

- Anbefalingane gjeld ikkje berre vannforbruk, men alle indikatorar. Også energieffektivitet og klimagassar (ref. IPCC, 2014), pga at valgt allokering er uavhengig av indikator.



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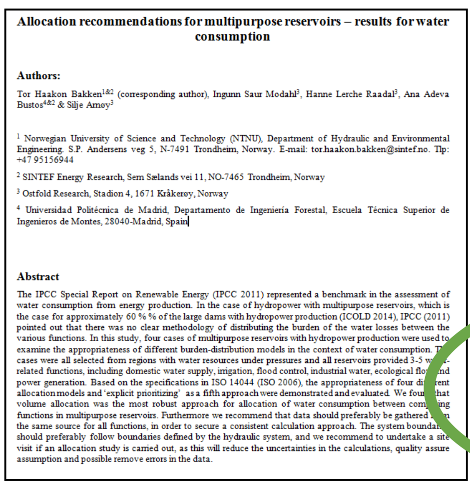
Dokumentasjon og bruk

Innspel i revisjonsprosessen av PCR for vasskraft.

Innsendt artikkel (Bakken et al. 2014)



Allocation recommendations for multipurpose reservoirs – results for water consumption

Authors:

Tor Haakon Bakken[1&2] (corresponding author), Ingunn Saur Modahl[3], Hanne Lerche Raadal[3], Ana Adeva Bustos[4&2] & Silje Arnøy[3]

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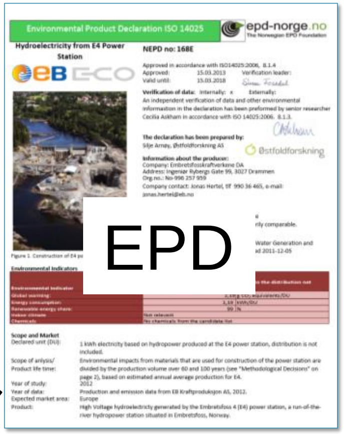
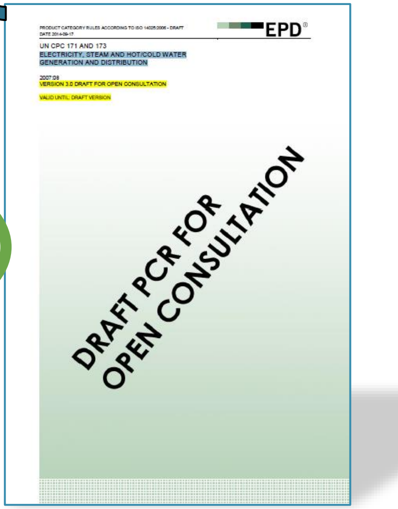
Abstract

The IPCC Special Report on Renewable Energy (IPCC 2011) represented a benchmark in the assessment of water consumption from energy production. In the case of hydropower with multipurpose reservoirs, which is the case for approximately 60 % % of the large dams with hydropower production (ICOLD 2014), IPCC (2011) pointed out that there was no clear methodology of distributing the burden of the water losses between the various functions. In this study, four cases of multipurpose reservoirs with hydropower production were used to examine the appropriateness of different burden-distribution models in the context of water consumption. T[illegible] cases were all selected from regions with water resources under pressures and all reservoirs provided 3-5 w[illegible]-related functions, including domestic water supply, irrigation, flood control, industrial water, ecological flo[illegible] and power generation. Based on the specifications in ISO 14044 (ISO 2006), the appropriateness of four di[illegible]rent allocation models and 'explicit prioritizing' as a fifth approach were demonstrated and evaluated. We fou[illegible] that volume allocation was the most robust approach for allocation of water consumption between com[illegible]ing functions in multipurpose reservoirs. Furthermore we recommend that data should preferably be gathered [illegible] the same source for all functions, in order to secure a consistent calculation approach. The system boundar[illegible] should preferably follow boundaries defined by the hydraulic system, and we recommend to undertake a site visit if an allocation study is carried out, as this will reduce the uncertainties in the calculations, quality assure assumption and possible remove errors in the data.

Version 3.0 Draft for open consultation: *The construction of dams is a prerequisite for regulation of water flows in a water course. Large dams may also represent reservoirs with multipurpose functions, such as irrigation, flood control, and water supply, in addition to hydropower generation. In such cases, allocation of the burdens from the dam infrastructure between the different functions (irrigation, flood control, water supply and hydropower generation) should therefore be considered. The allocation approach shall be described and motivated in the EPD.*



