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Demonstration of promising technologies to address emerging pollutants in water and waste water

WA 5: Fostering the uptake of novel technologies in the water sector

LCA and LCC of powdered activated carbon adsorption with ultrafiltration by polymeric and ceramic membranes for wastewater: Case study in Birsfelden (CH)

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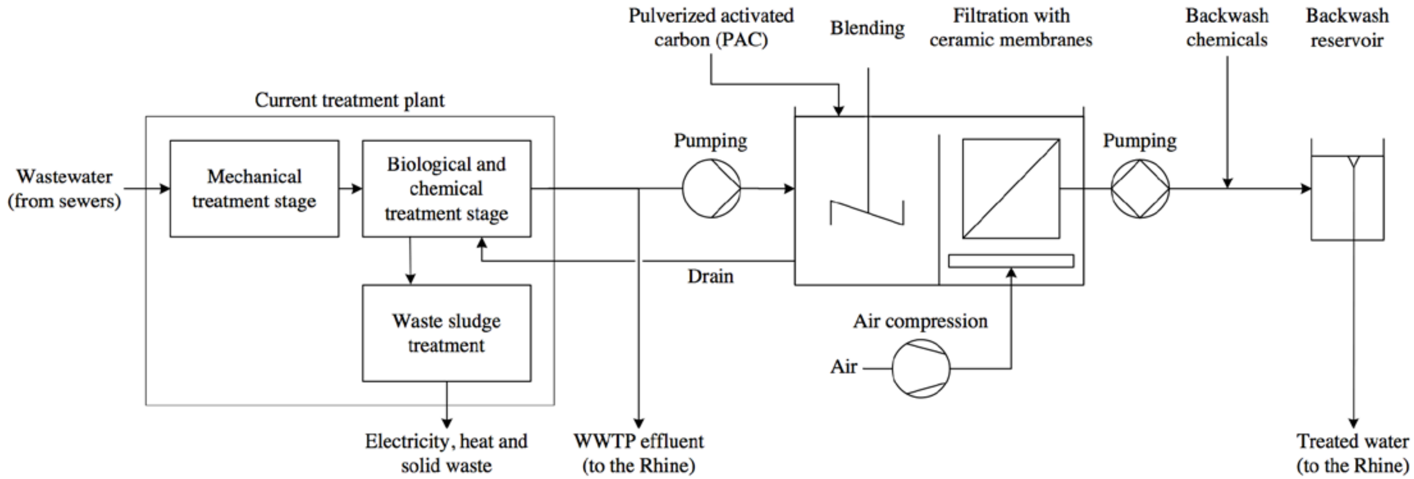
Case study in Birsfelden

- Case study: Powdered activated carbon adsorption (PAC) with ultrafiltration (UF) by polymeric and ceramic membranes (HPMS and **HCMS**) for micropollutant removal from wastewater
- Application at pilot scale; LCA and LCC based on a full-scale design (master thesis at FHNW and RWTH: *Sustainability assessment of micropollutant sequestration from pre-treated wastewater via hybrid ceramic membrane processing*, Ch. Oberschelp)
- Scenarios
  1) Baseline Scenario: Status Quo (without membrane filtration)
  2) HCMS: Status Quo + HCMS (infrastructure and operation)
  3) HPMS: Status Quo + HPMS (infrastructure and operation)

HCMS – studied system

- The micropollutant removal system is the final treatment step
- At this final stage, **pulverized activated carbon (PAC)** is dosed to the water stream which is then thoroughly mixed
- Adsorption of **micropollutants** and also **residual phosphorus** onto the surface of the activated carbon starts immediately
- The mixture of activated carbon and wastewater is separated by a contact reactor that contains **submerged membrane modules**
- An **under-pressure** is applied to the membranes as driving force so the water molecules permeate through the membrane pores
- A **disinfection effect** takes place because bacteria cannot pass the membranes either



Assumptions and key figures

Lifetime of membranes*

- Ceramic: Average lifetime of 12 years.
- Polymeric: Average lifetime of 7 years.

Cost of membranes*

- Ceramic: Price of 200 EUR m^{-2} is assumed
- Polymeric: Price of 60 EUR m^{-2} is assumed

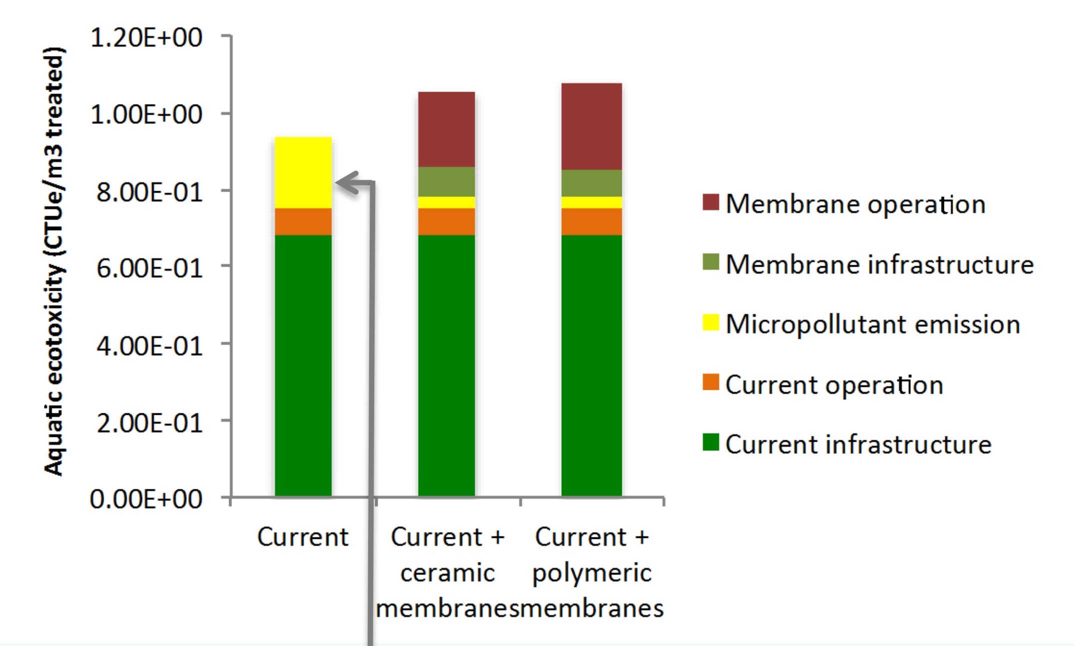
Energy cost: 0.12 CHF kWh^{-1}

PAC dose: 15 mg L^{-1}

Aeration: 0.3 m^3 m^{-2} h^{-1}

* based on manufacturer data

LCA: Aquatic ecotoxicity



Freshwater ecotoxic impact of the wastewater treatment plant emissions when considering only 25 organic micropollutants (no heavy metals)

