EcoManage brukermøte torsdag 11. desember 2014
WP 2: «Energy payback ratio» (energiindikatorar)

Allokering i fleirbruksmagasin og tilpassing av eksisterande LCA-modellar for beregning av vannfotavtrykk

Status og vidare arbeid

Ingunn Saur Modahl og Hanne Lerche Raadal

Innhald

1. **Energiindikatorar**
   Resultat for ulike teknologiar (elektrisitetsproduksjon). Rapport + publisert artikkel i Energy Policy, 2013 v/Ingunn Saur Modahl, Hanne Lerche Raadal, Luc Gagnon og Tor Haakon Bakken.

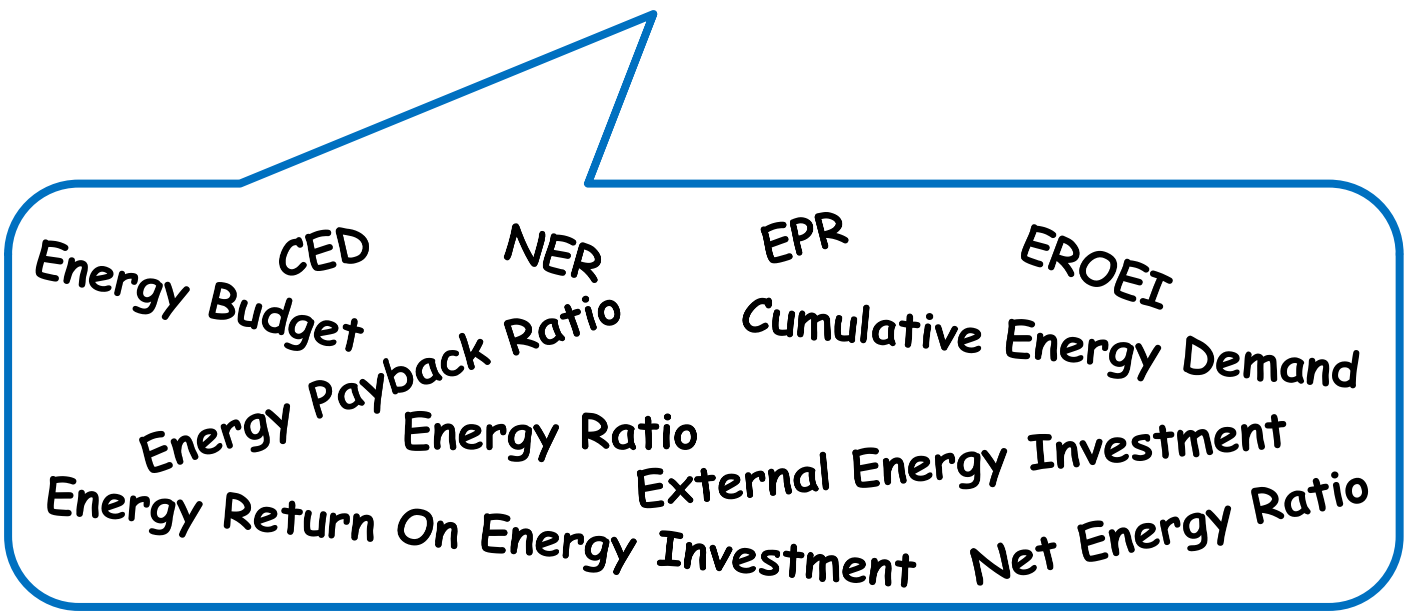
2. **Allokering i fleirbruksmagasin**
   Innsendt artikkel: «Allocation recommendations for multipurpose reservoirs - results for water consumption». Forfattarar: Tor Haakon Bakken, Ingunn Saur Modahl, Hanne Lerche Raadal, Ana Adeva Bustos og Silje Arnøy.

3. **Vannfotavtrykk**
   Vannforbruk som ein indikator i LCA av vasskraft. Påbegynt artikkel.

4. **Vidare arbeid**

1. Energiindikatorar

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

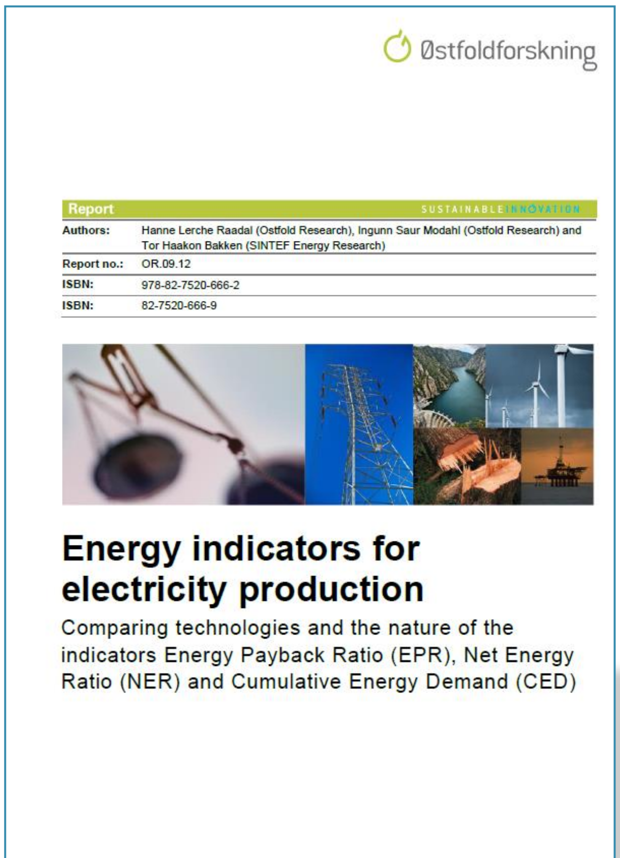


Ingunn Saur Modahl and Hanne Lerche Raadal (both Ostfold Research, Norway), Luc Gagnon (Energy and Climate Change consultant, Canada) and Tor Haakon Bakken (SINTEF Energy Research, Norway)*
** Stadion 4, 1671 Kråkerøy, Norway. E-mail: ism@ostfoldforskning.no*

Mål

- Auke forståinga av resultata ved samanlikning av energiprodukt.
- Diskuterer korleis systemgrenser kan påverke resultata for dei ulike energiindikatorane. Artikkelen er basert på resultat for vasskraft, vindkraft og elektrisitet frå biomasse, gass og kol.

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

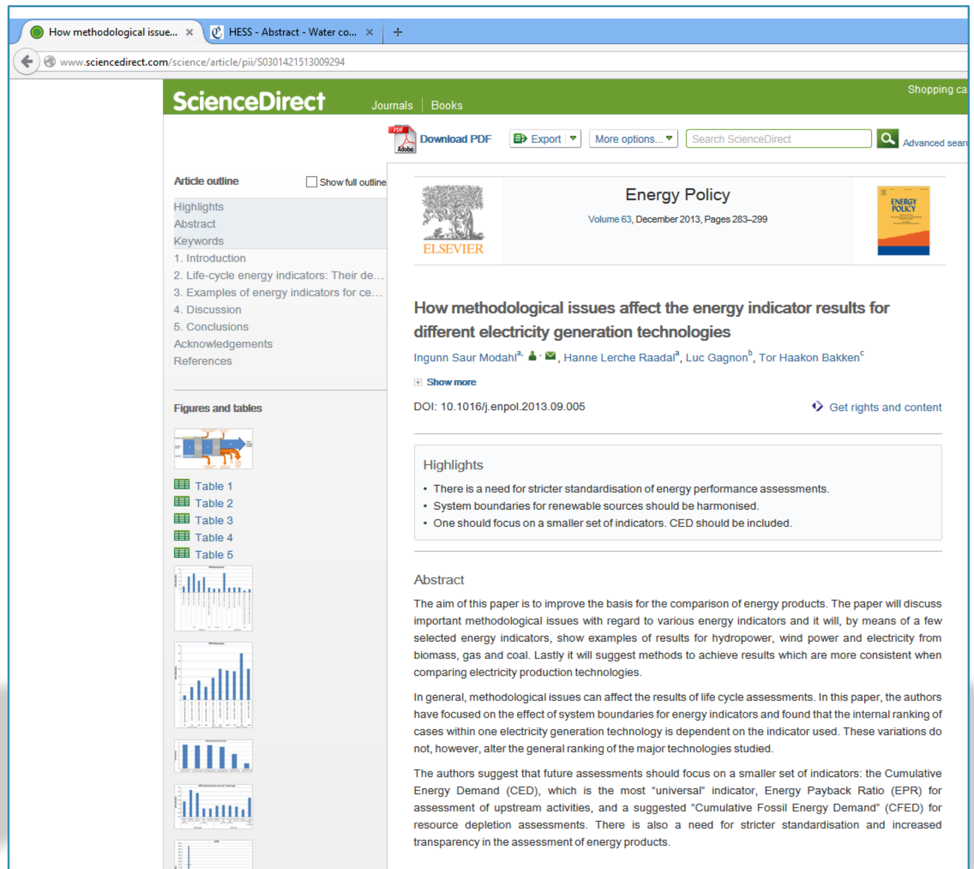

Østfoldforskning

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

ScienceDirect Journals Books

Download PDF Export More options... Search ScienceDirect Advanced search

Article outline Show full outline
Highlights
Abstract
Keywords
1. Introduction
2. Life-cycle energy indicators: Their de...
3. Examples of energy indicators for ce...
4. Discussion
5. Conclusions
Acknowledgements
References

Figures and tables
Table 1
Table 2
Table 3
Table 4
Table 5

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 Get rights and content

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.