Godkjent



3. Vannfotavtrykk (water scarcity) for vasskraft

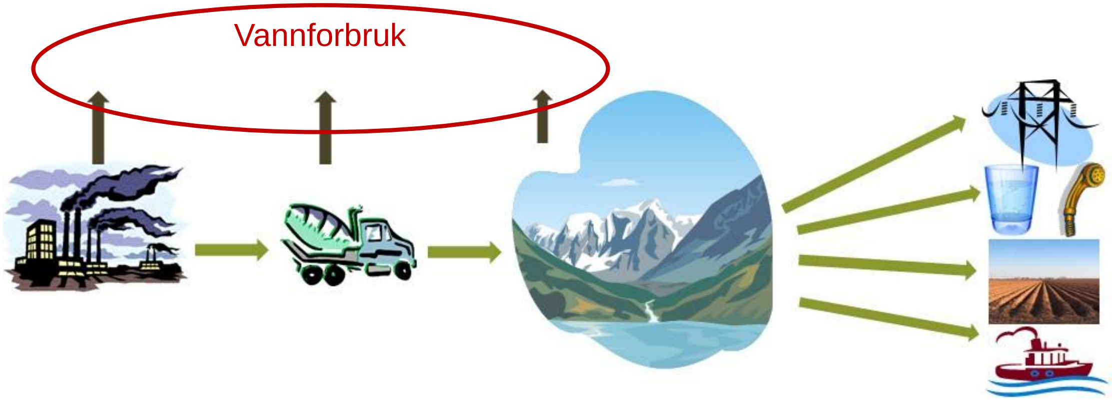
Innsendt og revidert artikkel:

"The life-cycle water footprint of two hydropower projects in Norway"

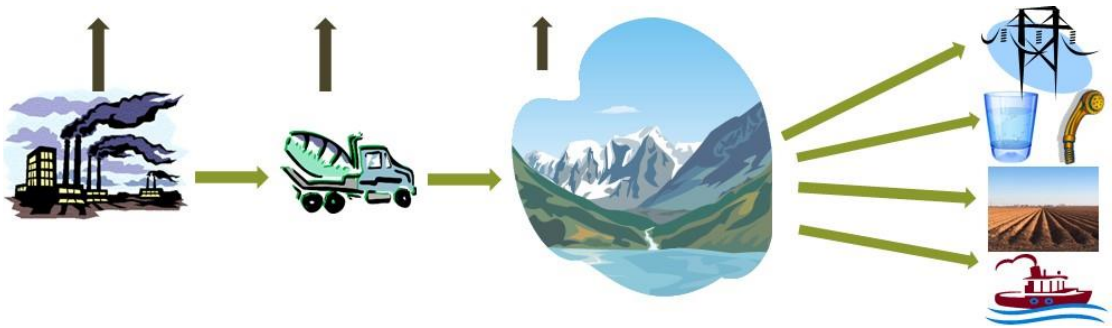
Tor Haakon Bakken, Ingunn Saur Modahl, Kolbjørn Engeland, Hanne Lerche Raadal og Silje Arnøy

Hovedtema i artikkelen

- Kva er vannforbruket over livsløpet for norsk vannkraft?
- Kor viktig er fordamping frå dam/vannvegar?



Bakgrunn



- Det er antatt at vannforbruket for vasskraft er dominert av den operative fasen/fordamping (Inhaber, 2004; Fthenakis & Kim, 2010; Pfister et al., 2011; Mekonnen & Hoekstra, 2012). Dette er derimot ikkje godt nok dokumentert.
- Korleis er forholdet mellom vannforbruk frå fordamping samanlikna med vannforbruk ved konstruksjon og drift?

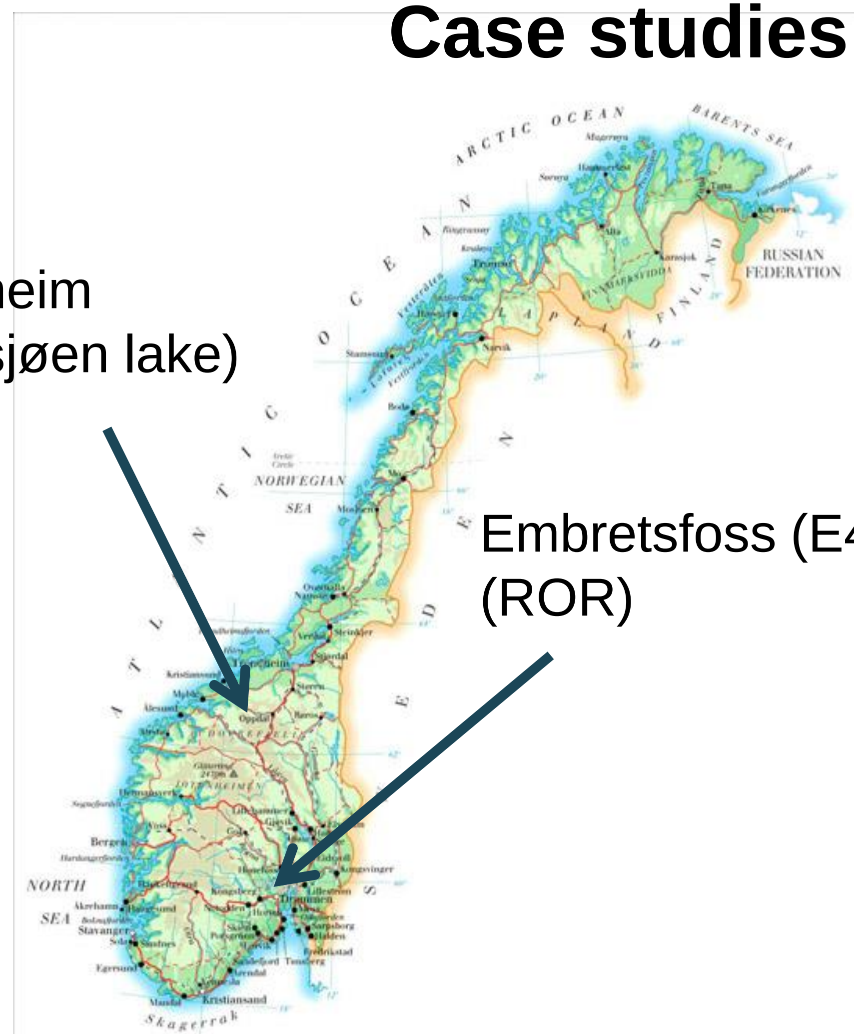
Aukande interesse for beregning og dokumentasjon av vannforbruk for både produkt og tenester.