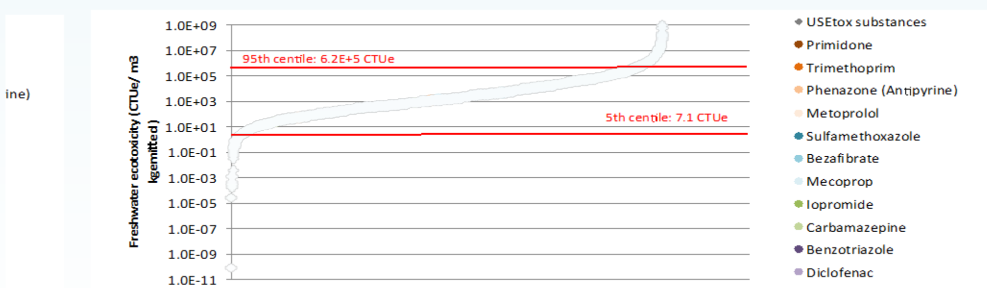
Aquatic ecotoxicity, , intermediate results with 25 substances:

- **In the baseline scenario, the aquatic ecotoxicity is** dominated by current infrastructure
- The benefit of the micropollutant removal through membrane filtration is **visible**. However, when **considering only 25 substances**, this impact reduction does not completely compensate for the additional toxic emissions generated by the membrane operation (mainly electricity and heat)

LCA: Toxicity extrapolation

Extrapolation

- Given that monitoring data for 25 micropollutants was available, we extrapolated the (eco)toxicity score to the entire micropollutant load present in municipal wastewater
- **Micropollutant load**: We estimated total micropollutant load as an average of the load reported in Schwentner (2011), Margot et al. (2013) and Goetz et al. (2010)
- **Toxicity uncertainty**: Given the lack of knowledge on the average toxicity of the entire micropollutant load, we generated a toxicity characterization factor for 3 scenarios: **5th percentile**, median and **95th percentile** of the toxicity of the 3074 organic substances covered in USEtox
- **Substance removal**: We assume that 76% of substances are removed over the membrane treatment (average over 26 monitored substances in Margot et al. 2013, Sterkele et Gujer 2009 and Löwenberg 2014)



Comparison of the toxicity of the substances monitored at the Neugut wastewater treatment plant (per kg substance emitted) compared with organic substances covered in the USEtox database

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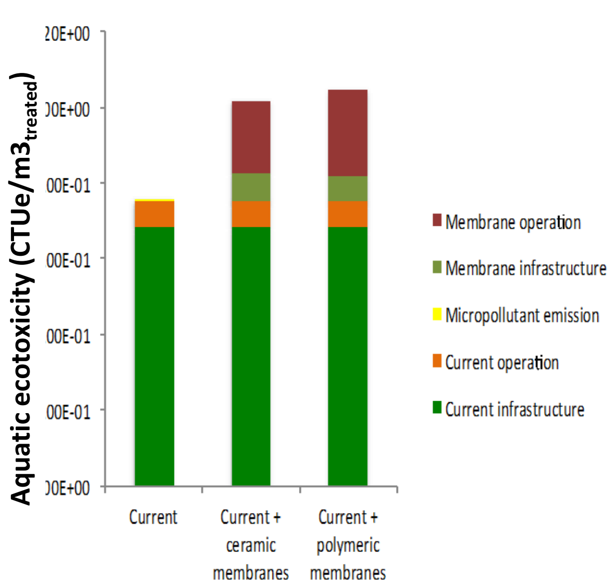
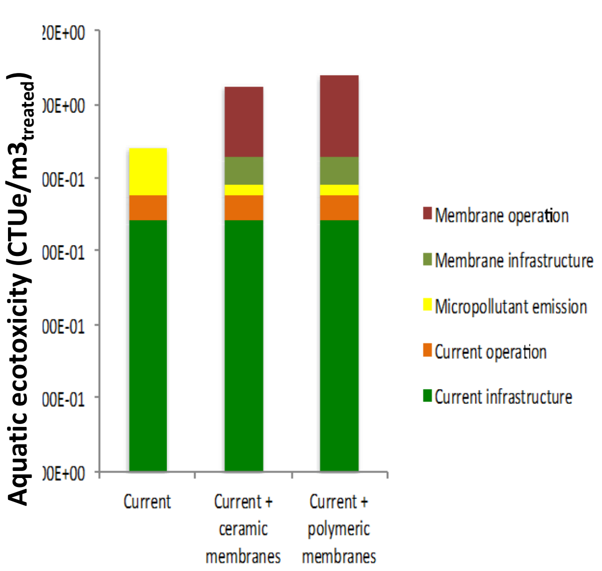
LCA: aquatic ecotoxicity extrapolation