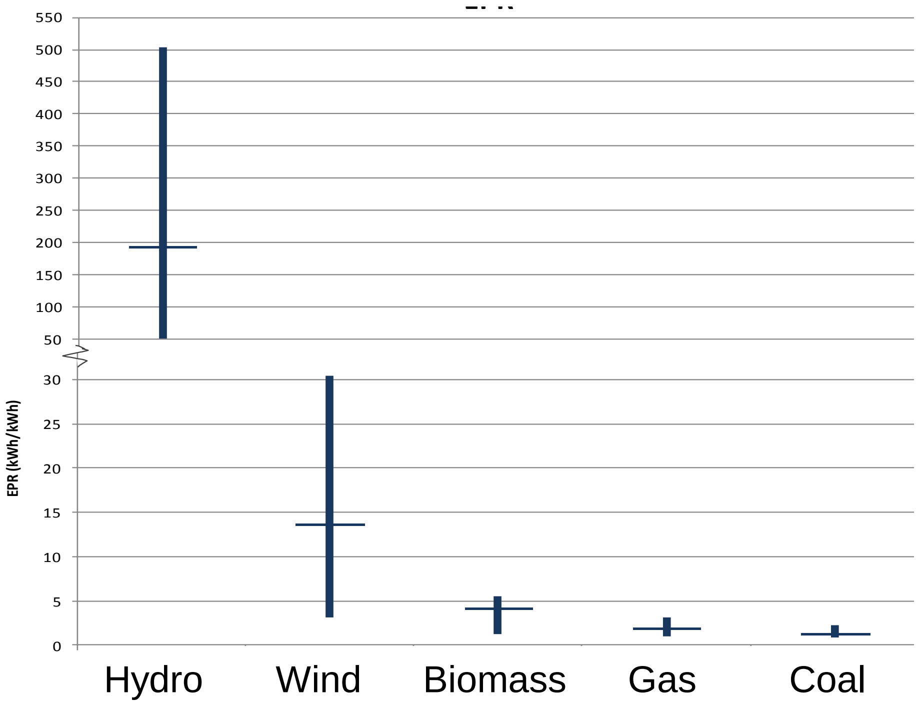
The authors suggest that future assessments should focus on a smaller set of indicators: the Cumulative Energy Demand (CED), which is the most "universal" indicator, Energy Payback Ratio (EPR) for assessment of upstream activities, and a suggested "Cumulative Fossil Energy Demand" (CFED) for resource 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

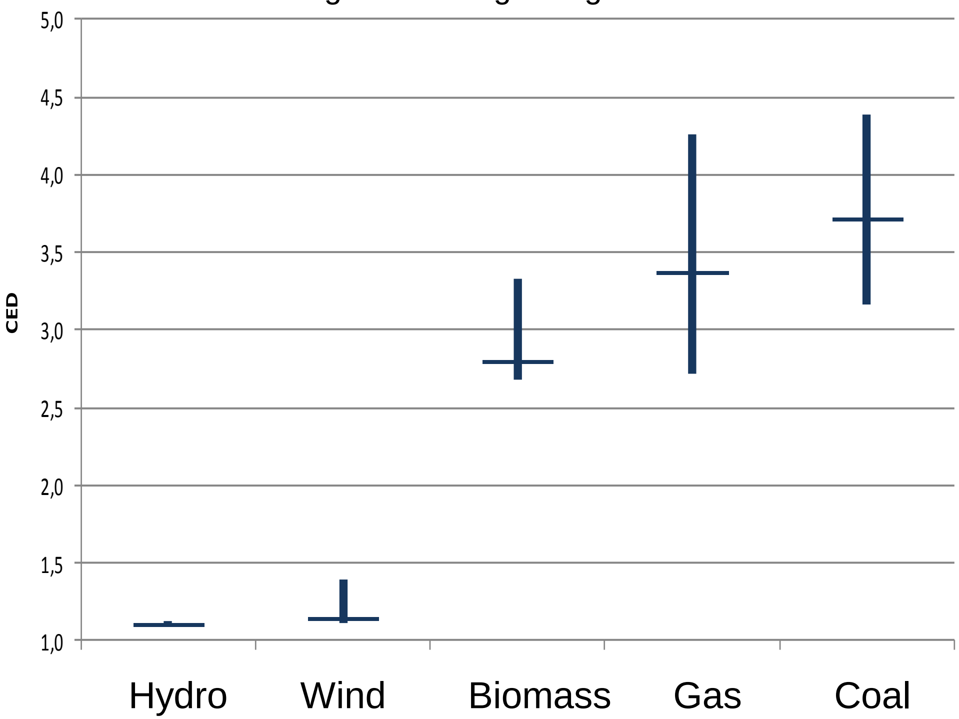
EPR=Energy Payback Ratio

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)

Østfoldforskning

SUSTAINABLE INNOVATION

Kostnadsanalogi:

Kapitalkostnad per km (km per krone kapitalkostnad) eller totalkostnad per km?

Kapitalkostnad →

Drivstoff →

→ Total kjørelengde

Kapitalkostnad →

Drivstoff →

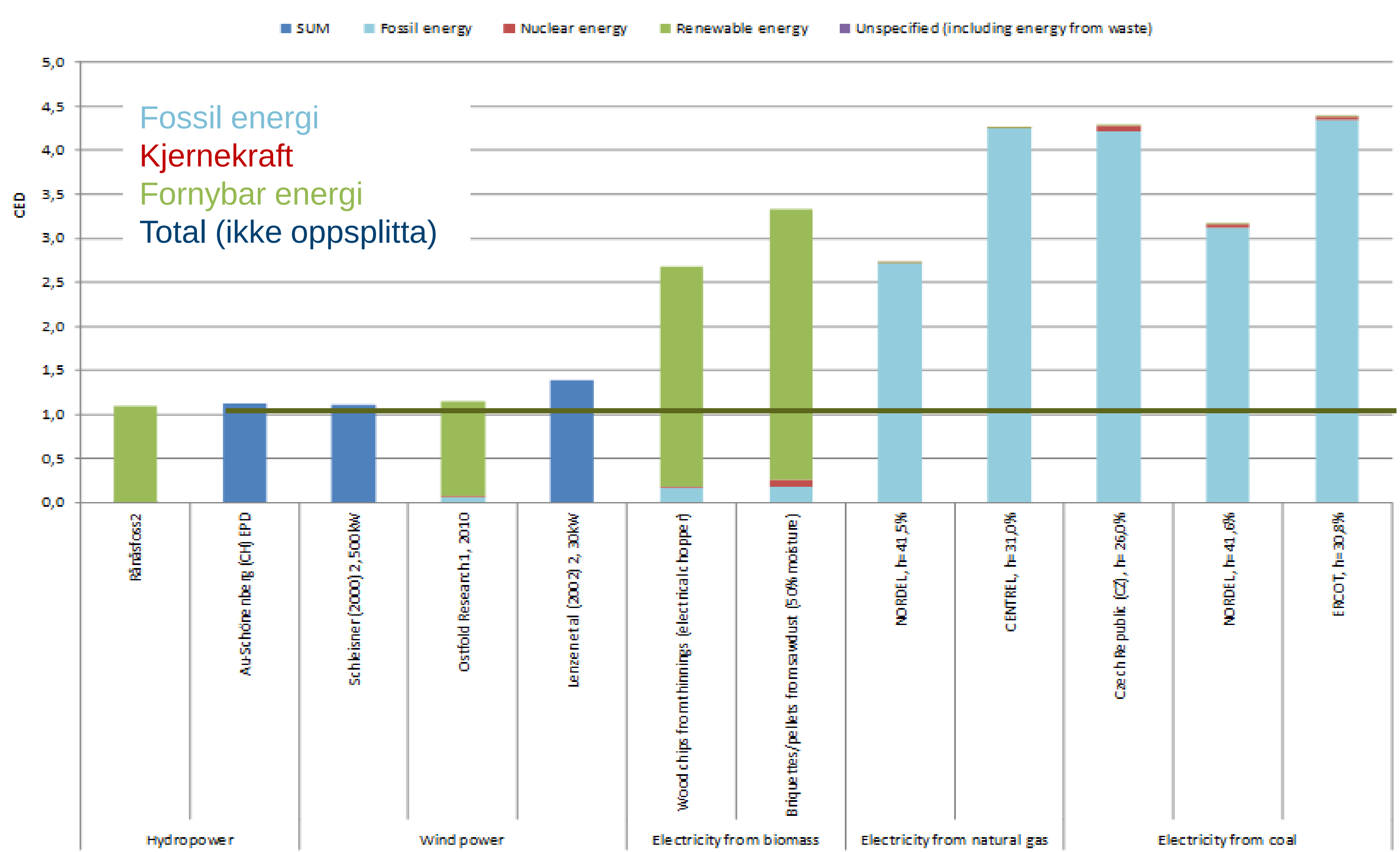
→ Total kjørelengde

Østfoldforskning

SUSTAINABLE INNOVATION

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.