Det finnst få vannforbruk-beregningar på vasskraft, og dei fleste har berre konsentrert seg om fordamping.

Metodikken har vore kritisert pga:

- Beregningar basert på brutto fordampingsverdiar
- Manglande allokering mellom parallelle funksjonar
- Uklare systemgrenser i tid og rom

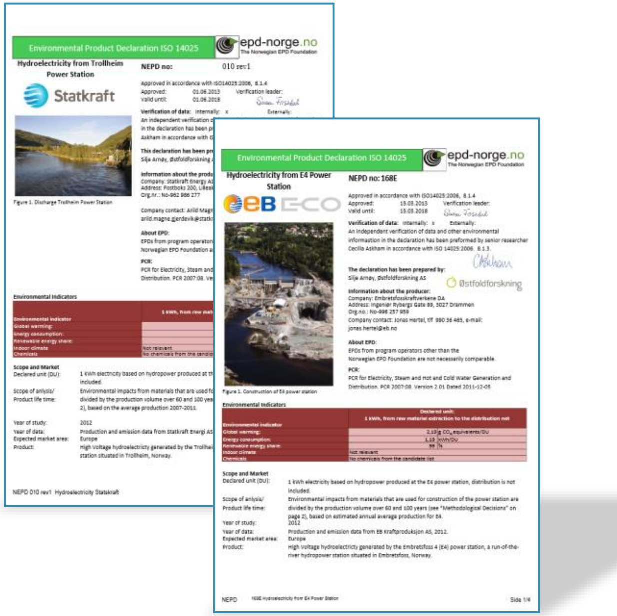
Case studies Norway



Trollheim
(Follsjøen lake)

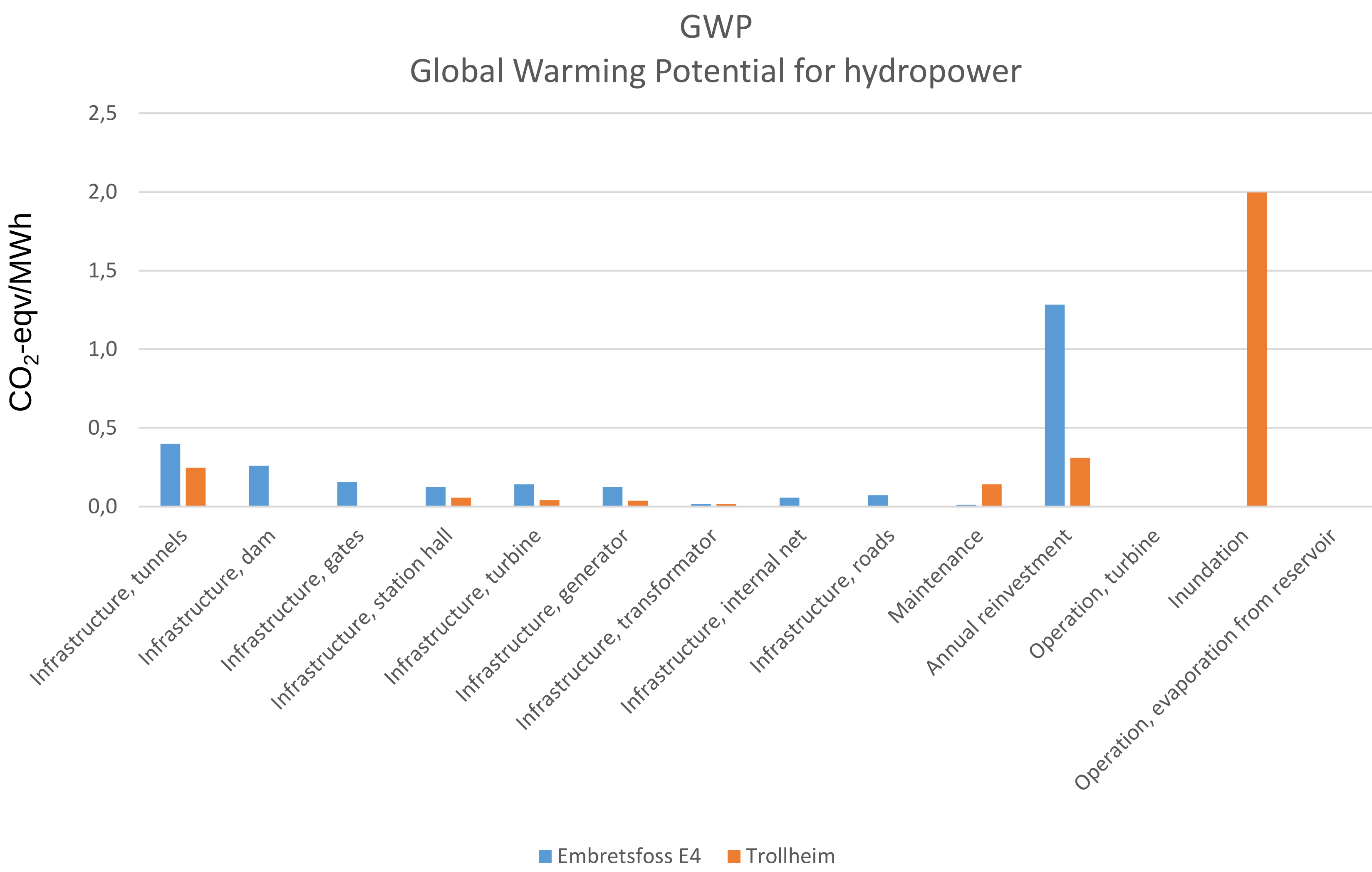
Embretsfoss (E4)
(ROR)

