Nye - Assessing the environmental and economic sustainability

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Nye - Assessing the environmental and economic sustainability

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Master thesis project:

Eco-efficiency evaluation of a new urban water system with rainwater collection in Aarhus

- COWI

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aarhusvand

Vision

New urban water system with rainwater collection

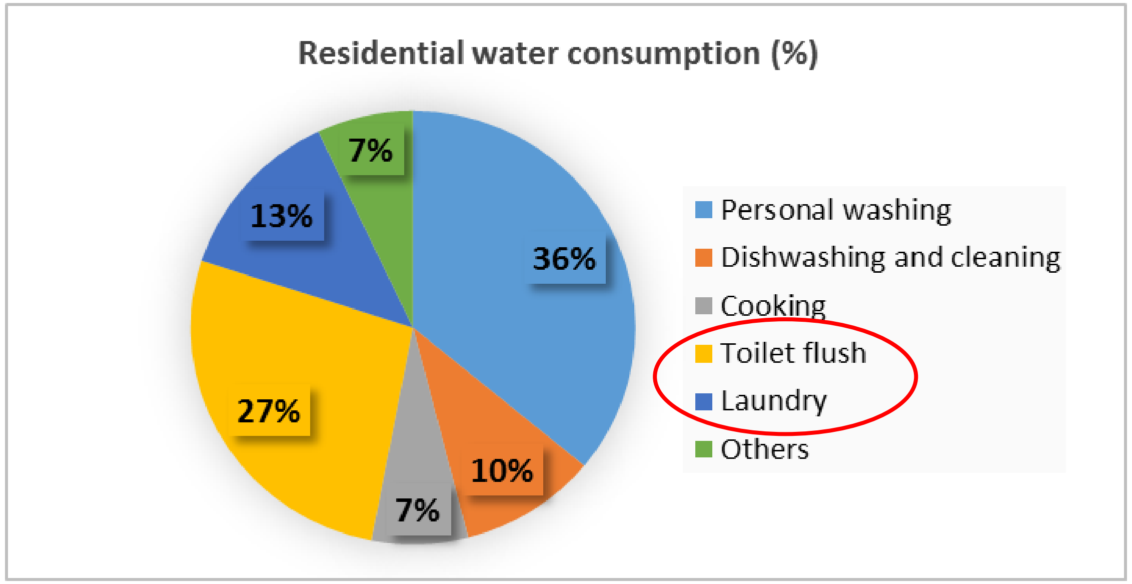
1 Flood protection

2 Rainwater use for toilet flushing and laundry

Area: 200 ha

● Nye (source: Nye Lokal plan, 2016)

Motivation



(source: DANVA, 2013)

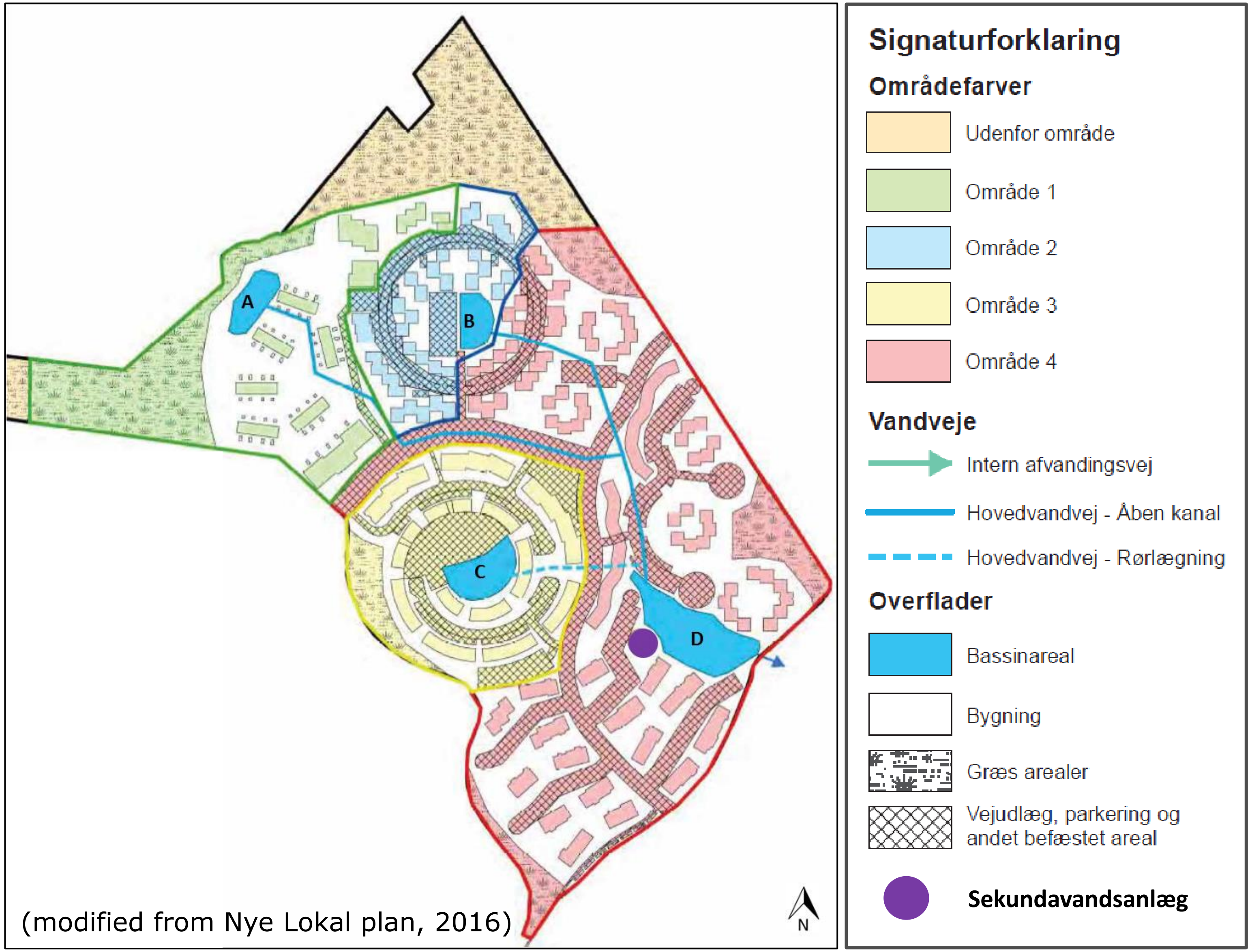
- Aarhus average annual rainfall intensity:

688 mm/year

- Nye 1st phase: ca. 18 ha --> reduced area: ca. 9 ha
- Population: 2,000 inhabitants

- Estimated runoff: ca. 50,000 m^3/y
- Water demand (toilet flushing & laundry): 31,000 m^3/y