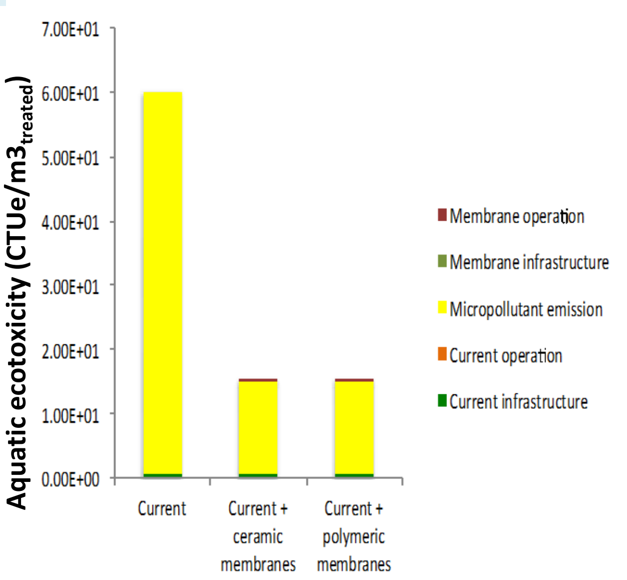
CF 5th centile: 7.1 CTUe/kg$_{emitted}$



CF median: 1.36E+3 CTUe/kg$_{emitted}$

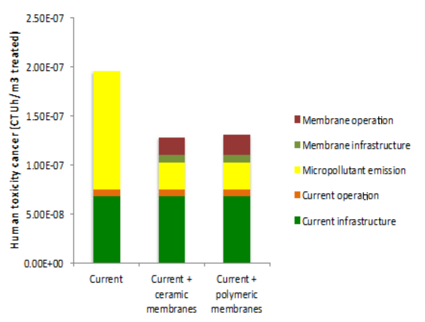


CF 95th centile: 6.2E+5 CTUe/kg$_{emitted}$

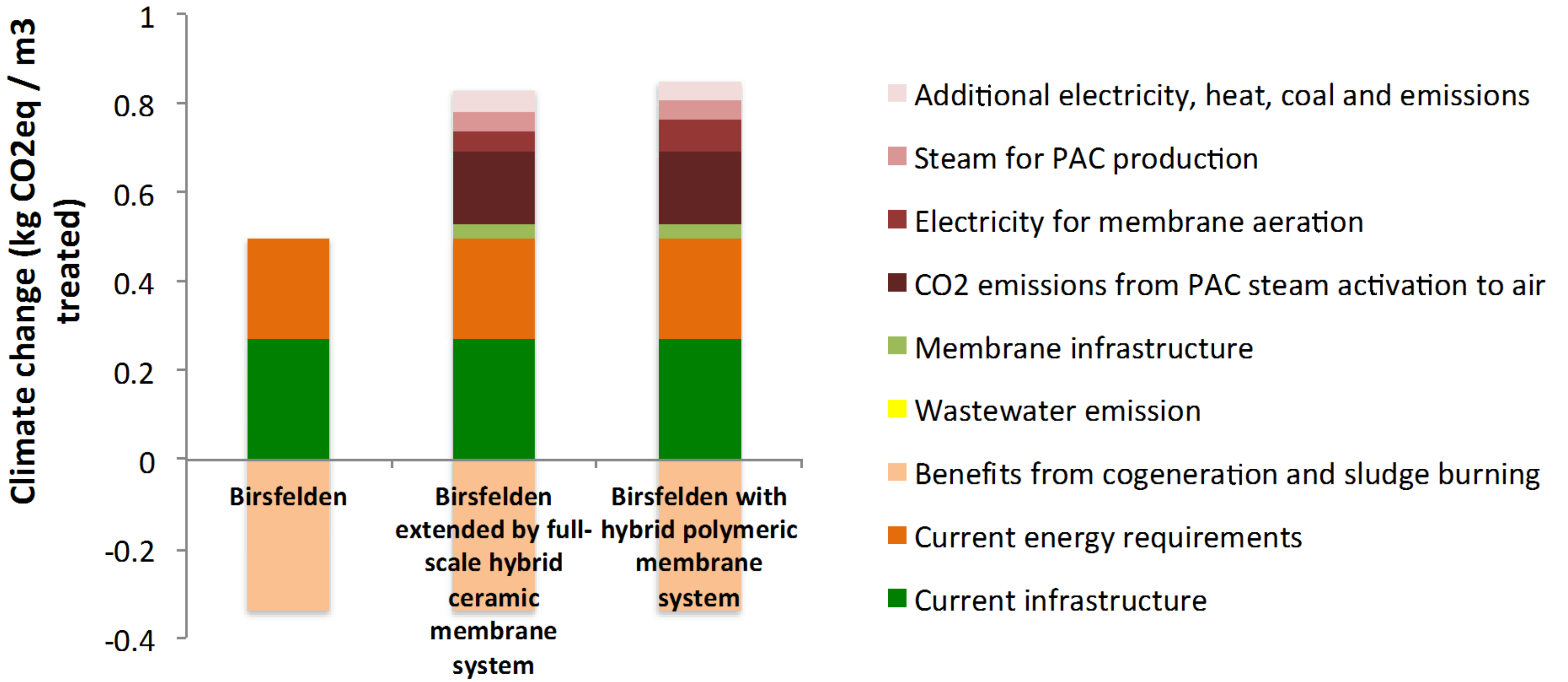


Aquatic ecotoxicity extrapolation

- Micropollutant emissions represent a significant contribution to the impact on aquatic ecotoxicity **from a median to high toxicity**
- Based on our initial assumption, the HCMS system **reduces the impact of micropollutants by 76%**.
- For a micropollutant load which is at a medium to high toxicity range, the HCMS has a net benefit in terms of aquatic ecotoxicity



LCA: Climate change



Climate change, intermediate results:

- In **baseline scenario**, the main impacts come from the **current infrastructure** (concrete and metal). The current plant operation sums overall as a net climate change benefit due to the production of heat and electric energy
- The **ceramic and polymeric membrane scenarios increase CO_2 emissions due to PAC activation** and electricity requirements for membrane aeration

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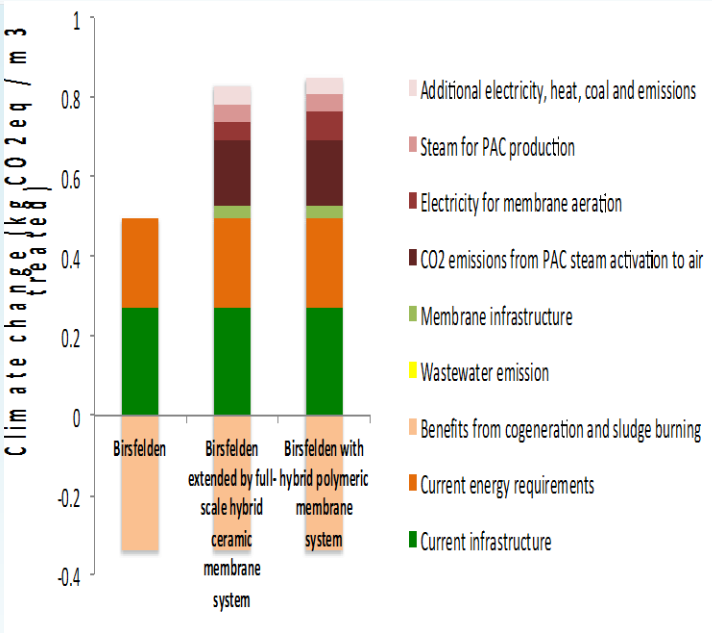
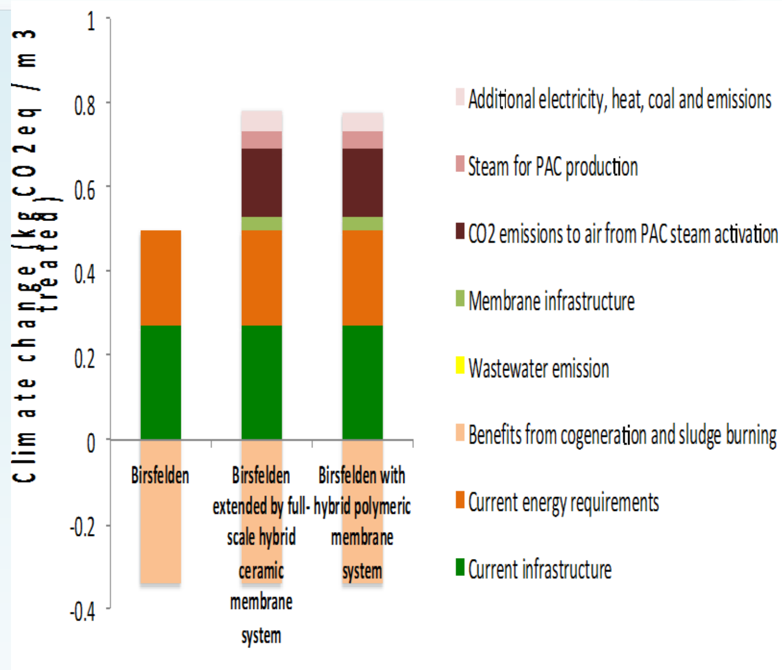
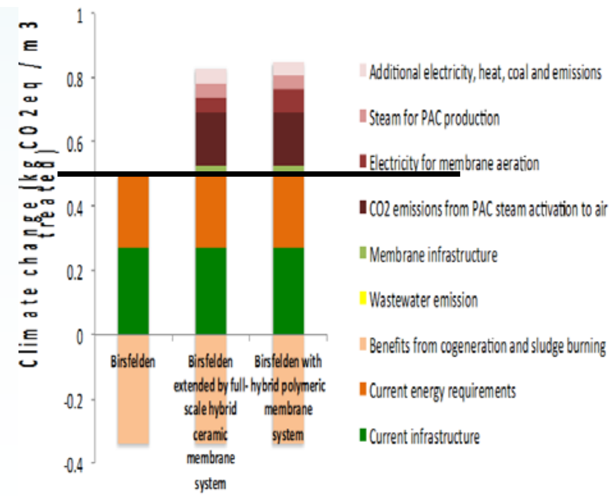
LCA: Climate change