EPD's: GWP, AP etc



http://www.epd-norge.no/category.php?categoryID=623

Er vannforbruket for vasskraft dominert av den operative fasen (fordamping frå dam og vannvegar)?


GWP
Global Warming Potential for hydropower
CO_2-eqv/MWh
2,5
2,0
1,5
1,0
0,5
0,0
Infrastructure, tunnels
Infrastructure, dam
Infrastructure, gates
Infrastructure, station hall
Infrastructure, turbine
Infrastructure, generator
Infrastructure, transformator
Infrastructure, internal net
Infrastructure, roads
Maintenance
Annual reinvestment
Operation, turbine
Inundation
Operation, evaporation from reservoir
Embretsfoss E4
Trollheim

Kva med vannforbruk?

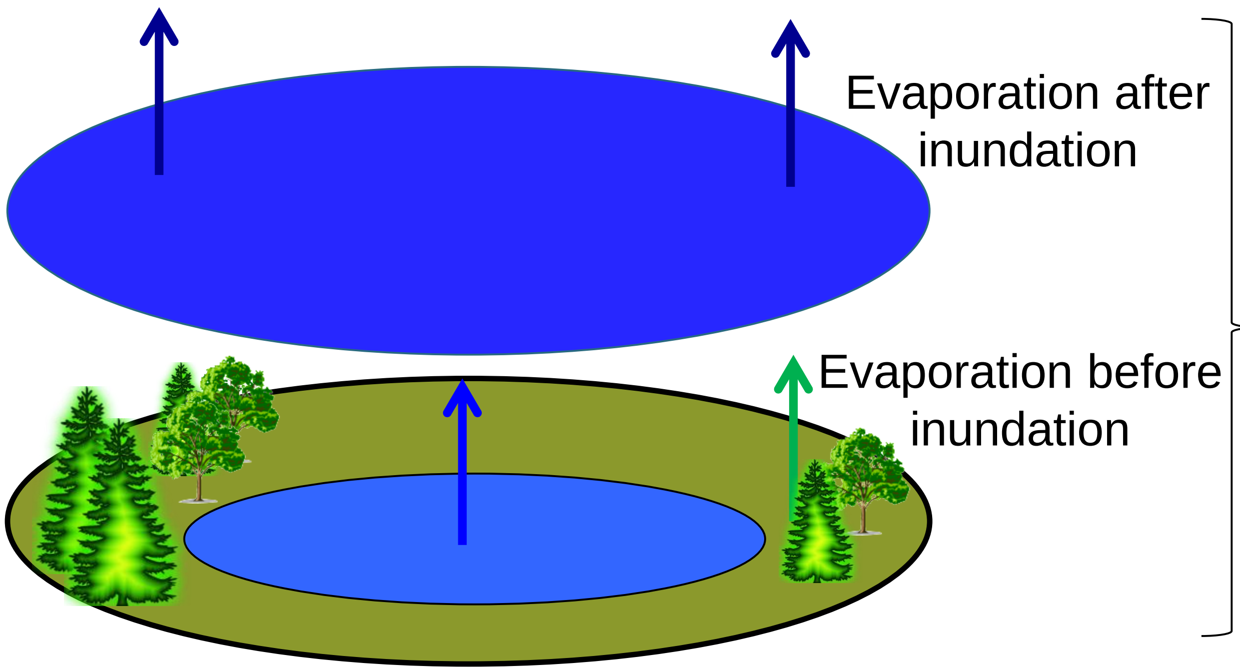
Tilpassingar for å kunne bruke eksisterande LCA-modellar for å beregne vannforbruk:

- Omforming av modellane frå å bruke Ecoinvent 2 til Ecoinvent 3 som database.
- Manuell omforming av fleire gjenståande prosessar.
- Inkludering av fordampingsdata.

Vannforbruk fordelt på region (land) og kjelde (elv, innsjø, brønn osv).