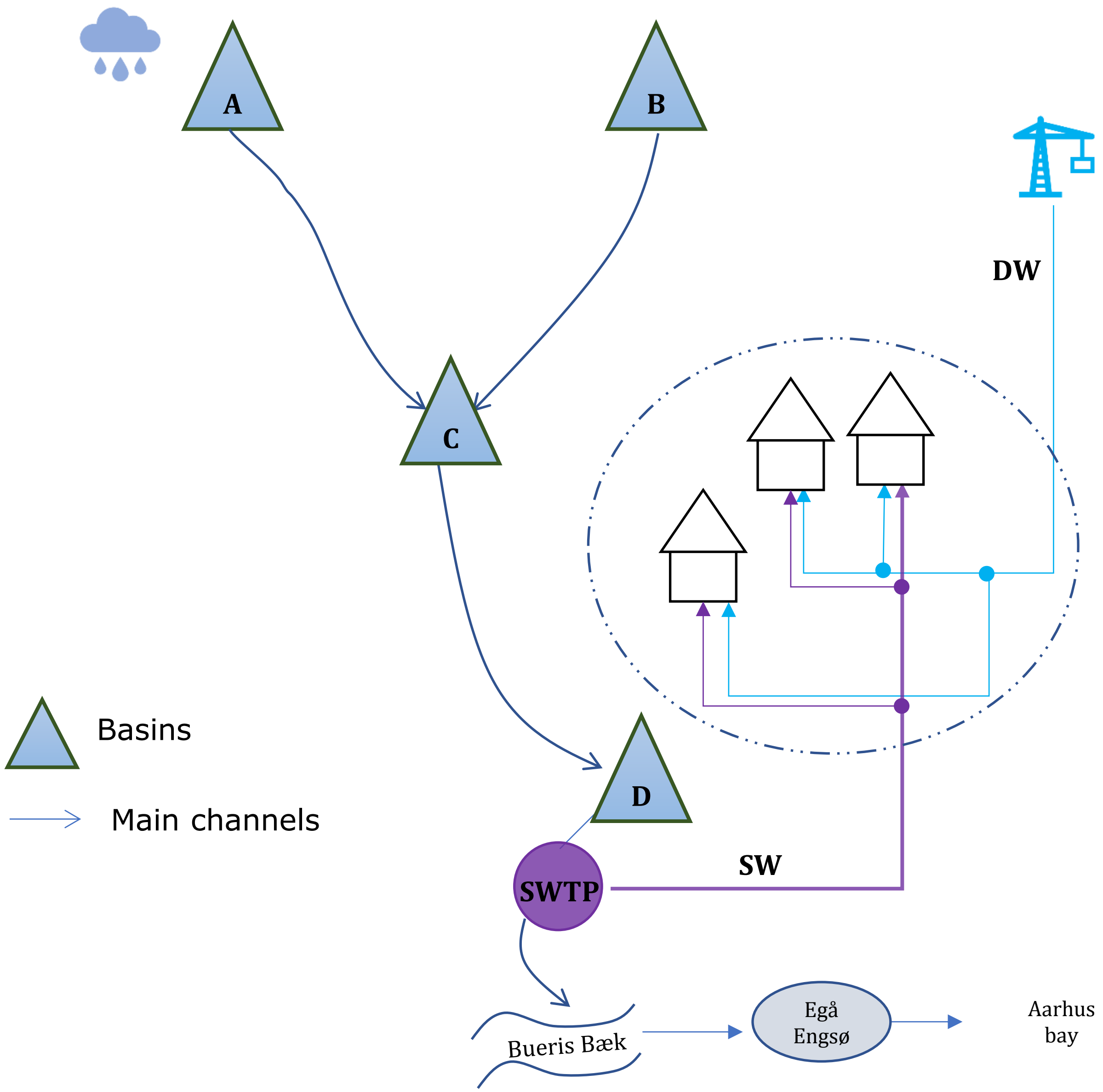
Planning area: Nye, first phase



(modified from Nye Lokal plan, 2016)

- Four main basins: Volume of 8600 m^3
- Trenches/Channels: ca. 1 Km length

Planning area: Nye, first phase



Two water supply networks:

1. **DW network** → potable water demand
2. **SW network** → non-potable water demand
3. **SW Treatment Plant** → capacity ca 6 m^3/h

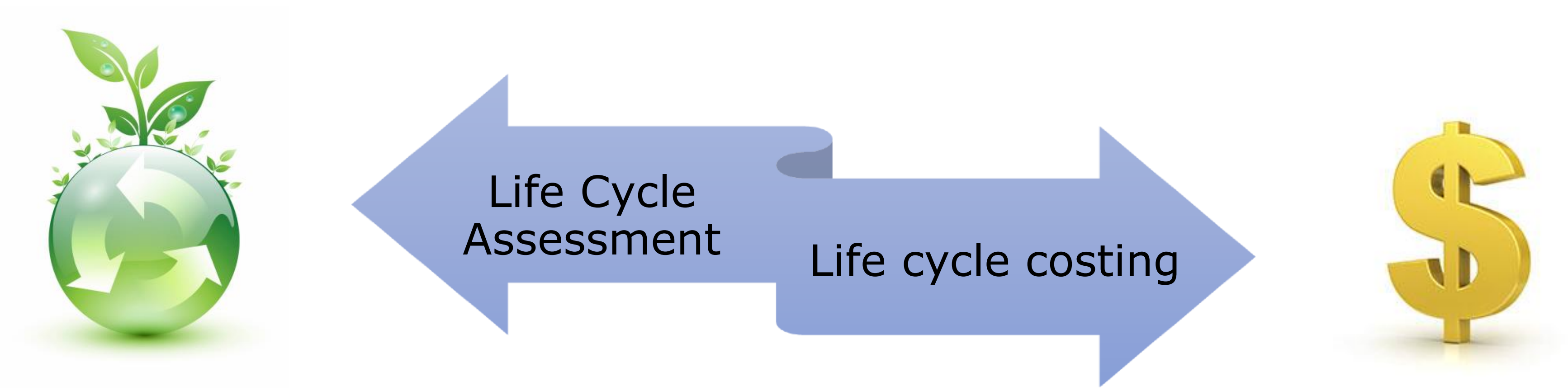
Source	Runoff [m^3/year]	Contribution to the total runoff [%]
Roofs	38,000	76 %
Streets	3,710	8 %
Main roads	5,838	12 %
Other	1,820	4 %
Total	50,000	

Aim of the master thesis project

Sustainability Assessment

- ✓ Assess the sustainability of options for collecting and re-using the rainwater for non-potable use as an alternative to conventional groundwater-based drinking water in Nye, Aarhus

- ✓ Two dimensions of sustainability: Environmental and Economic



Eco-efficiency

Methodology: Eco-efficiency

Phases:

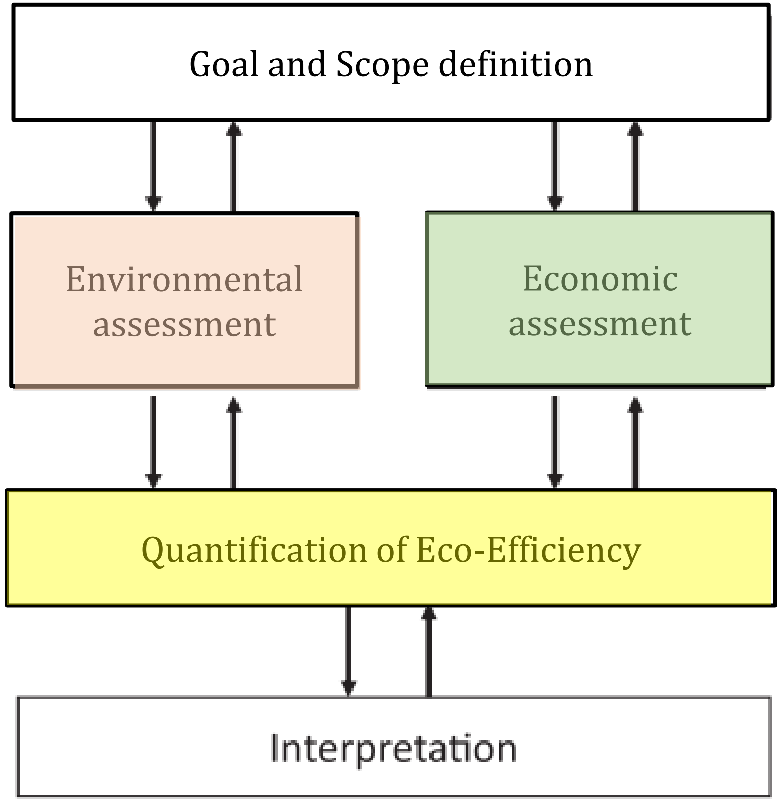


Fig. 1. Phases in eco-efficiency assessment according to ISO 14045 (ISO 14045, 2012).