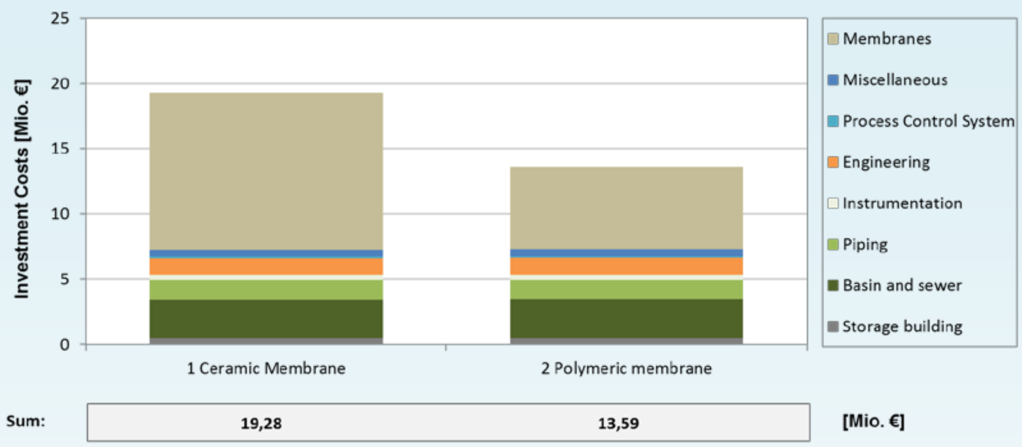


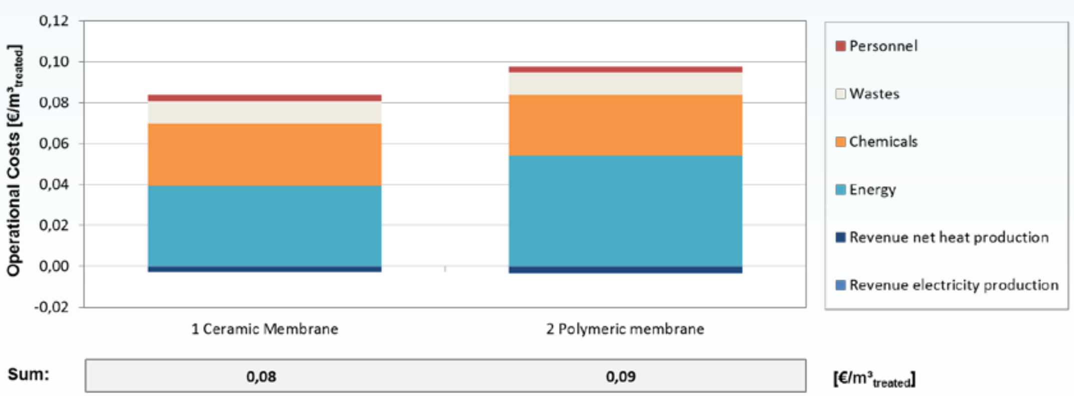
Scenario with pressurized membrane:

- The suspended membrane system at Birsfelden needs aeration which can be avoided with a pressurized system (other case study in Demeau by RWB, KWR and FHNW)
- No more electricity for membrane aeration → reduced impacts related to membrane operation



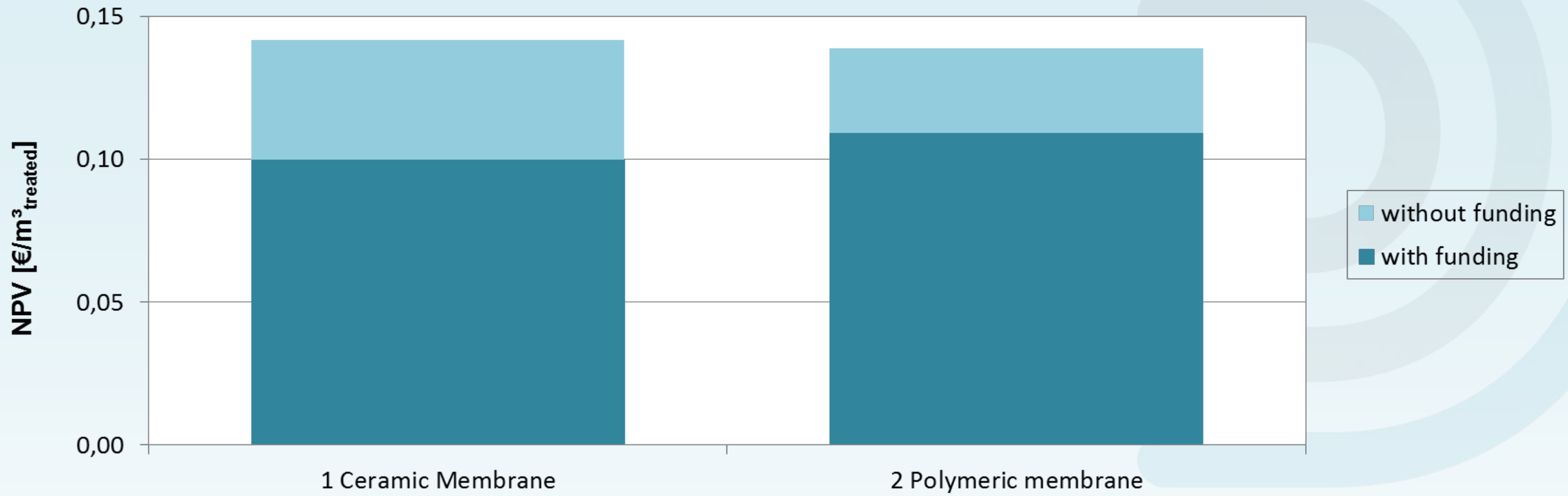
LCC: CAPEX and OPEX





- The estimated **additional investment costs for the ceramic membrane system are 42 % higher** compared to the polymeric system for a full-scale extension of the current treatment plant.
- The largest fraction of these costs is due to the **membrane price** (assumption: 200 € per m^2 for ceramic membrane; 60 € per m^2 for the polymeric membranes).
- In contrast, **operating costs for the ceramic membrane system are about 16 % lower** in comparison to those of the polymeric membrane system (0.15 Mio €/a).
- The difference is mainly caused by the **reduced energy demand** needed for the ceramic membrane process.