7966 processes involved

Methodological approach: evaporation calculations



Net evaporation
= Evaporation after
– Evaporation before

Measured and modelled values

Evaporation/evapotranspiration based on the Penman-Monteith model on daily time steps for one year:

- Precipitation, temperature, wind speed, relative humidity, global radiation/cloud cover
- Vegetation type, vegetation height and season (leafes)

Metodar for beregning av "water scarcity"

Midtpunkt-metodar basert på knappheit av ferskvatn (mengde tilgjengeleg vatn):

- Pfister et al. 2009
- Boulay et al. 2011 (simplified)
- Hoekstra 2012
- Ecological scarcity 2006

Forskjellen på metodane:

- Datakjelde
- Metode for å beregne knappheit;
  - uttak i forhold til tilgjengeleg mengde (withdrawal-to-availability ratio), eller
  - forbruk i forhold til tilgjengeleg mengde (consumption-to-availability ratio)

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Regionale karakteriseringsfaktorar (eksempel)

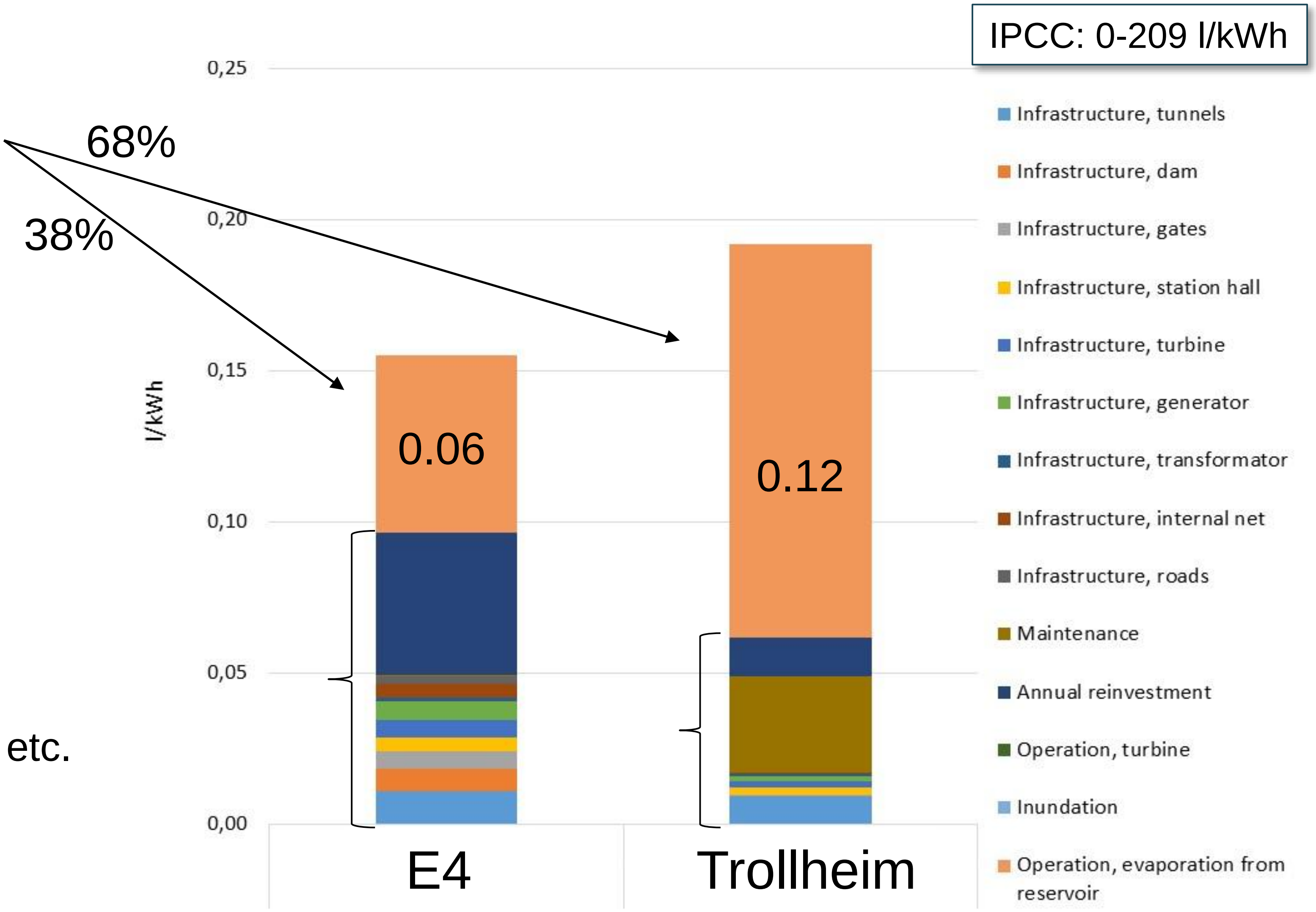
	Water, lake					
Water footprint method	Norway	Germany	Egypt	India	Spain	Unit
Pfister et al. 2009	0,08	0,12	0,98	0,97	0,71	m3/m3
Boulay et al. 2011 (simplified)	0,00	0,04	1,00	0,9997	0,998	m3/m3
Hoekstra 2012	0,34	0,88	0,87	2,44	1,36	m3/m3
Ecological scarcity 2006	0,32	32	13000	1100	990	UBP/m3

Vannforbruk i Noreg er ikkje så ille som i mange andre land. Korleis påverkar dette fordampingsresultata?