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]

[1] Norwegian University of Science and Technology, Trondheim, Norway

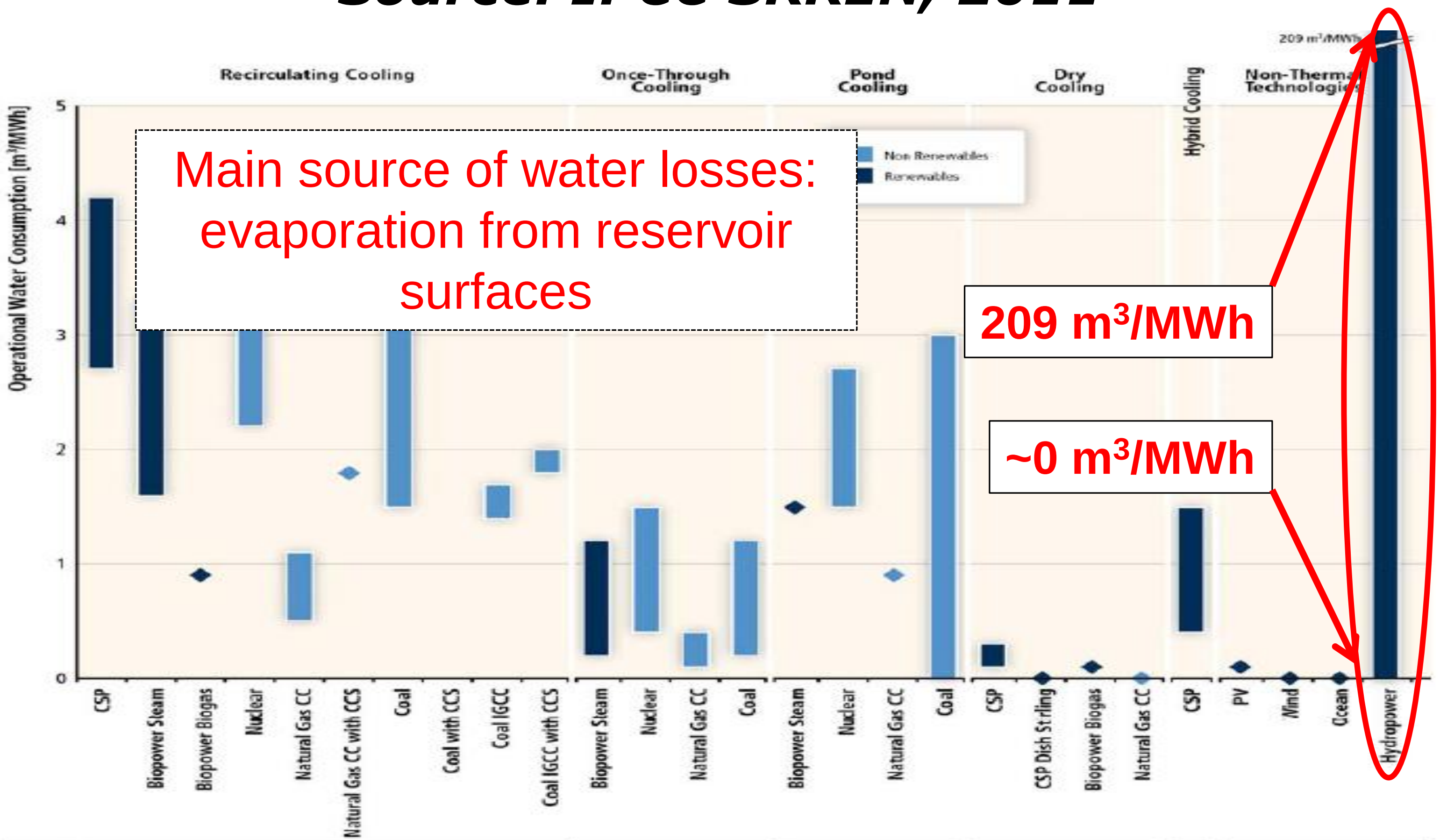
tor.haakon.bakken@sintef.no

[2] SINTEF Energy Research, Trondheim, Norway

[3] Ostfold Research, Fredrikstad, Norway

[4] Universidad Politécnica de Madrid, Spain

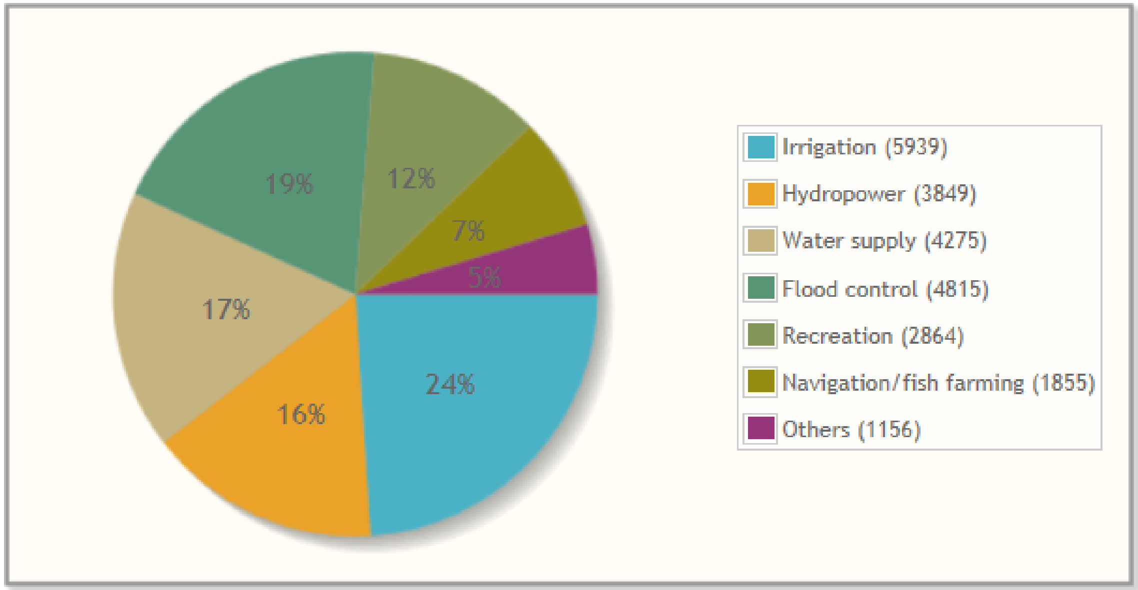
Water consumption from energy generation: *Source: IPCC SRREN, 2011*



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

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

Har identifisert mangel på klar metodikk:

IPCC: "*allocation schemes … can significantly influence reported water consumption values". "Many LCAs to date allocate all impacts of hydropower projects to the electricity generation function, which in some cases may overstate the emissions for which they are 'responsible' '"*.

PCR for hydropower: "*The construction of dams is a prerequisite for regulation of water flows in a water course. Regulation may prevent flooding but nevertheless all the processes necessary for constructing and maintaining dams shall be allocated to hydropower."*

ISO-standarden for Water footprint manglar klare retningslinjer for allokering. Mangelen på omforent metodikk er stadfesta av Mekonnen og Hoekstra 2012; Demeke et al. 2013; Bakken et al. 2013.

Arbeidet vil også vere nyttig for andre miljøindikatorar, feks energieffektivitet og klimagassar (ref. IPCC, 2014), pga at valgt allokering er uavhengig av indikator.

Mål med artikkelen (og arbeidet bak)