LCC: NPV per m³ treated



Sum:	0,10 / 0,14	0,11 / 0,14	[€/m³treated]

- The **Swiss government offers a subsidiary** for technologies against micropollutants in WWTPs by which costs for the **initial investment costs can be lowered by 75 %**. After the first replacement of equipment full costs have to be paid by the operator.
- **Without funding,** the net present value (over the course of 30 years) is about 1.0 million EUR higher for ceramic membranes than those of polymeric membranes.
- **Including this funding,** the cost advantage shifts from polymeric membrane systems to ceramic membrane systems .

Conclusions HCMS

Ecotoxicity

- Micropollutant emissions represent a significant contribution to the human health and freshwater ecotoxicity impact **in case the toxicity of the micropollutant load is high** (extrapolation)
- Between medium and high ecotoxicity levels, the HCMS operation comes out as a net benefit in terms of aquatic ecotoxicity and human toxicity
- **Powdered Activated Carbon (PAC)** has significant impacts → optimization potential (e.g., renewable raw products)

Ceramic and polymeric membranes

- **Comparison between hybrid ceramic membrane and polymeric membrane scenarios:** there is no significant difference between the impact of the ceramic and polymeric systems

Climate change

- The **ceramic and polymeric membrane scenarios contribute to CO_2 emissions for PAC activation** and electricity requirements for membrane aeration
- **Scenario with pressurized membrane:** In case a pressurized membranes are used, there is no more electricity for membrane aeration, which reduces the impact related to membrane operation

Lifecycle Costs

- Investment costs for HCMS are **much higher** in comparison to the polymeric membrane systems due to a higher module price, whereas operational costs are **lower**.
- Without funding the NPV of HCMS is in our case app. **1 million EUR** higher than those of the polymeric system.

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WA 5: Fostering the uptake of novel technologies in the water sector

LCA and LCC of an automatic neural net control system (ANCS): Case study in Roetgen (DE)

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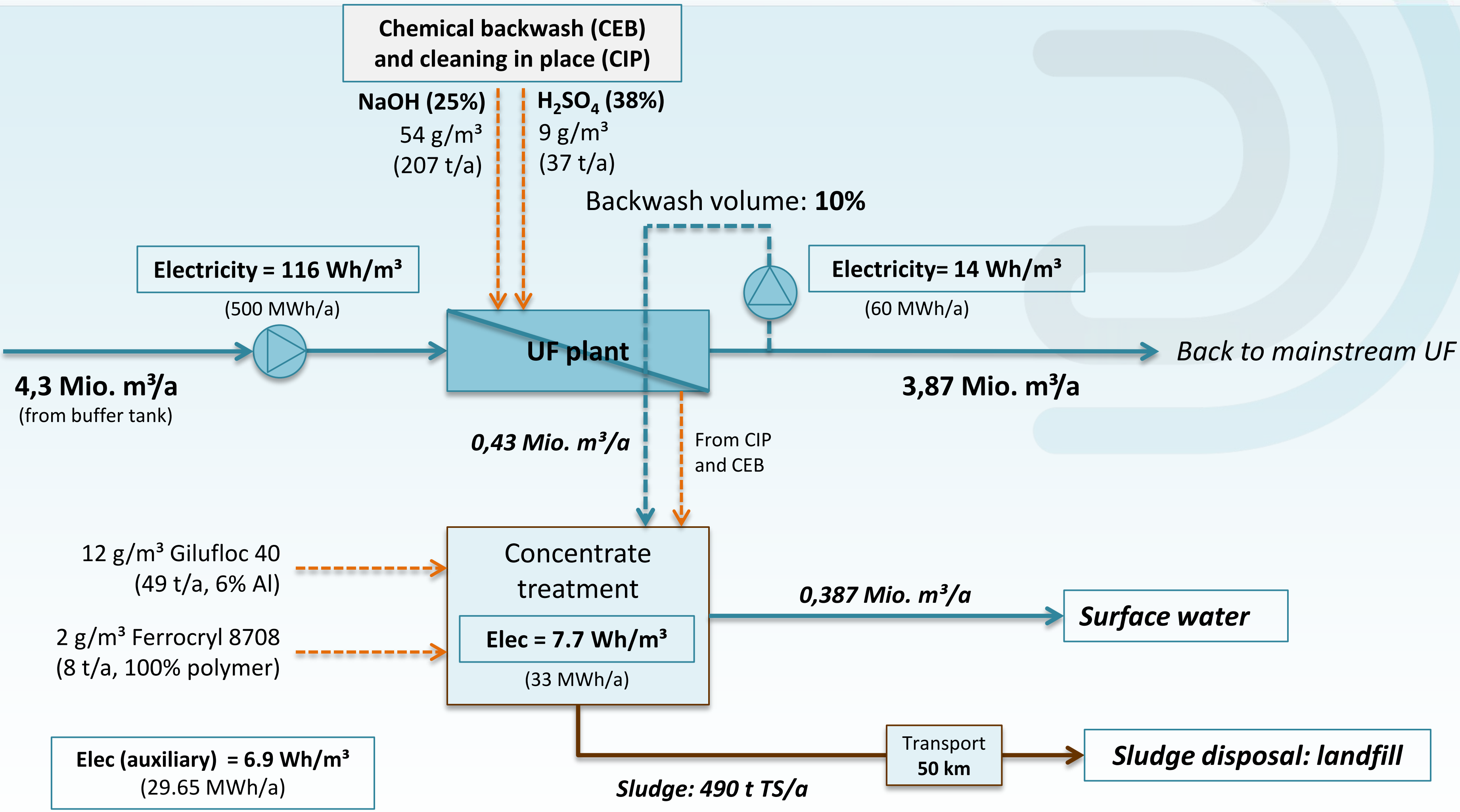
Case study of WAG

- Case study: optimisation of membrane plant for backwash water treatment in drinking water process of WAG (Germany)

- System assesssment with LCA includes:
  - **Operation:** electricity, chemicals, sludge disposal
  - **Construction:** infrastructure (materials of the plant)