Inventory results

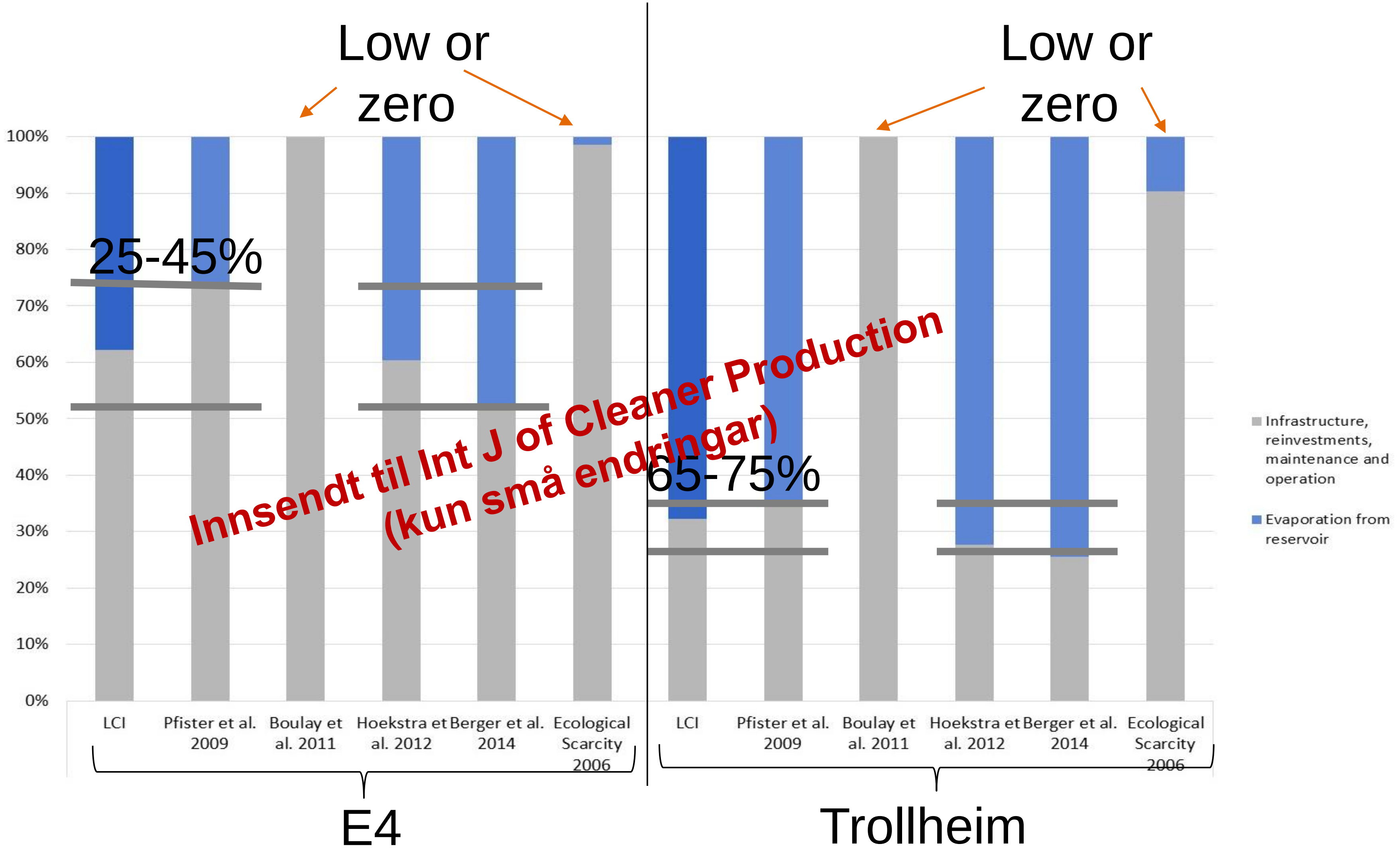
Evaporation (in Norway)

Production of copper, steel, plastics etc, produced in Europe, China etc.



How important is evaporation?

Water scarcity results (mid-point)



Innsendt til Int J of Cleaner Production (kun små endringar)

- Kva er vannforbruket over livsløpet for norsk vannkraft?
  - 0,16 og 0,19 l/kWh for E4 og Trollheim.

- Kor viktig er fordamping frå dam/vannvegar?
  - Mengde: fordamping bidrar 38% og 68% av totalt vannforbruk for E4 og Trollheim.
  - Karakteriserte resultat: fordamping bidrar 0-45% og 0-75% av water scarcity for E4 og Trollheim.

Norske resultat er mykje lågare enn talla frå IPCC.

Andelen frå fordamping er ikkje totalt dominerande.

LCM Bordeaux 2015, D-II, ID 217

Regionalization of water consumption and the effect on water footprint results for hydropower

A part of the EcoManage project:
Improved development and management of energy and water resources

Ingunn Saur Modahl[1)], Hanne Lerche Raadal[1)], Tor Haakon Bakken[2)] and Kolbjørn Engeland[3)]

[1]Ostfold Research, Norway; [2]Norwegian University of Science and Technology (NTNU), Norway; [3]University of Oslo, Norway

What would the result be if this evaporation happened in another region?