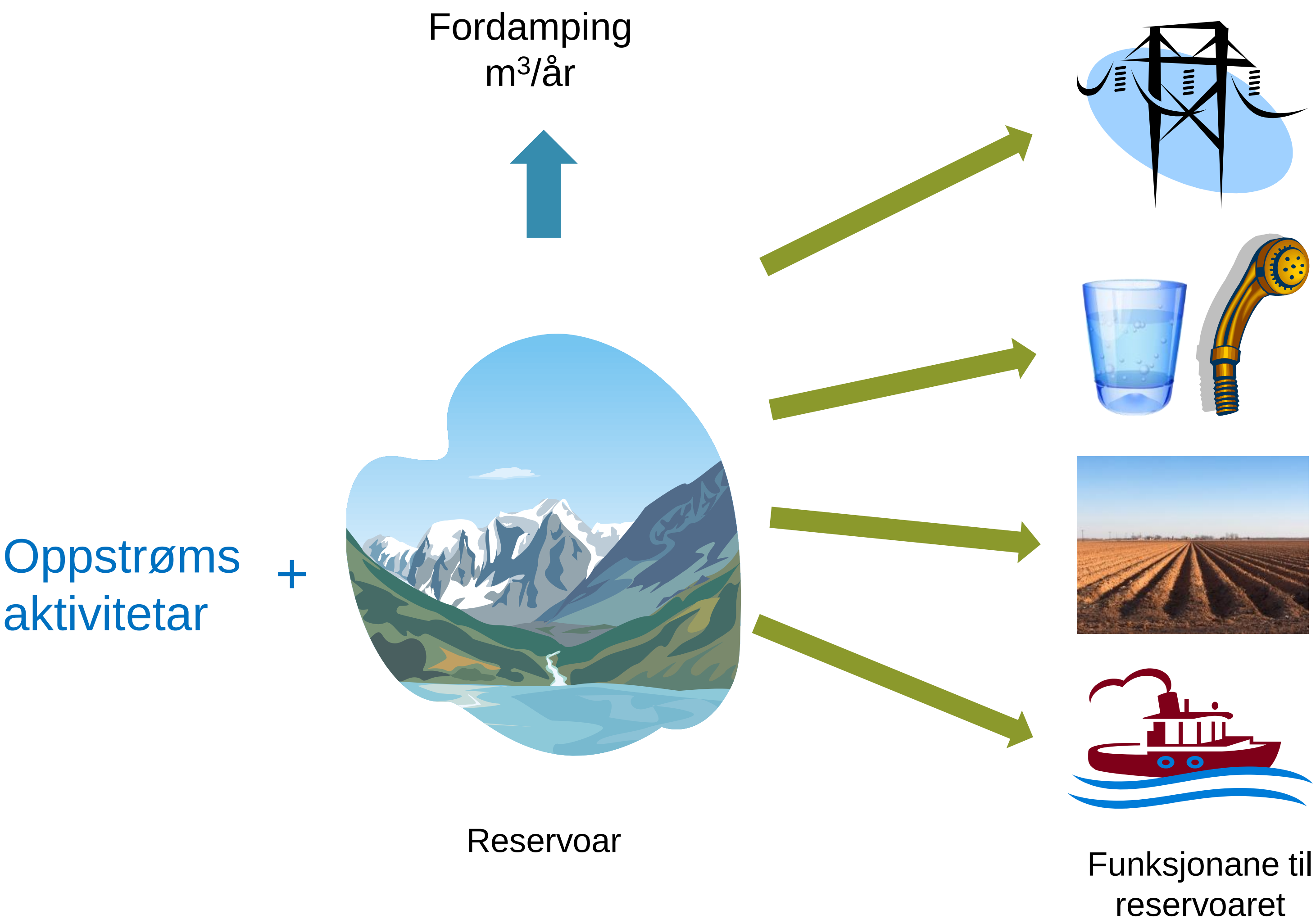
1. Gjennomgang av dei vanlegaste tilnærmingane for fordeling/allokering av ressursbruk, basert på prinsippa i ISO-standarden 14044 (2006).

2. Bruke ulike allokeringsmetodar på reelle case og synleggjere resultata.

3. Foreslå retningslinjer for bruk av allokeringsprosedyrer i fleirbruksmagasin med kraftproduksjon.

4. Vurdere kor relevant desse allokeringsprosedyrene er for LCA-studier av fleirfunksjonsreservoar generelt.

Situasjon som krev allokering



Allokeringsmetodar

Har testa metodar basert på tilrådingar for byrdefordeling i fleirfunksjons-prosessar, gitt av ISO 14044 (2006):

If possible, allocation should be avoided by:

1A: Subdividing the product system – considered not possible.

1B: Using system expansion/avoided burdens to include the additional functions (substitution), understood as **Water footprint for alternative means of fulfilling the functions** - considered inappropriate.

If allocation cannot be avoided, allocation should be based on:

2A: Physical relationships (mass, volume or energy)

2B: Other relationships (economic or others relationship, e.g. explicit prioritizing)

4 casestudiar

Data	Sri Ram Sagar Project, India	Aswan High Dam Pro Egy	Mularroya dam, Spain	Porma Dam and reservoir, Spain
Evaporation rate [mm]	1696	3 0	1100	858
Surface area [km²]	453	5	4.63	12.5
Total annual evaporation [mill. m³]	768.3	[illegible]	5.09	10.7
Installed capacity [MW]	36	[illegible]	23.5	23.2
Annual power production [GWh]	236.5	20	25.9	48.8
Water consumption rate [m³/MWh]	3248	250	196.6	255.9

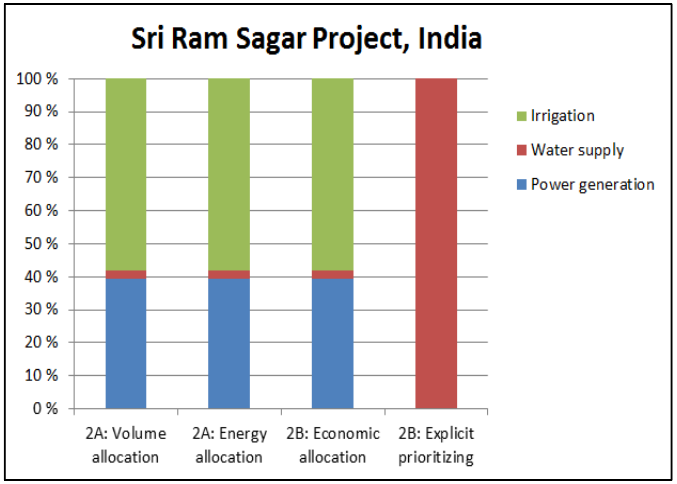
To be corrected

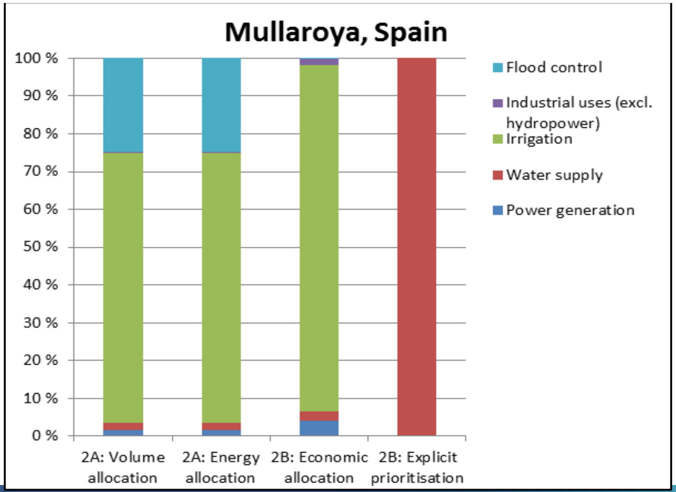
I tillegg til informasjon om masse, volum, energi, økonomi, prioritering

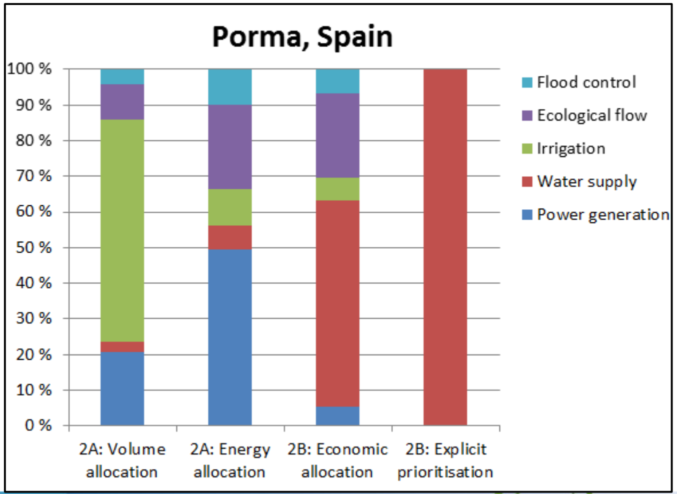
Resultat: Kor stor andel av totalt vannforbruk bør kvar funksjon belastast med?

Aswan High Dam, Egypt

Flomvern
Økologi
Vatning
Drikkevatn
Kraftproduksjon







Recommendations

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

- We recommend that data should preferably be gathered from one source for all functions, to secure a consistent calculation approach.

- The system boundaries should be flexible, but preferably follow boundaries defined by the hydraulic system, as the volumes of water, energy allocation based on water volumes and possibly also economic value is to a large extent determined by the hydraulic system boundaries.

- We propose that a site visit should be undertaken 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.

Dokumentasjon og bruk

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]

[1] Norwegian University of Science and Technology (NTNU), Department of Hydraulic and Environmental Engineering. S.P. Andersens veg 5, N-7491 Trondheim, Norway. E-mail: tor.haakon.bakken@sintef.no. Tlp: +47 95156944

[2] SINTEF Energy Research, Sem Sælands vei 11, NO-7465 Trondheim, Norway

[3] Ostfold Research, Stadion 4, 1671 Kråkerøy, Norway

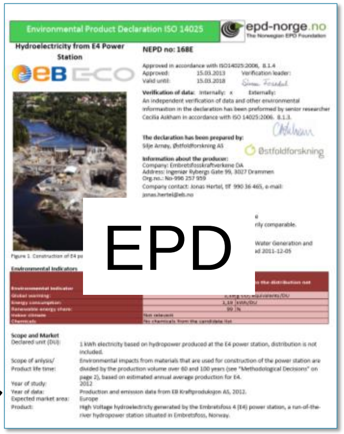
[4] Universidad Politécnica de Madrid, Departamento de Ingeniería Forestal, Escuela Técnica Superior de Ingenieros de Montes, 28040-Madrid, Spain

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. The cases were all selected from regions with water resources under pressures and all reservoirs provided 3-5 water-related functions, including domestic water supply, irrigation, flood control, industrial water, ecological flow and power generation. Based on the specifications in ISO 14044 (ISO 2006), the appropriateness of four different allocation models and 'explicit prioritizing' as a fifth approach were demonstrated and evaluated. We found that volume allocation was the most robust approach for allocation of water consumption between competing functions in multipurpose reservoirs. Furthermore we recommend that data should preferably be gathered from the same source for all functions, in order to secure a consistent calculation approach. The system boundaries 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.