Tools:

Life cycle assessment (LCA)

Life cycle costing (LCC)

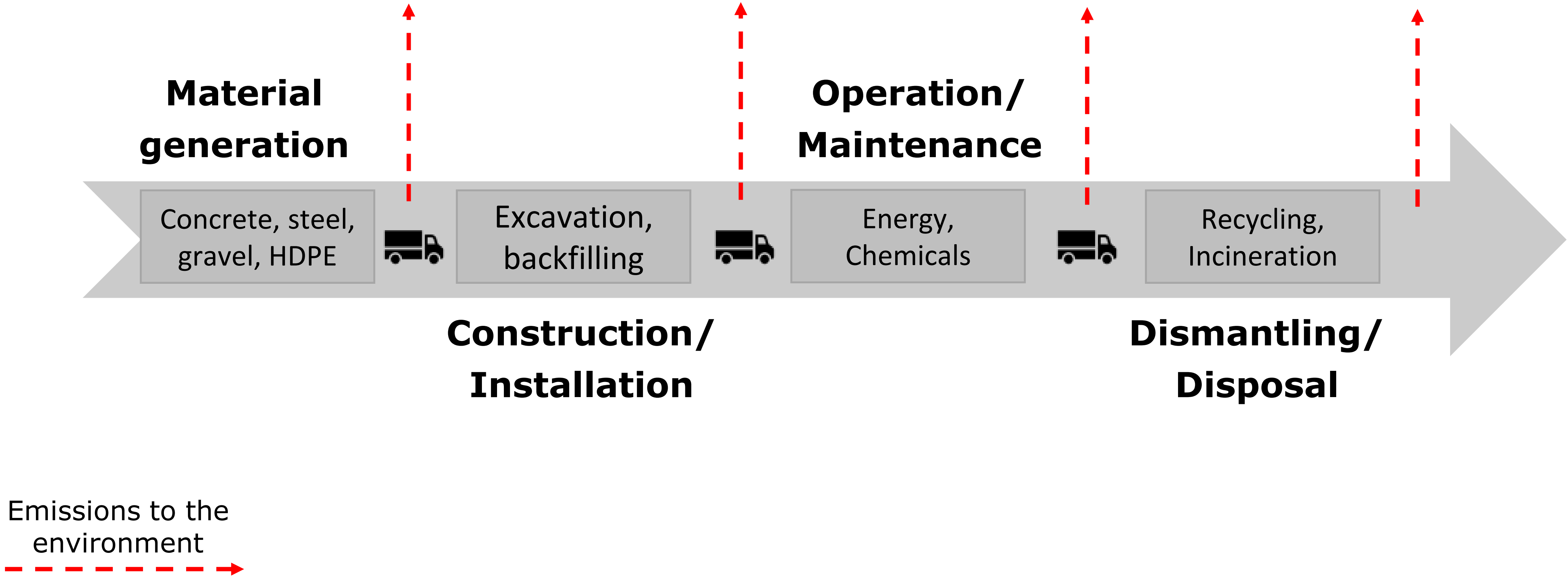
$$System\ value = \frac{1}{LCC}$$

$$\text{Eco-efficiency} = \frac{\text{System value}}{\text{Environmental Indicators}}$$

Methodology: LCA

ISO 14040: 2006

Cradle to grave approach → Inventory of materials' consumption and emissions along the life cycle



Methodology: LCA

Example of a life cycle **inventory analysis**

Secondary Water pipes				
Process: SW pipes	**Amount**	**Unit**	**Assumptions/Calculations**	**Source**
Material: HD-PE	1841	Kg	Estimated from total length, volume, and density	Aarhus Vand/ AV-Wavin
Transportation of pipes to construction site	46211	Kg.km	Distance 25.1 Km	See Appendix F-I
Construction: Excavation volume	1699	m^3	Estimated	See Appendix F-I
Construction: Filling with soil from another construction site	448521	Kg	22 % of total excavated volume is filled with soil from another construction site.	See Appendix F-I
Transportation of soil from another construction site	2242604	Kg.km	Distance: 5 Km	See Appendix F-I
Operation: Distribution energy of the secondary water	127357	Kwh	Specific energy: app. 0.2 Kwh/m^3, estimated through Haaland and Darcy-Weisbach equation.	See Appendix P
Decommissioning: Excavation volume	1699	m^3	Assumption	See Appendix F-I
Disposal: HD-PE	1565	Kg	85 % recyclable	See Appendix F-I
Life time SW pipes	100	years	It is assumed that the system is dismantled after 25 years, and thus the recycling occur at the end of the 25 years even though the life time of the pipes can be up to 100 years	