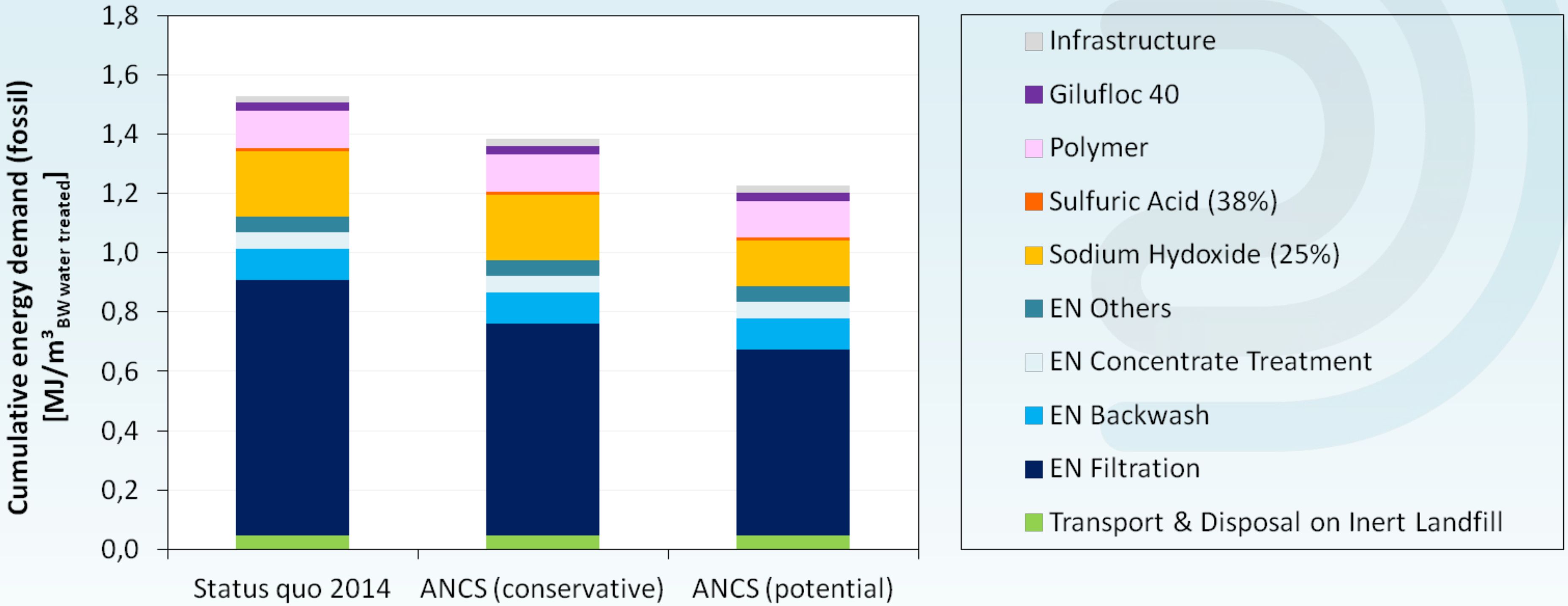
- Sceanrios without ANCS (status quo) and with ANCS optimisation:
  1) Status quo of the plant in 2014
  2) ANCS optmisation (conservative) = savings in electricity (-17%)
  3) ANCS optimisation (potential) = savings in electricity (-27%) and chemicals for cleaning (-30% for H_2SO_4 and NaOH) due to longer intervals for chemical backwash

Status quo of the plant in 2014



*Data relates to **1 m³ backwash water** = input flow*

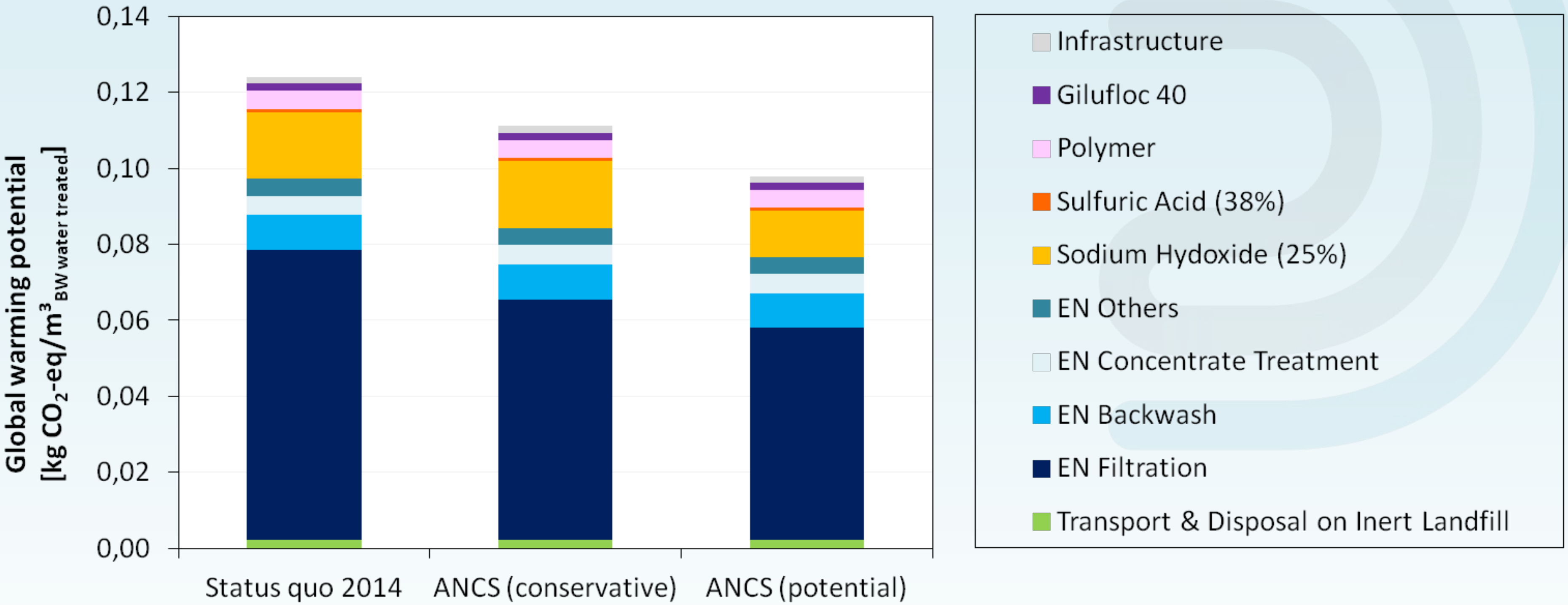
LCA: Cumulative energy demand



NET:	Status quo 2014	ANCS (conservative)	ANCS (potential)	
	1,53	**1,38**	**1,23**	**$MJ/m^3_{BW\ water\ treated}$**