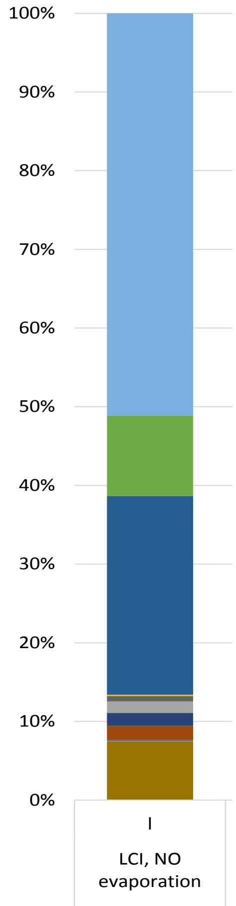
- Evaporation would most probably increase.
- How much will the scarcity issue affect the total results, assuming Norwegian evaporation rates in another region?
- Virtually «moving» the Trollheim HPP/Follsjøen reservoir («exercise»).

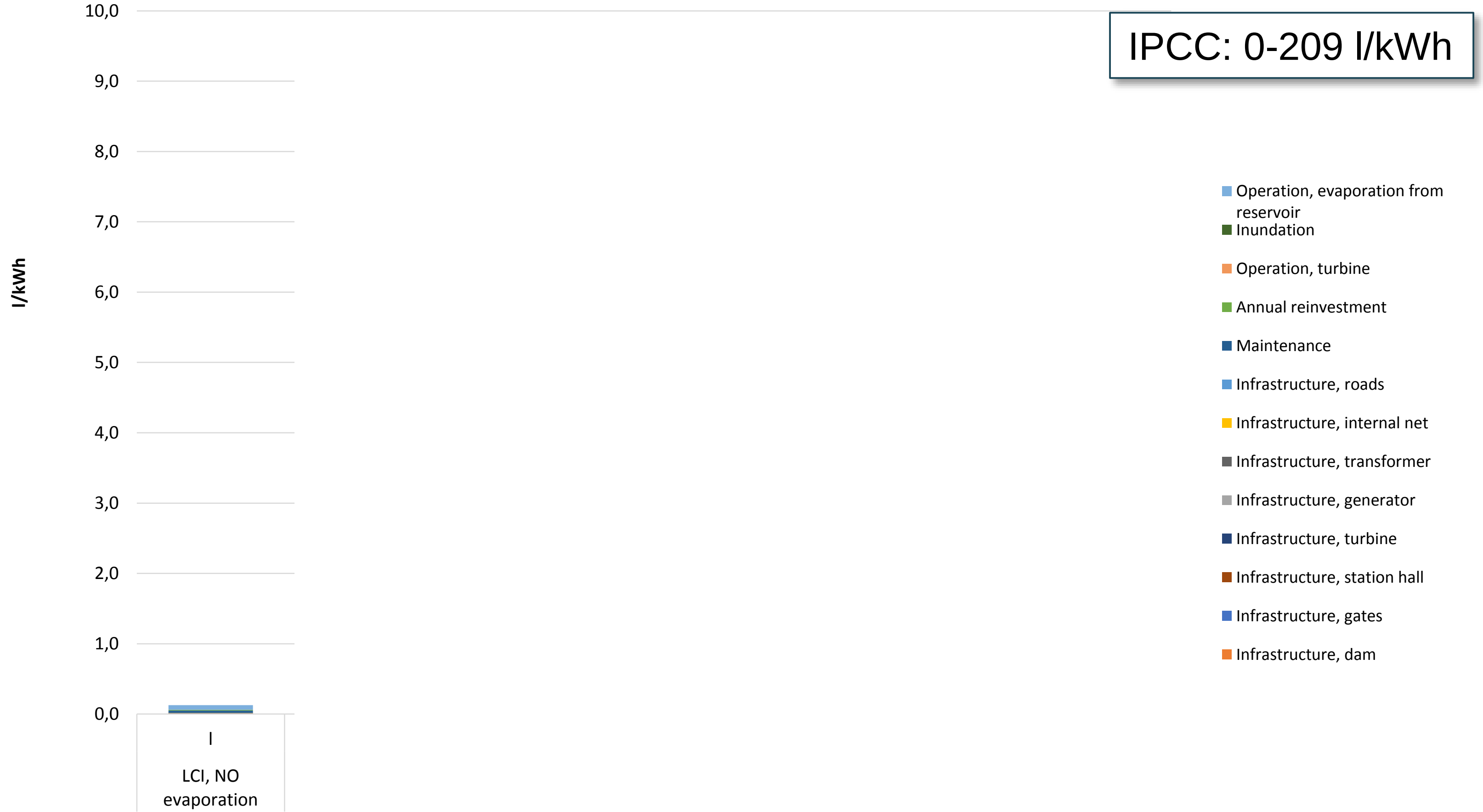
Results presented at LCM Bordeaux.