Methodology: LCA

Inventory of inputs and outputs

Secondary Water pipes				
Process: SW pipes	**Amount**	**Unit**	**Assumptions/Calculations**	**Source**
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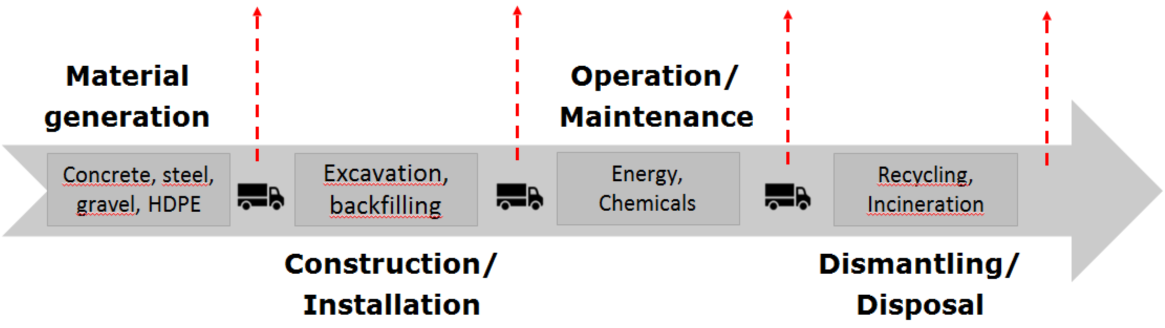
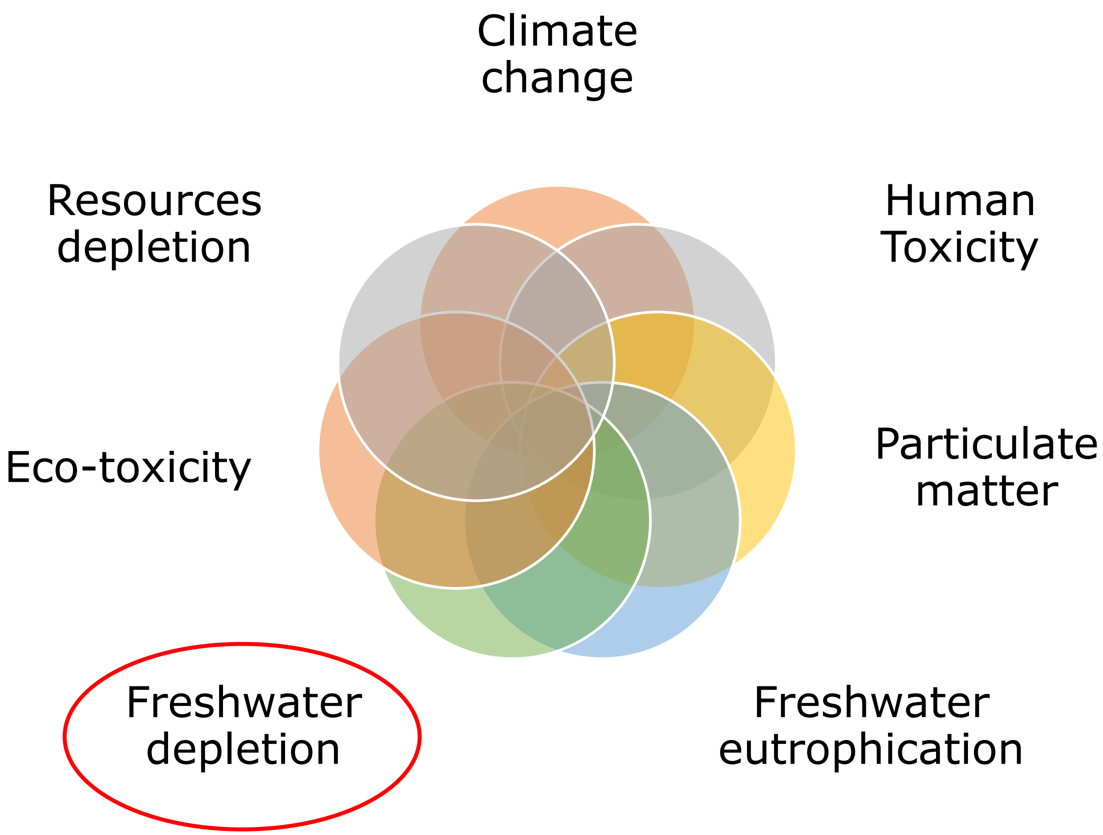


Impacts



ILCD methodology

Methodology: Life Cycle Costing

$$LCC = C_{IC} + C_C + C_{OM}$$

C_{IC}: Initial Costs
C_C: Construction and installation costs
C_{OM}: Operational and Maintenance costs

Amortization Formula:

$$C = P\left(\frac{r(1+r)^n}{(1+r)^n - 1}\right)$$

P = initial investment
r = annual interest rate
n = life time or number of payments

$$System\ value = \frac{1}{LCC}$$

Lower costs – Higher System value

Alternatives' definition

Alternative	Description	Source	Water treatment			Transport	Use	
A0-GW	BAU: Groundwater only	GW abstraction	Aeration & Filtration	UV	DW	DW pipes	Toilet flushing and laundry	+ RW collection: roofs and roads
CT1 UF-UV	Centralised SW Treatment UF-UV	RW collection	Ultrafiltration	UV	SW	SW pipes	Toilet flushing and laundry	
CT2 UF-H_2O_2	Centralised SW Treatment UF-H_2O_2	RW collection	Ultrafiltration	On-site H_2O_2	SW	SW pipes	Toilet flushing and laundry	
CT3 RO-UV	Centralised SW Treatment RO-UV	RW collection	Reverse osmosis	UV	SW	SW pipes	Toilet flushing and laundry	
DT-RWH	Decentralised private RWH systems	RW collection from roofs	Stainless steel filter	PVC underground tanks	SW	Direct pumping + PP pipes	Toilet flushing and laundry	+ RW collection: roads

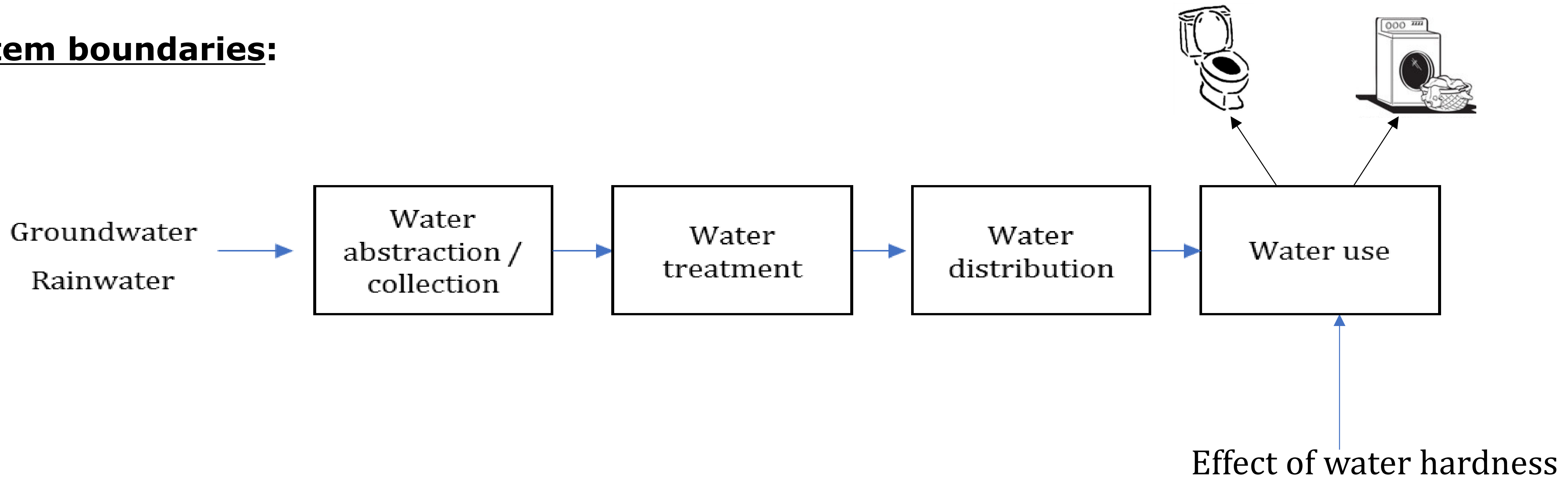
Functional Unit and System boundaries

Functional Unit:

"An urban water system aimed at *providing 31000 m^3/year of water for non-potable applications, to 2000 inhabitants in Nye, while protecting from flooding"*

Assessment time: 25 years

System boundaries:



Results

1 **LCA**

- ✓ Total normalised impacts
- ✓ Life stages contribution
- ✓ Overall comparison
- ✓ Effect of runoff pollutants