- Energy demand (fossil fuels) of the plant is 1,5 MJ/m^3 (electricity: 70%, chemicals: 25%)
- ANCS system can reduce **10-20% of fossil fuel demand**

LCA: Carbon footprint



NET:	**0,124**	**0,111**	**0,098**	**kg CO_2-eq/m^3$_{BW\ water\ treated}$**

- Emission of greenhouse gases is 0,12 kg CO_2-eq/m^3 (Electricity: 77% with power mix D2013, chemicals: 20%)
- ANCS system can save **10-21% of GHG emissions** (= 56-112 t CO_2-eq/a)

LCC: Investment costs

Cost Type		REF (status quo)	ANCS: -17% EN - project -	ANCS: -27% EN, -30% CHEM – project -	ANCS: -17% EN - contracting -	ANCS: -27% EN, -30% CHEM - contracting -
Capital expenditure						
Initial Investment		5.285.000	5.285.000	5.285.000	5.285.000	5.285.000
ANCS	€	-	155.000	155.000	59.770	65.846
hardware	€	-	5.000	5.000	5.000	5.000
software licence	€	-	50.000	50.000	50.000	50.000
other	€	-	100.000	100.000	4.770 (p. a.)	10.846 (p. a.)
Operational expenditure						
energy	€/a	103.983	88.084	78.732		78.732
operating supplies	€/a	100.151	100.151	89.250	100.151	89.250
other	€/a	540.000	540.000	540.000)	540.000	540.000

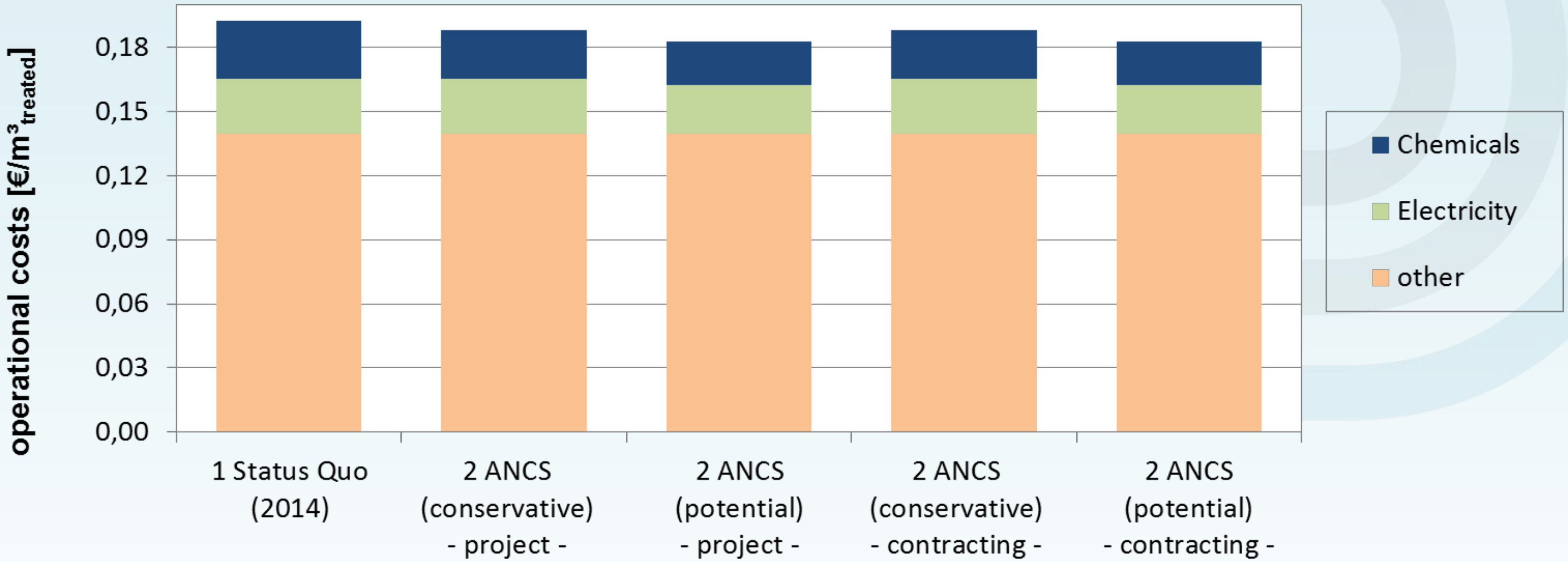
Two exemplary financing modes:

a) project: app. 155.000 € (single payment)

b) contracting: 55.000 € (single payment)
+ 30 % of the annual cost savings in electricity and chemicals

- Investment costs of the **ANCS-system** are between **59.770 - 155.000 €**. In relation to the initial investment costs of the plant only **1,1 – 2,8 %** of the whole investment costs are caused by ANCS investment.