Innspel i revisjonsprosessen av PCR for vasskraft.

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

Artikkel (under arbeid):

"On the track of the water footprint of hydropower production"
Incl. calculation of evaporation from natural lakes and reservoirs

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

Bakgrunn

Construction of plant + Operation of plant + Decommission of plant

- 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? Korleis er dette forholdet om reservoaret har lite overflateareal eller ligg i eit område med låg avdamping?

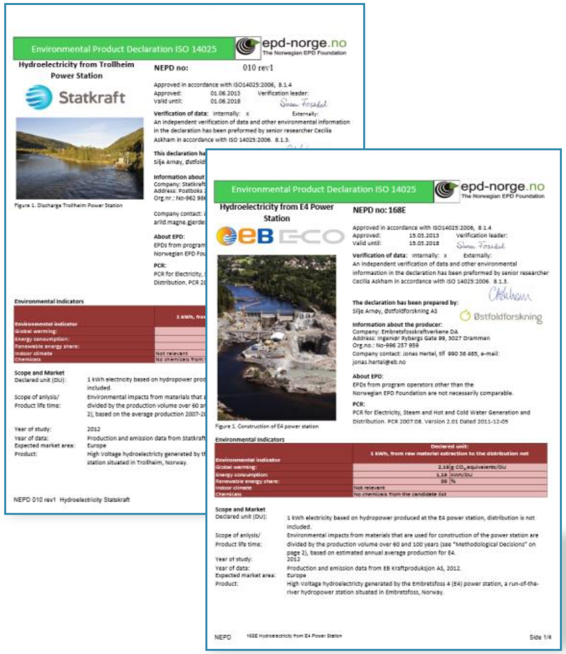
Aukande interesse for beregning og dokumentasjon av vannforbruk for både produkt og tenester.

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

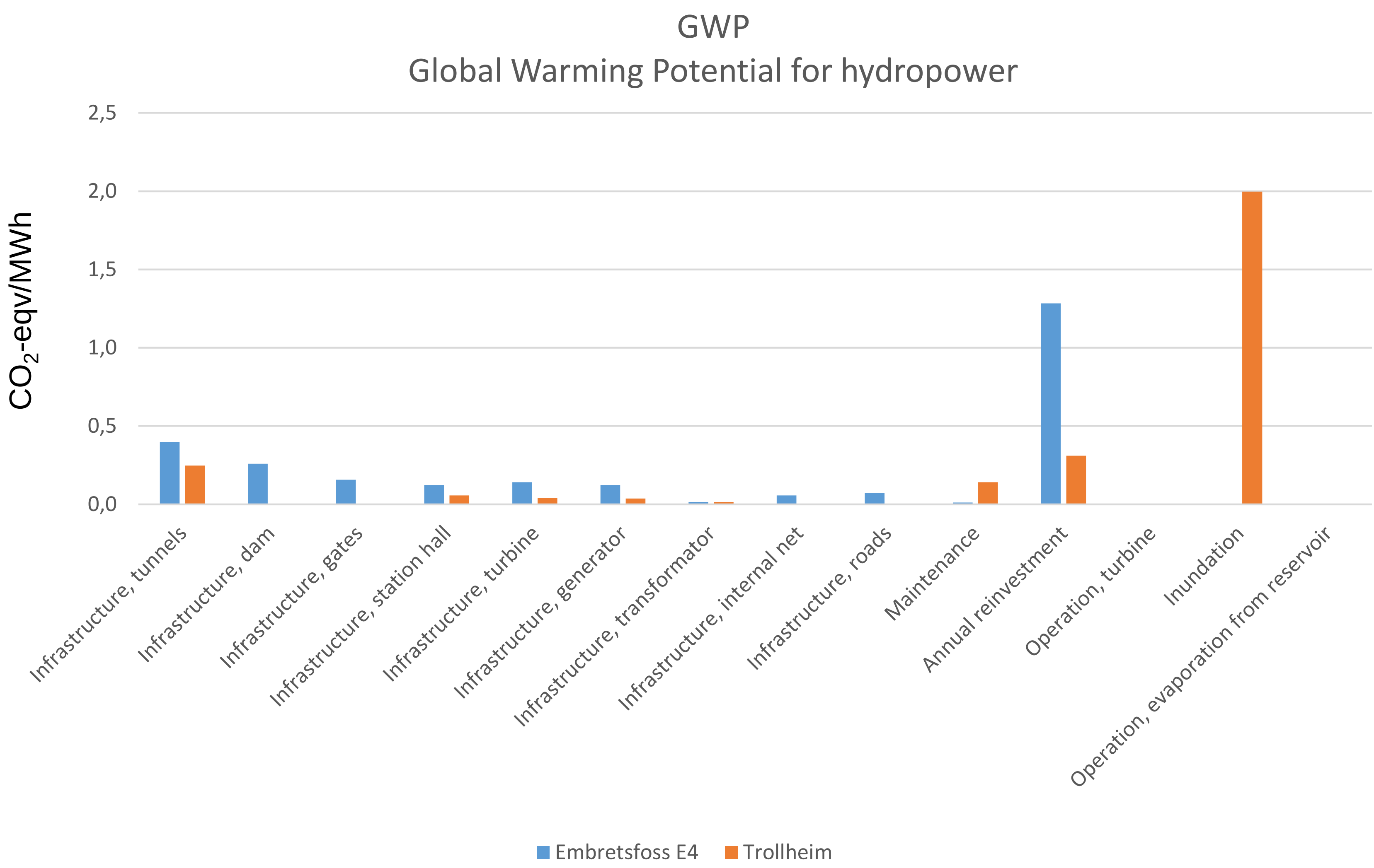
Casestudiar i Noreg



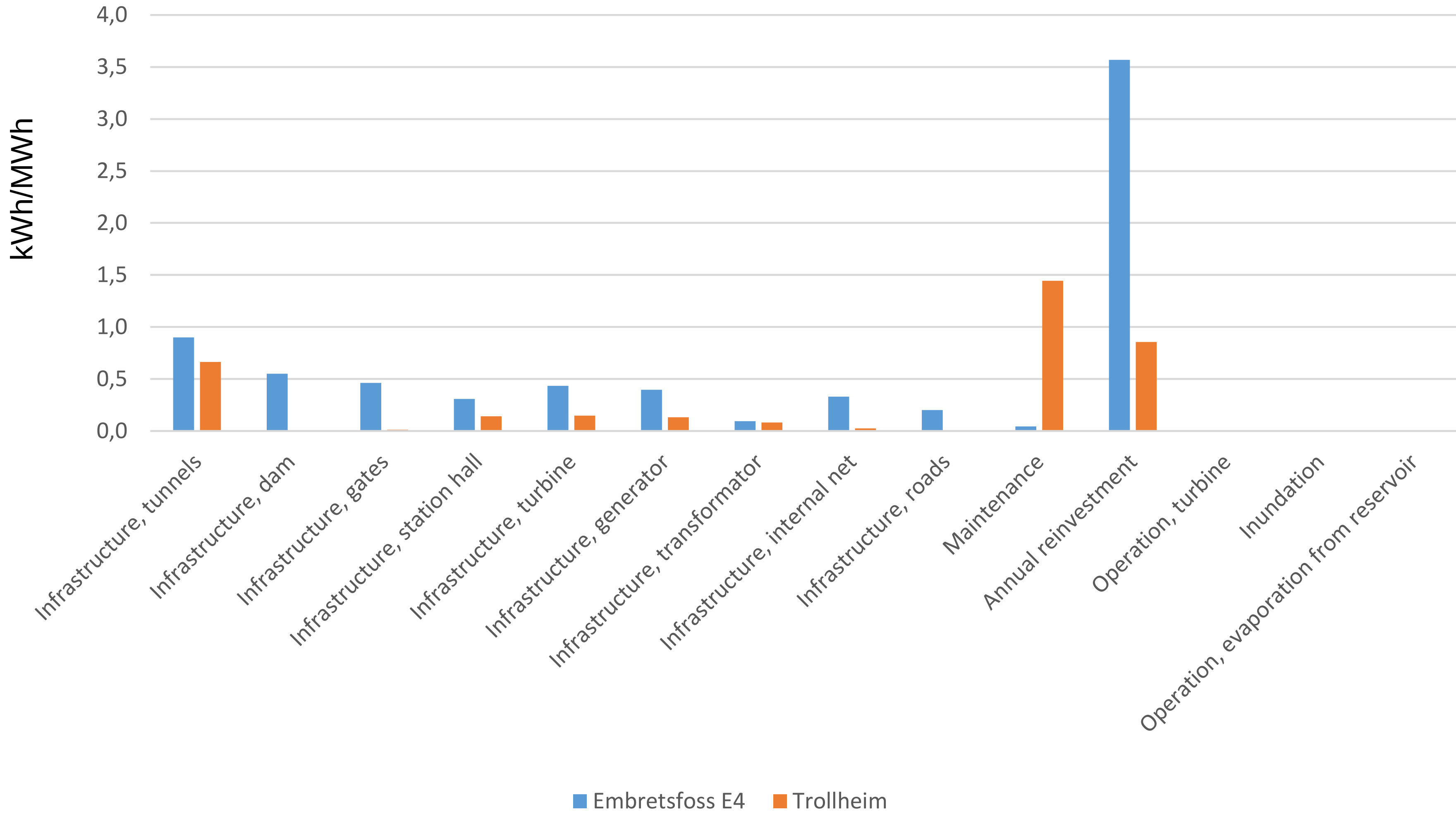
Trollheim HPP og Foldsjøen

Embretsfoss 4 (ROR)