2 **LCC**

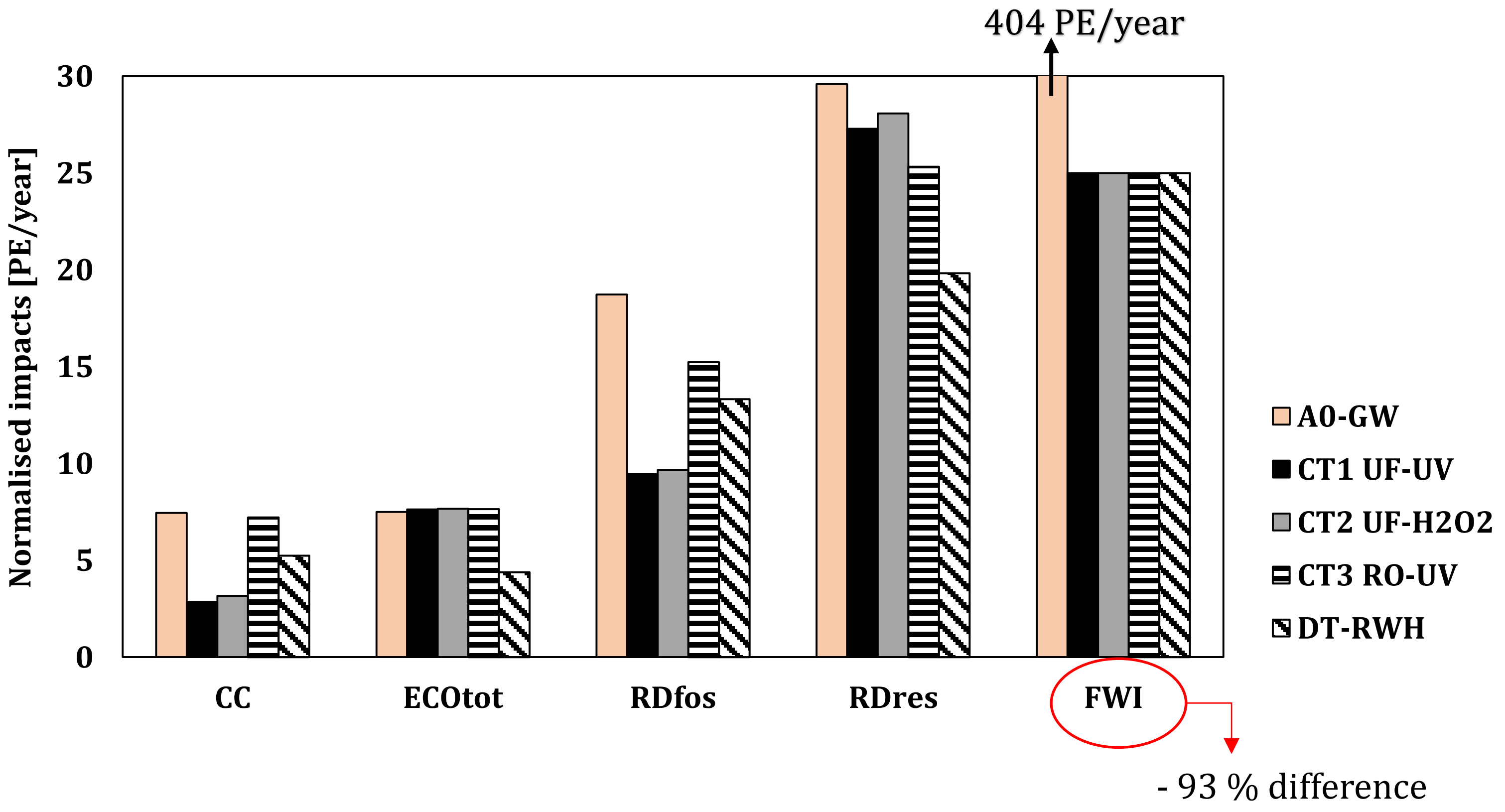
- ✓ Total costs
- ✓ System value

3 **Eco-efficiency**

- ✓ EEA quantification
- ✓ Overall interpretation

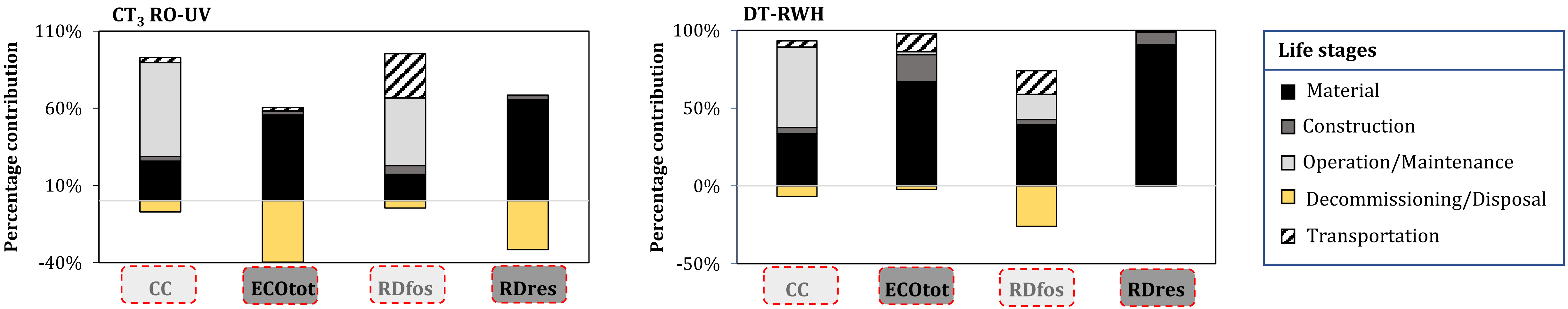
1. LCA: Total Normalised Impacts

- ✓ The performance of A0-GW is the worst → due to the relative increase in energy and detergents consumption at the end-user level
- ✓ Large percentage difference between A0 and the other alternatives in the Freshwater Withdrawal Impacts
- ✓ Only in the Eco-toxicity, A0 performs slightly better compared to CT1, CT2, and CT3 (2 % lower impacts)

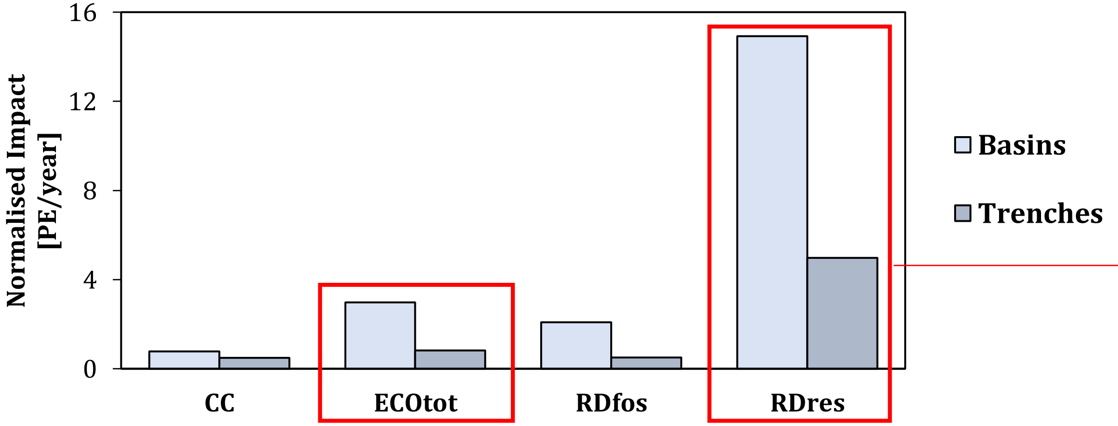


Abbreviation	Impact category name
CC	Climate Change
ECOtot	Eco-toxicity (total)
RDfos	Resource Depletion (fossil)
RDres	Resource Depletion (reserve base)
FWI	Freshwater Withdrawal Impacts