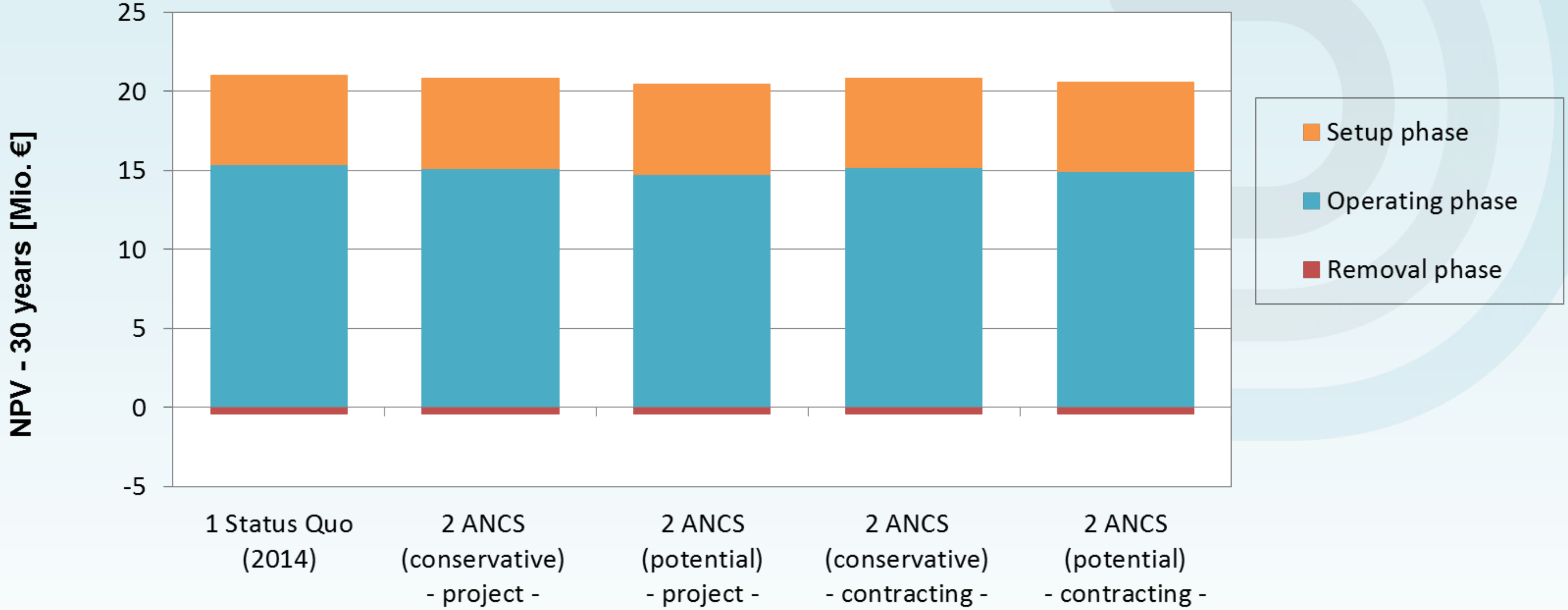
LCC: Operational costs



Sum:	**0,192**	**0,188**	**0,183**	**0,188**	**0,183**	**[€/m³$_{treated}$]**

- Cost savings caused by the ANCS system are between **16.000 – 36.000 €/year**.
- Thereof up to 11.000 € are the result of a decreased used of chemicals and 15.000 – 25.000 € are caused by a lower electrical demand.

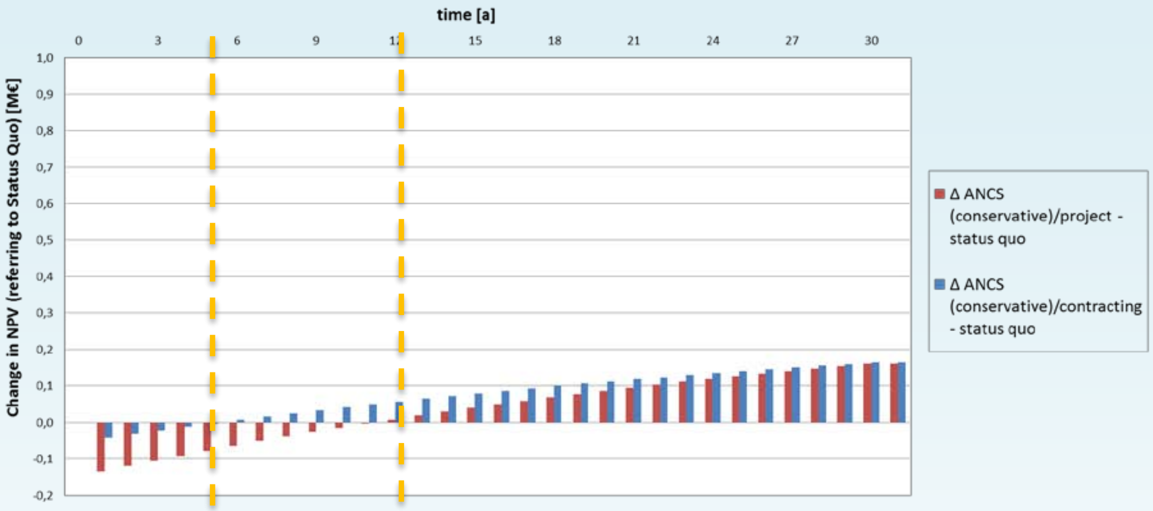
LCC: Life cycle costs per m³

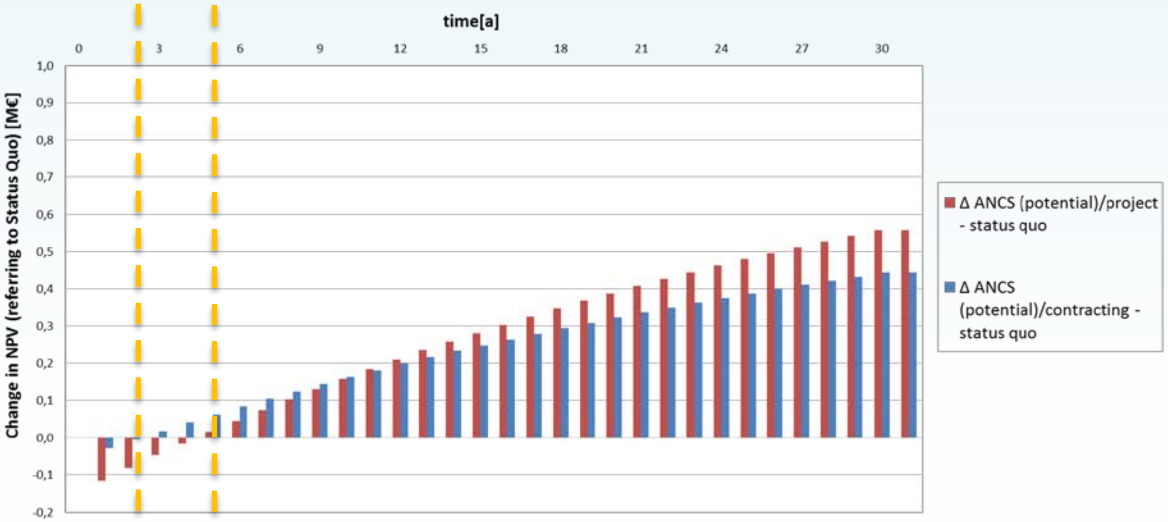


Sum:	20,57	20,41	20,01	20,24	20,13	NPV [Mio. €]

- Status quo: 0.18 €/m³ treated
- ANCS (conservative): 0.17-0.18 €/m³
- ANCS (potential): 0.17-0.18 €/m³

LCC: Life cycle cost trend





Conservative estimation:

- With **contracting** costs of the ANCS system amortize in **app. 5 years**.
- If the investment is financed as a **project**, a positive NPV value is reached after **12 years** which **exceeds the expected lifetime of the ANCS´ hardware and software** (max. 10 years).

Potential estimation:

- With **contracting** the ANCS investment amortizes in a **few years**.
- **Project**-financed this effect occures clearly later (app. **5 years**) but the revenue after 30 years is higher (app. 0,1 Mio. €) than with contracting.

Conclusions ANCS

- By enabling savings in energy and chemicals ANCS improves **cumulative energy demand and carbon footprint** of the whole treatment plant
  - 10-20% less fossil fuel demand
  - 10-21% less GHG emissions

- Life cycle costs of ANCS strongly depend on the **expected savings in energy and chemicals** as well as on the **financing mode**
  - conservative estimation just profitable with contracting
  - potential estimation: profitable in any case

  Note: In reality, the financing mode will be customized.

- Unique selling point of ANCS-optimization?
  - **optimisation of energy used**
  - costs are strongly case specific (!)

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Thank you for your attention!

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