Kjent		Ukjent avdamping		Kjent
↑		↑		↑
Construction of plant	+	Operation of plant	+	Decommission of plant


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

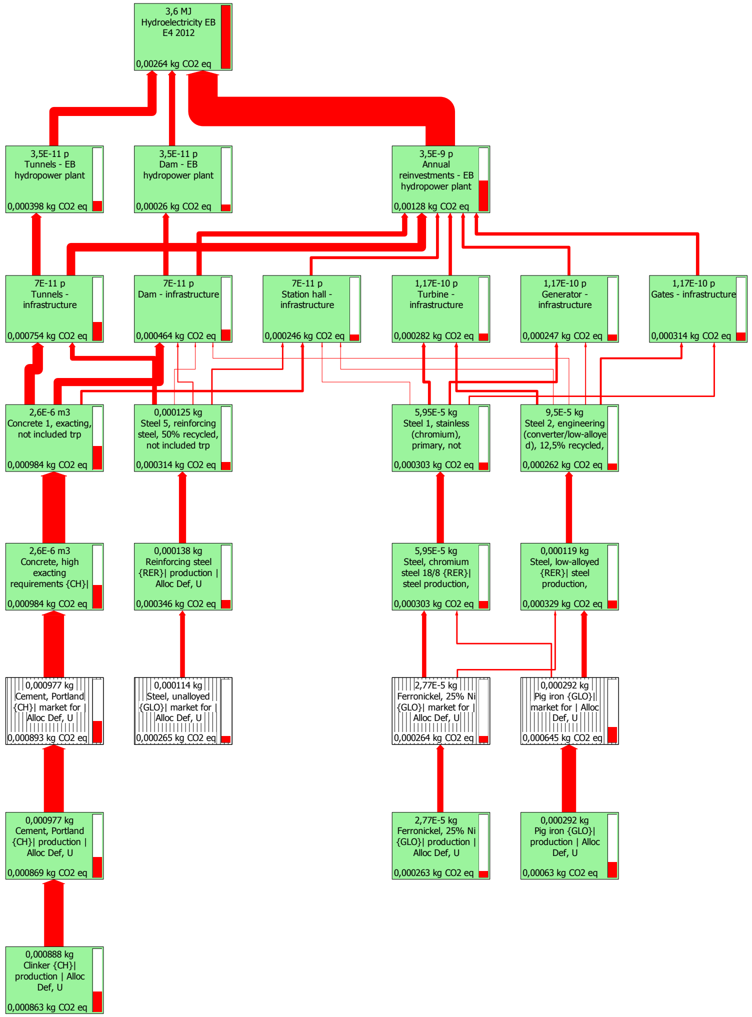
$CED_{non\text{-}renewable}$
Cumulative Energy Demand (non-renewable energy sources)



Kva med vannforbruk?

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

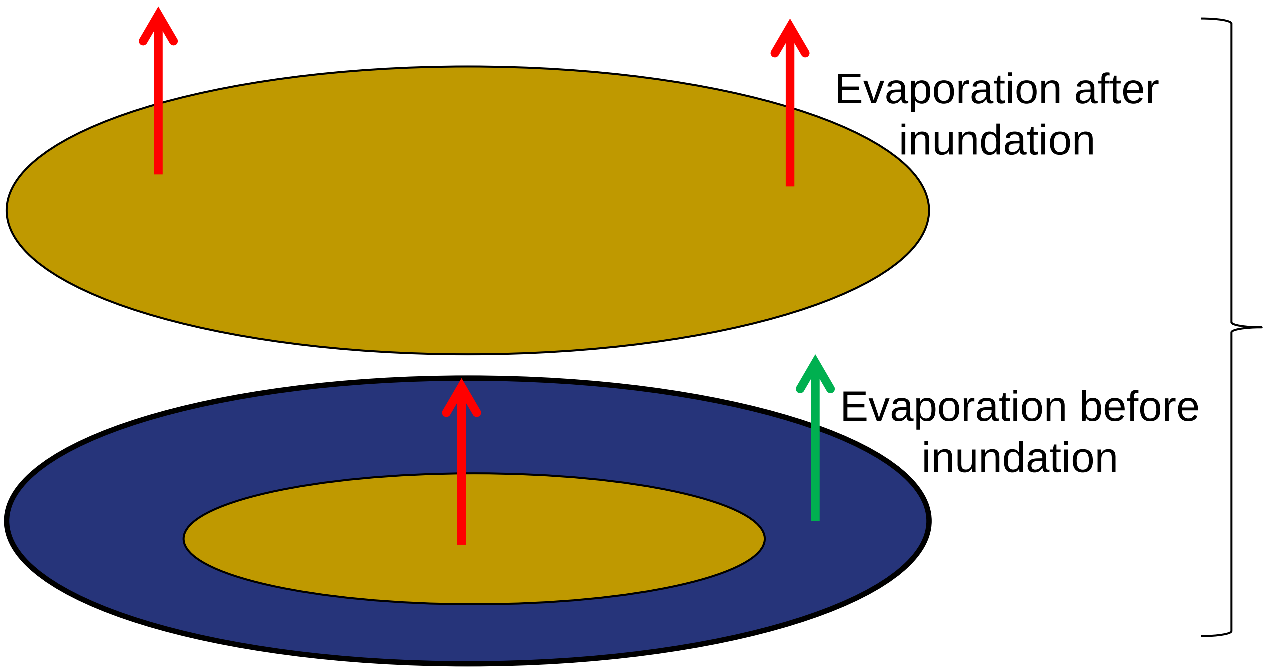
- Omforming av modellane frå å bruke Ecoinvent 2 til Ecoinvent 3 som database (automatisk utbytting av prosessar).
- Manuell omforming av fleire gjenståande prosessar.
- Inkludering av fordampingsdata.



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

7966 processes involved

Fordampingsdata: metodisk tilnærming

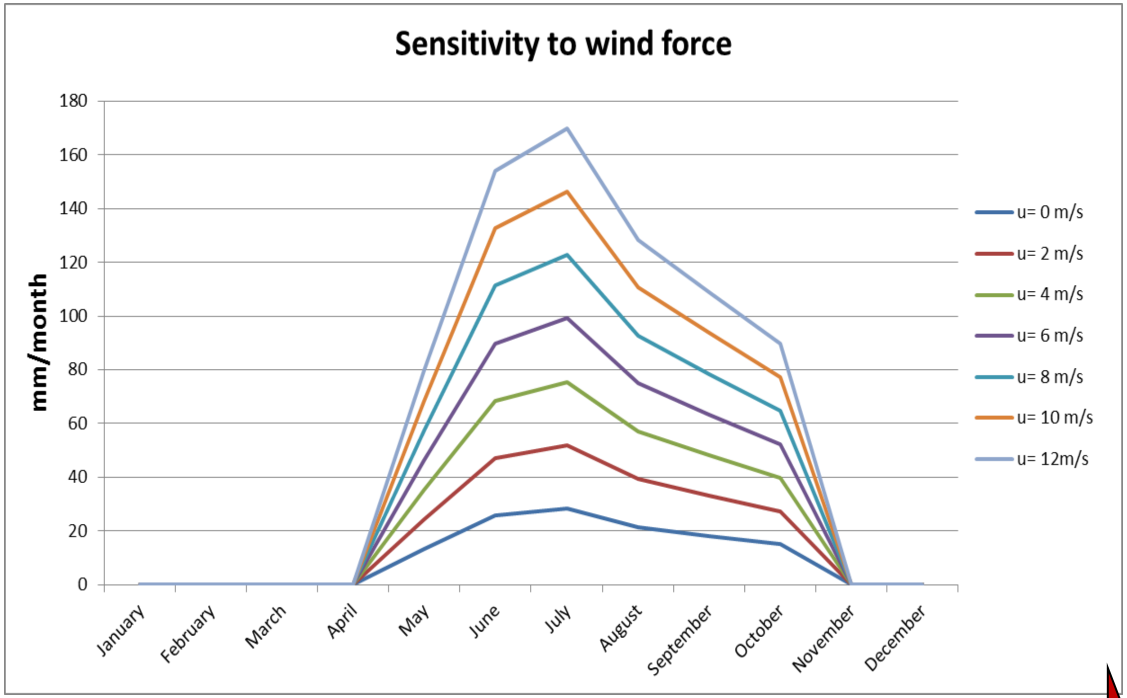


Net evaporation
= Evaporation after
– Evaporation before

<u>Measured/modelled values; indications of range</u>

1. NVE Avrenningskart Norge
2. Measurements Andøya
3. Measurements and calculations Tydalen
4. Other sources
5. A large set of different equations