1. LCA: Life stage's contribution/performance

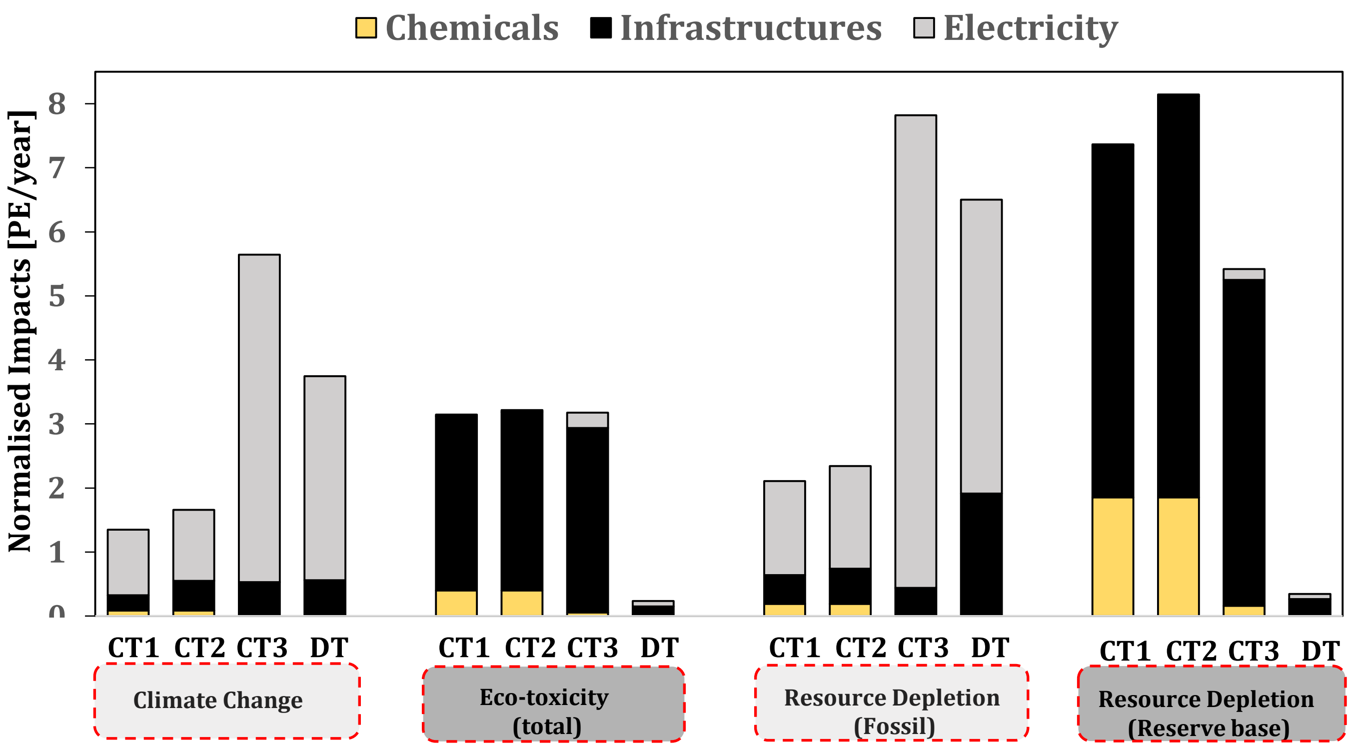


- ✓ Operation and Maintenance (OM) contributes to CC and RDfos
- ✓ Materials contribute to ECOtot and RDres



Dominance of materials coming from the stormwater collection system

1. LCA: Overall comparison of the alternatives with rainwater use



- ✓ The electricity in OM was found to be the most impacting parameter in Climate Change and Resource Depletion (Fossil)
- ✓ The infrastructures (s. steel components) were found to be the most impacting in Eco-toxicity and Resource Depletion (reserve base) expect for DT-RWH
- ✓ The chemicals' consumption showed significant impacts in CT1 and CT2 in particular in the Resource Depletion (reserve base)

Alternatives
CT1 UF-UV
CT2 UF-H2O2
CT3 RO-UV
DT-RWH

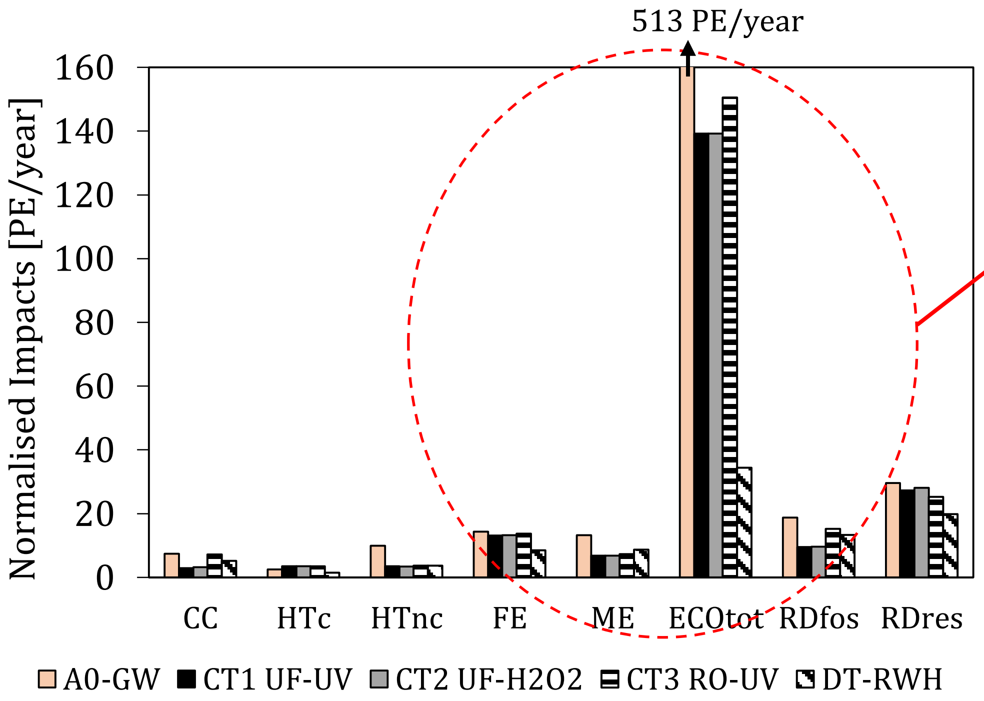
1. CT1 and CT2 seem the most sustainable according to *Climate Change* and *Fossil* Resource Depletion ↓ Energy consumption