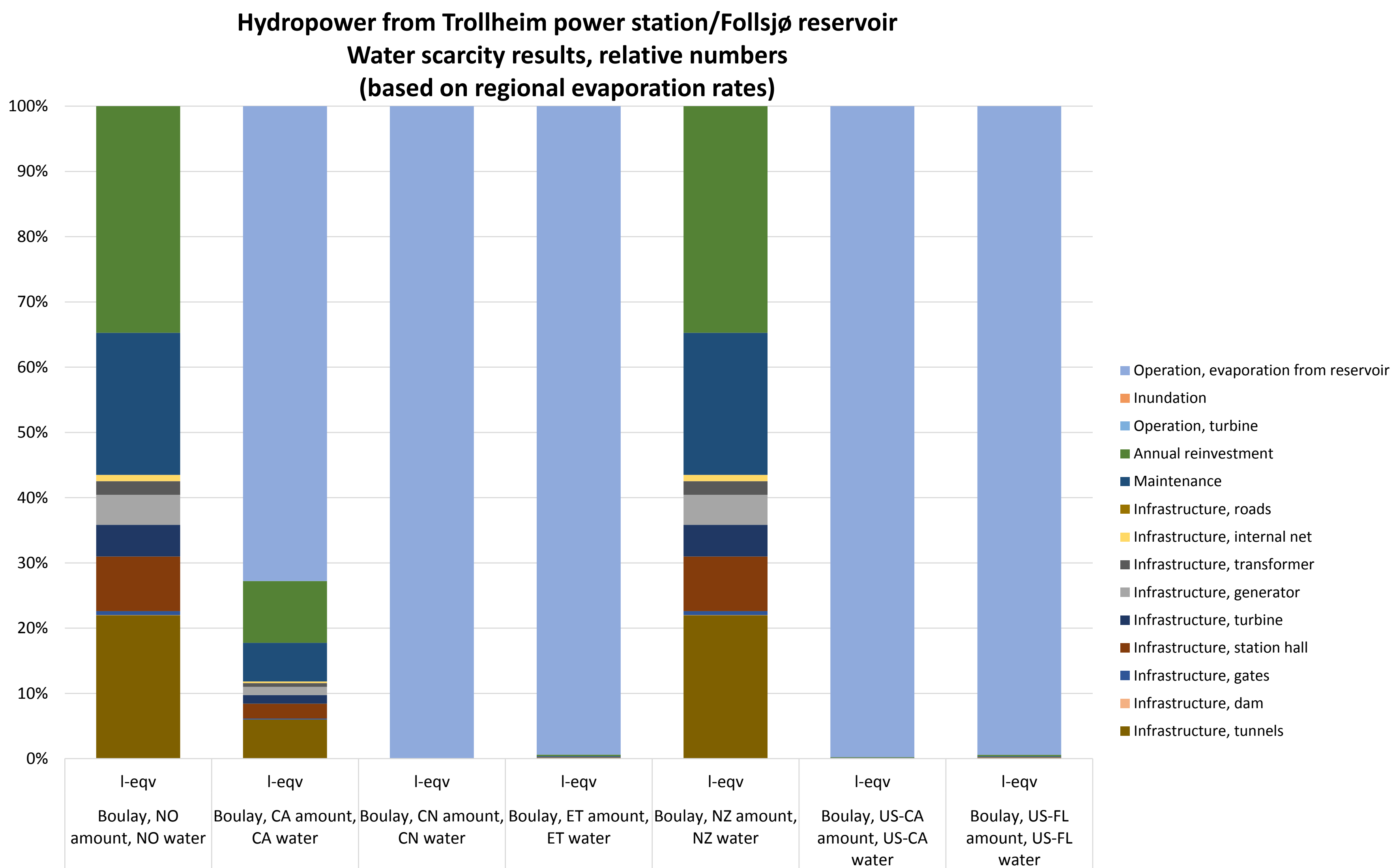
Etter LCM:

- Utrekna reelle, spesifikke fordampingstall for ulike regionar.
- Beregna water scarcity på nytt for Canada, Kina, Etiopia, New Zealand, California og Florida.
- Karakteriseringsfaktorar frå Boulay et al. (2011).

Hydropower from Trollheim power station/Follsjø reservoir
Life cycle inventory
(based on regional evaporation rates)






Hydropower from Trollheim power station/Follsjø reservoir
Water scarcity results, relative numbers
(based on regional evaporation rates)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
l-eqv
Boulay, NO amount, NO water
l-eqv
Boulay, CA amount, CA water
l-eqv
Boulay, CN amount, CN water
l-eqv
Boulay, ET amount, ET water
l-eqv
Boulay, NZ amount, NZ water
l-eqv
Boulay, US-CA amount, US-CA water
l-eqv
Boulay, US-FL amount, US-FL water
Operation, evaporation from reservoir
Inundation
Operation, turbine
Annual reinvestment
Maintenance
Infrastructure, roads
Infrastructure, internal net
Infrastructure, transformer
Infrastructure, generator
Infrastructure, turbine
Infrastructure, station hall
Infrastructure, gates
Infrastructure, dam
Infrastructure, tunnels

Conclusions

- Water scarcity of hydropower is not always dominated by evaporation from reservoir and waterways. Infrastructure, maintenance and reinvestment can also contribute in some regions. Site specific evaporation calculations necessary.

- Water scarcity instead of inventory results should be used for comparison of technologies/sites.

- Broaden the picture from IPCC (gross instead of net, not LCA-based, no characterisation). LCI results for all 7 regions much lower than the high IPCC number.

- More detailed regionalisation would enhance the results (CA-FL, China).

Forslag til vidare arbeid

- Skrive artikkel for å publisere resultata på regionalisering av vannfotavtrykk.

Kvifor bør regionalisert vannforbruk på dagsorden?

- Grunnlag for å vite kor i verda vasskraftproduksjon er potensielt problematisk (område med vannknappheit).

- I område der mange ikkje kjenner hydrologien og kor store vassressurser som er tilgjengeleg: regionaliserte resultat vil kunne avklare om vannforbruk (til elproduksjon) er eit problem eller ikkje.

- Norsk vasskraft i Noreg kan frikjennast!