Sensitivity analysis of Penman-Monteith



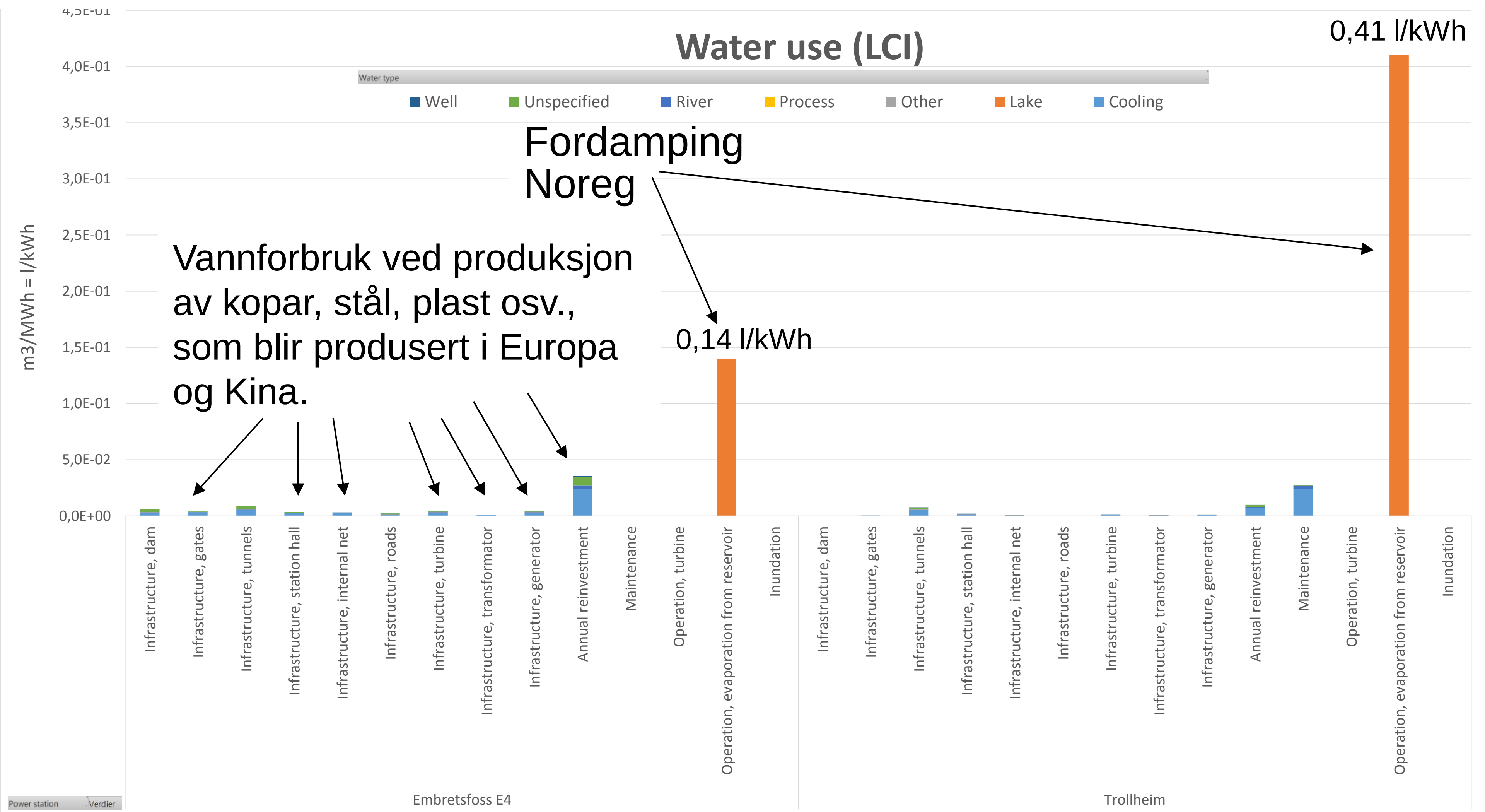
Sensitivity to wind, cloud cover, water temperature.

Annual volumes:

123 mm/year
224 mm/year
325 mm/year
426 mm/year
528 mm/year
629 mm/year
730 mm/year

Store usikkerheiter

Foreløpige resultat: vannforbruk



Metodar for beregning av vannfotavtrykk (karakterisering)

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)

Endpoint methods (to understand damages of water use on human health, ecosystem quality and resource depletion):

- Boulay et al. 2011 and Motoshita et al. 2010: impacts on human health only, but very comprehensive.
- Pfister et al. 2009 and Pfister et al. 2010: Different units. Consistent with the impact assessment methods Eco-indicator 99 and ReCiPe.

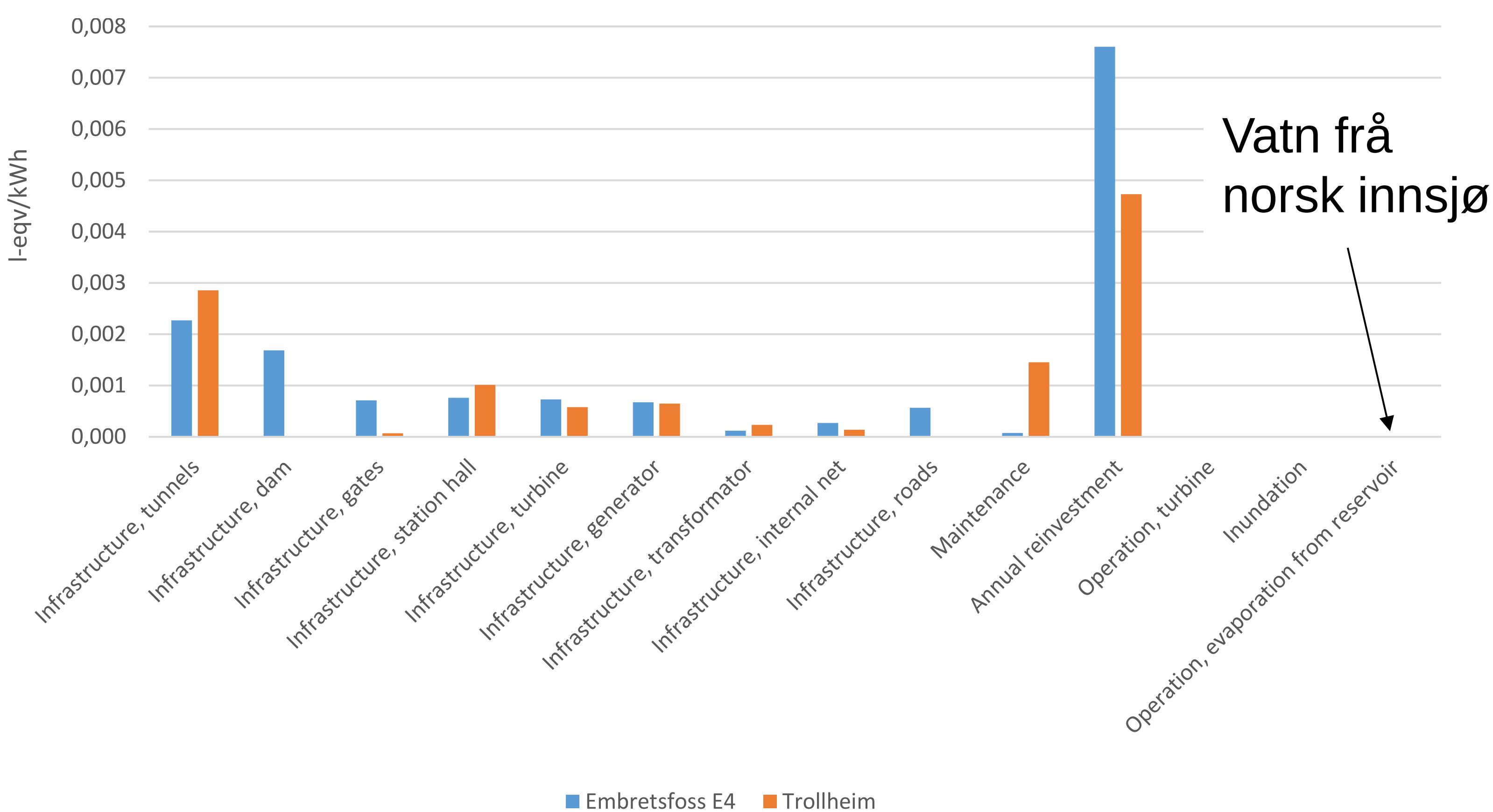
Regionale karakteriseringsfaktorar (eksempel)