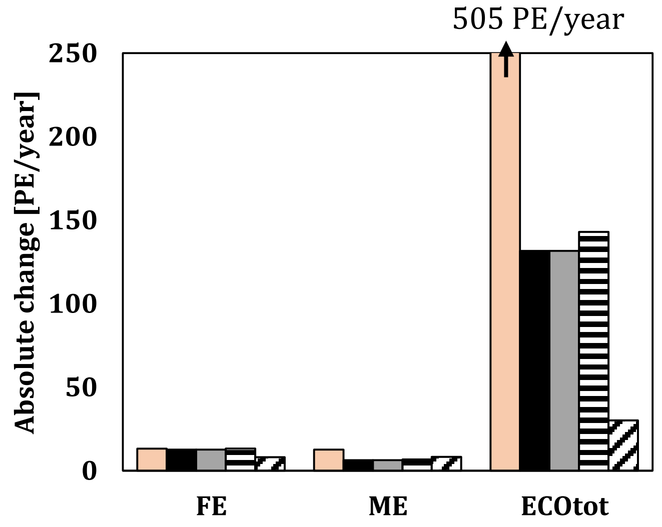
2. DT seem the most sustainable according to *Eco-toxicity* and *Reserve base* Resource Depletion ↓ Chemicals consumption and s. steel amount

1. LCA: Inclusion of the effect of runoff pollutants

Pollutants
TSS
Lead
Cadmium
Chromium
Copper
Zinc
Nickel
Mercury
16PAH
Nitrogen
Phosphorus
COD
BOD
Iron
Aluminium

- ✓ Increased Impacts in Ecotoxicity, freshwater, and marine eutrophication
- ✓ DT shows the best performance → filter rejection sent to WWTP discharging in Aarhus Bay

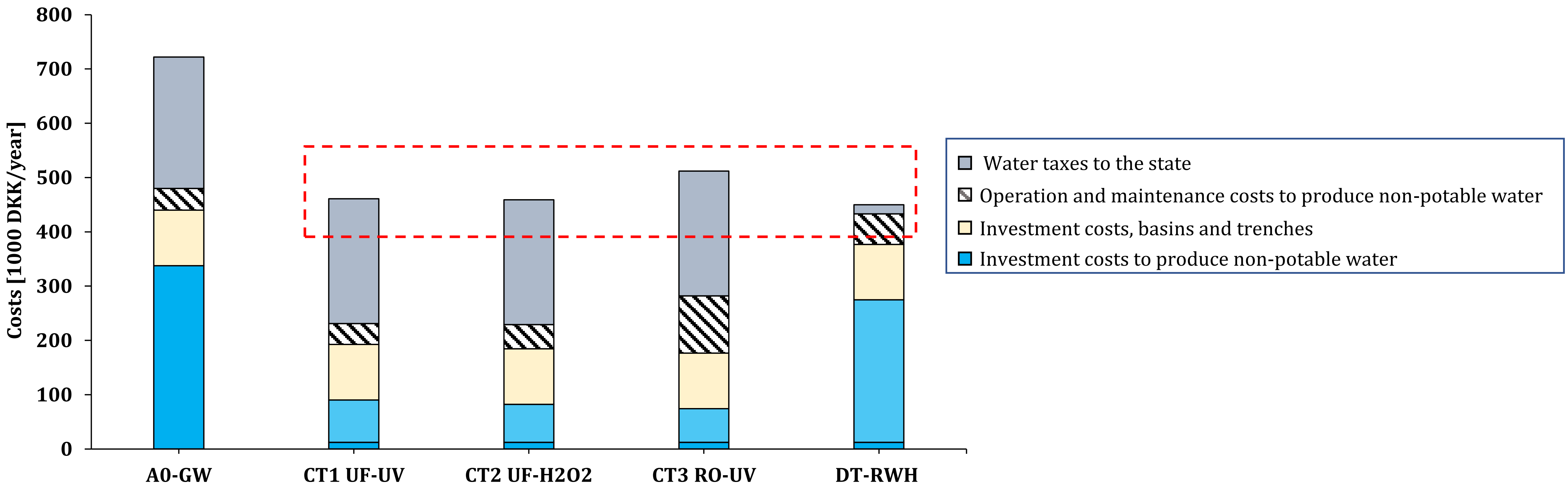




2. LCC: Total annual costs and system value

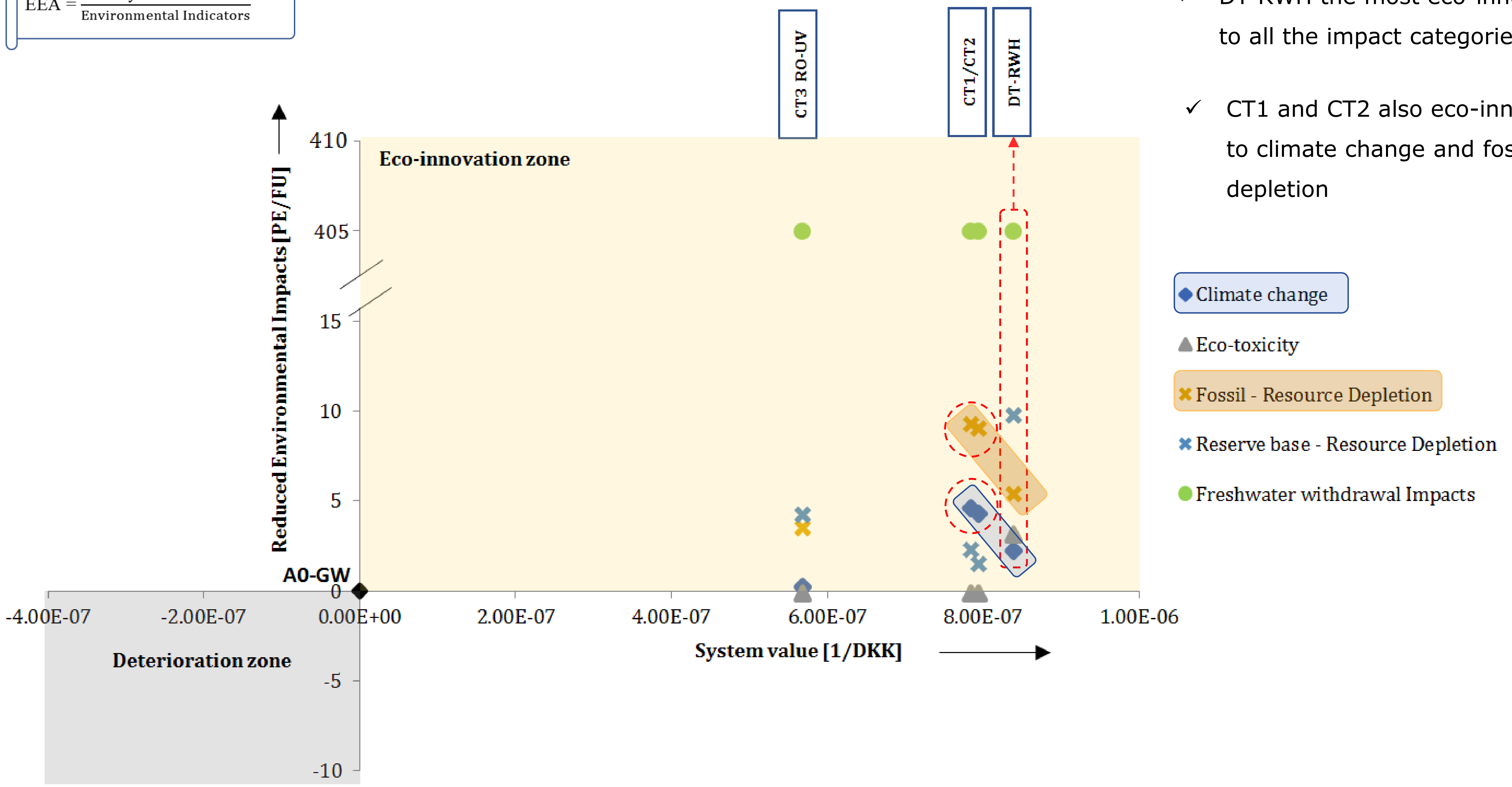
- ✓ A0 is more costly than the alternatives with rainwater use (around 30 %)
- ✓ Investment costs are the highest if we exclude water taxes
- ✓ Compared to A0, the alternatives with rainwater use show higher system value (lower costs)
- ✓ DT-RWH shows the lowest costs and the highest system value (3 – 14 % higher system value)