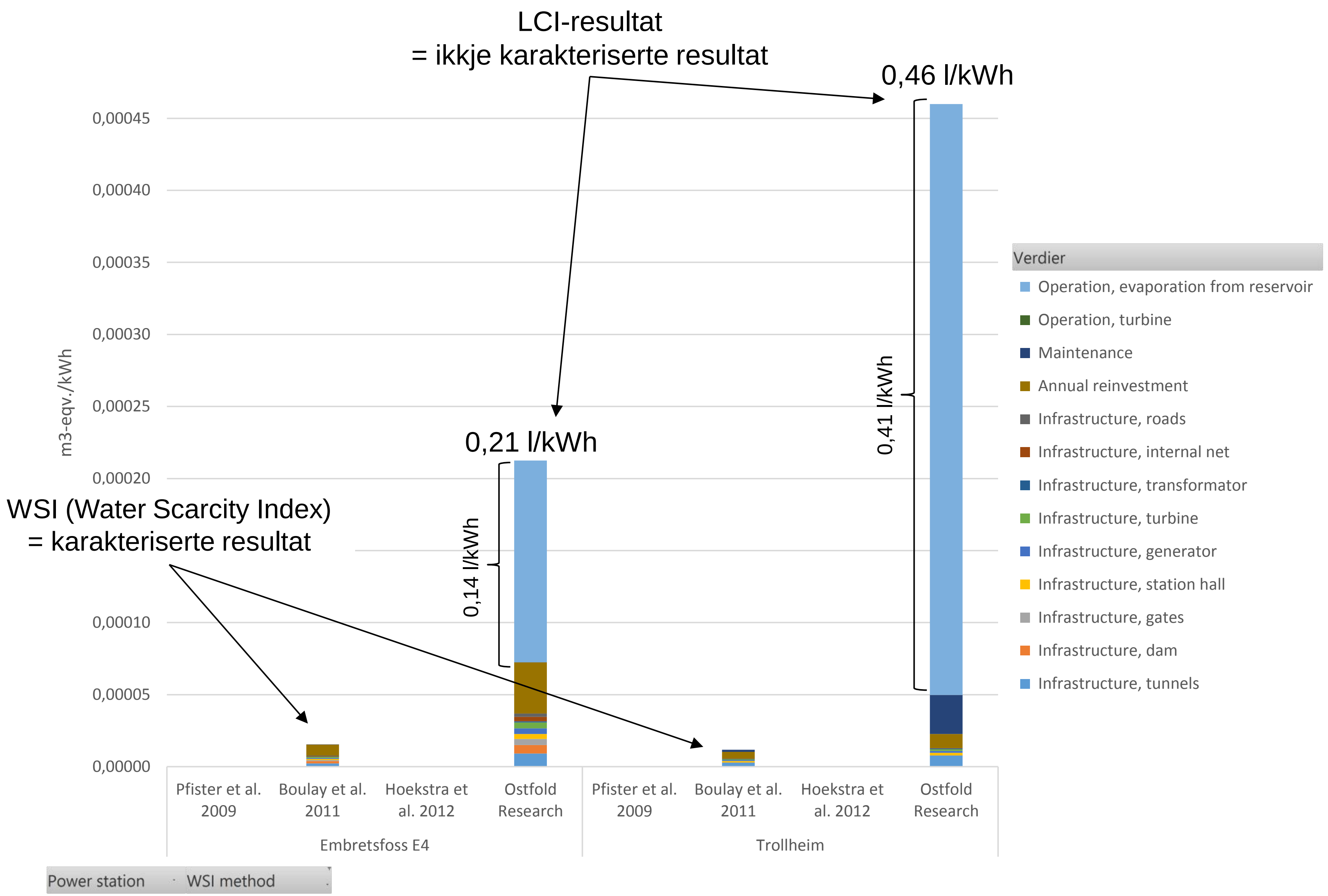
	Water, lake					
Water footprint method	Norway	Germany	Egypt	India	Spain	Unit
Pfister et al. 2009	0,08	0,12	0,98	0,97	0,71	m3/m3
Boulay et al. 2011 (simplified)	0,00	0,04	1,00	0,9997	0,998	m3/m3
Hoekstra 2012	0,34	0,88	0,87	2,44	1,36	m3/m3
Ecological scarcity 2006	0,32	32	13000	1100	990	UBP/m3

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

Mangel i Ecoinvent-databasen: vannforbruk (og frigjort vatn) manglar i enkelte prosessar. Må vente til neste oppdatering med å bruke vannfotavtrykkmetodane.

Foreløpige karakteriserte resultat:
Boulay Water Scarcity Indicator (vannfotavtrykk)

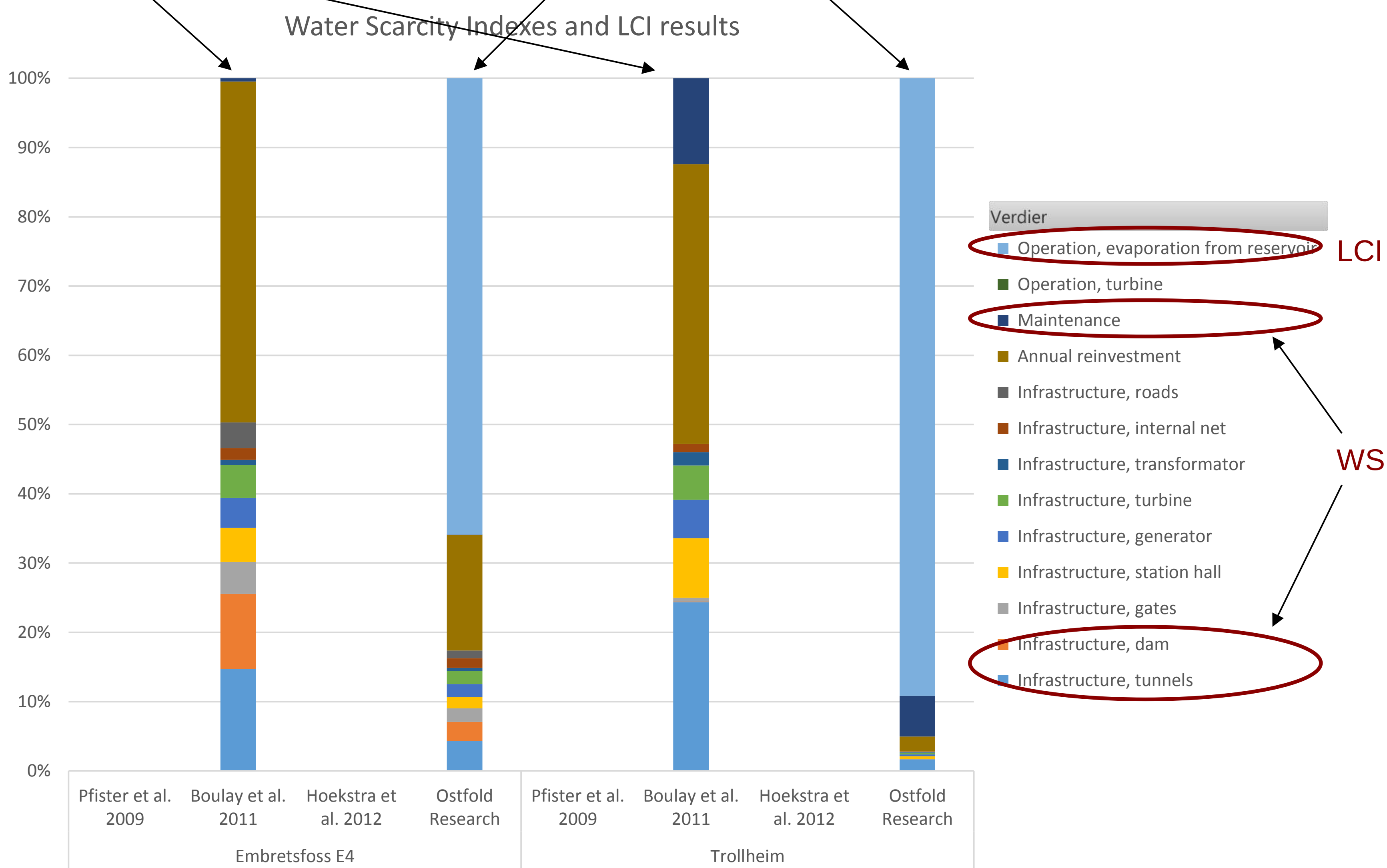



LCI-resultat
= ikkje karakteriserte resultat
0,46 l/kWh
0,21 l/kWh
0,41 l/kWh
0,14 l/kWh
WSI (Water Scarcity Index)
= karakteriserte resultat
m3-eqv./kWh
0,00045
0,00040
0,00035
0,00030
0,00025
0,00020
0,00010
0,00005
0,00000
Pfister et al. 2009
Boulay et al. 2011
Hoekstra et al. 2012
Ostfold Research
Embretsfoss E4
Trollheim
Verdier
Operation, evaporation from reservoir
Operation, turbine
Maintenance
Annual reinvestment
Infrastructure, roads
Infrastructure, internal net
Infrastructure, transformator
Infrastructure, turbine
Infrastructure, generator
Infrastructure, station hall
Infrastructure, gates
Infrastructure, dam
Infrastructure, tunnels
Power station
WSI method

WSI (Water Scarcity Index)
= karakteriserte resultat

LCI-resultat
= ikkje karakteriserte resultat

Relative verdiar



4. Vidare arbeid

Analysere dei to casa EB4 og Trollheim ved bruk av alle vannfotavtrykk-metodane (januar 2015).

Idé: «flytte» kraftverka (og reservoara) for Trollheim og Embretsfoss 4 til ein anna region. Konsekvensar:

- Fordampinga vil sannsynlegvis auke.
- Gitt konstant fordamping: kor mykje vil tilgjengelegheita til vatn påverke totalresultatet?

Skrive og publisere artikkelen «*On the track of the water footprint of hydropower production”.*

Evt samarbeid med WP Ecosystem services: Inkludere arealbruk-metodar (Ecological scarcity 2013, ILCD 2011, ReCiPe) for dei samme casa?