$$\text{System value} = \frac{1}{\text{LCC}}$$



3. Eco-efficiency assessment

$$EEA = \frac{\text{System value}}{\text{Environmental Indicators}}$$



- ✓ DT-RWH the most eco-innovative according to all the impact categories
- ✓ CT1 and CT2 also eco-innovative according to climate change and fossil resource depletion

Limitations and future perspectives

Limitations in the LCA assessment:

1. Effect of the temperature of the rainwater during winter→ not included
2. Water balance based on estimates provided by Aarhus Vand
3. Rainwater quality estimates missing: derived from literature

Limitations in the Economic assessment:

1. Secondary water price not yet estimated by Aarhus Vand
2. Missing costs were found through online search and literature
3. Costs of avoiding flooding and non-monetized costs not included
4. Total value added of each actor involved instead of system value calculated through LCC

Conclusion

With respect to the LCA assessment:

1. The alternatives with rainwater use are more sustainable than the BAU scenario → Lower Freshwater withdrawal impacts and lower energy and laundry detergents consumption at the households' level
2. The most influential life stages: Operation and Maintenance (electricity and chemicals) and materials' generation (basins, trenches, tank materials)
3. The treatment of rainwater with ultrafiltration (CT1 and CT2) was found to be the most sustainable according to climate change and fossil resource depletion.
4. The private rainwater harvesting systems (DT-RWH) the most sustainable according to Eco-toxicity and Resource depletion reserve base
5. The inclusion of the runoff pollutants increased the relevance primarily of the Eco-toxicity and secondarily of freshwater and marine eutrophication

Conclusion

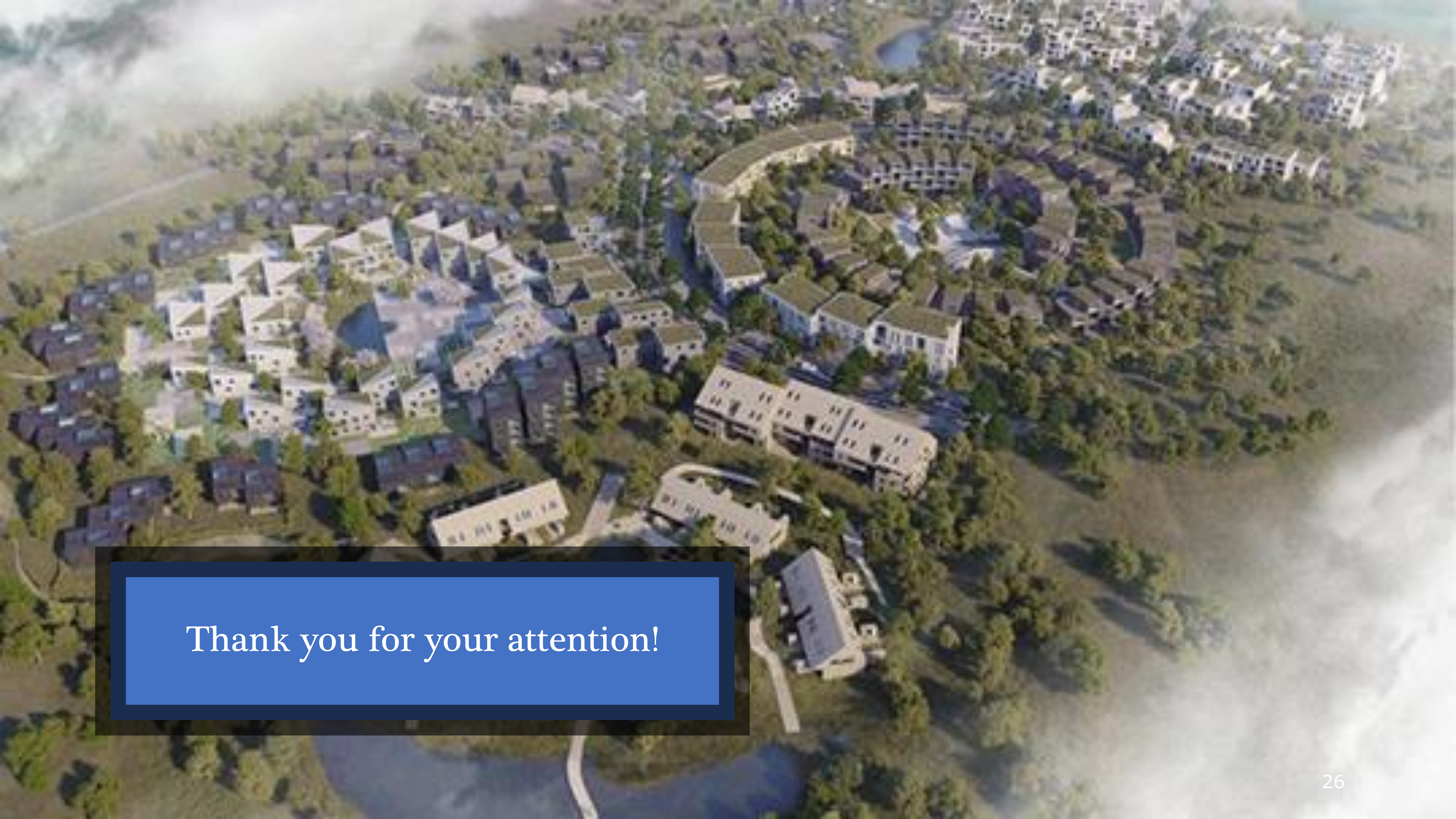
With respect to the Economic assessment:

1. The alternatives with rainwater use are less costly (around 30 %) than A0
2. The performance of the alternative with rainwater use are almost the same and the system value does not differ significantly between the alternatives
3. The decentralised private rainwater harvesting (DT-RWH) has slightly higher system value (2-14 %) compared to the centralised alternatives

Conclusion

With respect to the Eco-efficiency assessment:

1. LCA impacts were found to be the deciding factor in the selection of the most eco-efficient alternative
2. The DT-RWH is found to be the most eco-innovative according to all the impact categories
3. The alternatives CT1 and CT2 are "eco-innovative" according to Climate change and Fossil resource depletion
4. The urban water system in Nye can be considered a role model for sustainable and self-sufficient cities.



Thank you for your attention!

Questions?