Sustainable processes for nitrogen removal in WWTPs:

- Sludge return liquor treatment
- Control systems and life cycle analysis

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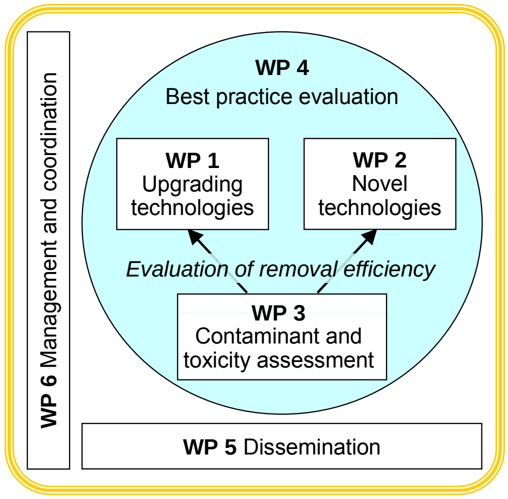
Overview

1. The EU-NEPTUNE project
2. Sludge return liquor treatment
3. Process control and LCA
4. Conclusions

Structure of the EU NEPTUNE project

New sustainable concepts and processes for optimisation and upgrading municipal wastewater and sludge treatment



Consortium:

7 GOs and Universities
2 Industry and consulting
7 SMEs
2 Non-European partners
(Australia + Canada)
28 End-users

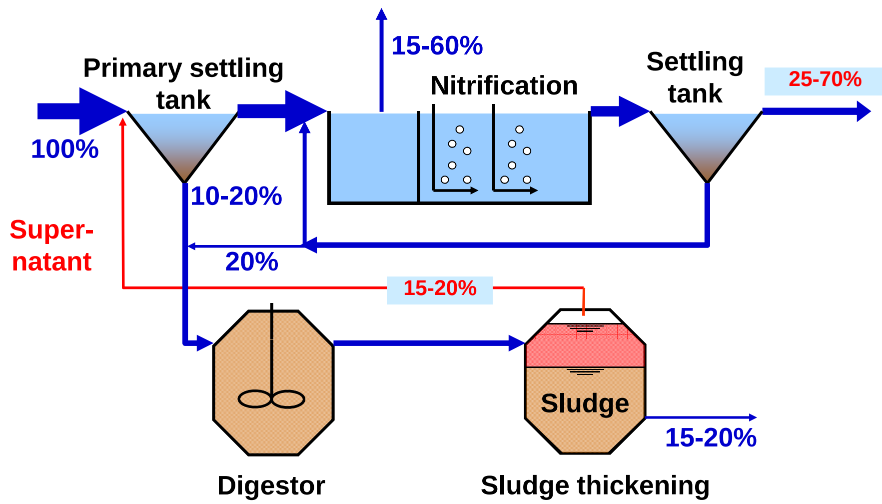
Budget: € 4.28 mio
($ 5.75 mio)

Sludge return liquor treament

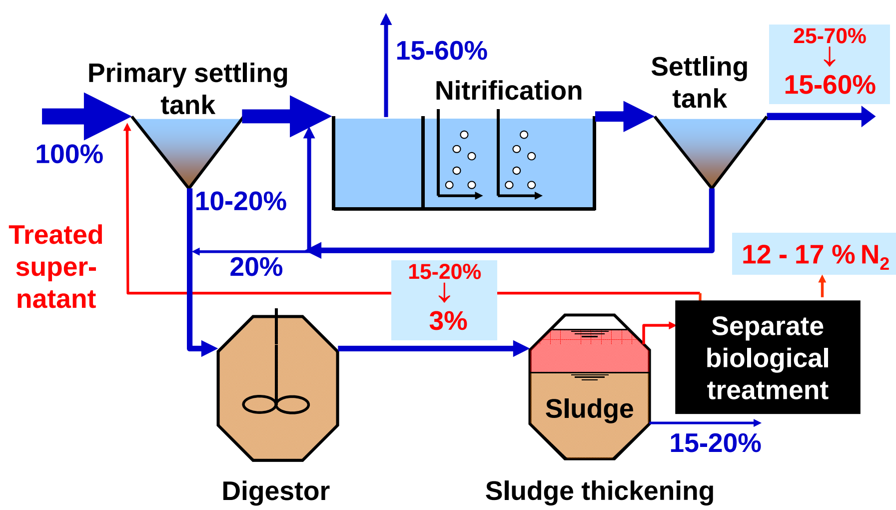
Scope of sludge return liquor treatment
The process
Process control
Greenhouse gas emissions

Conclusion

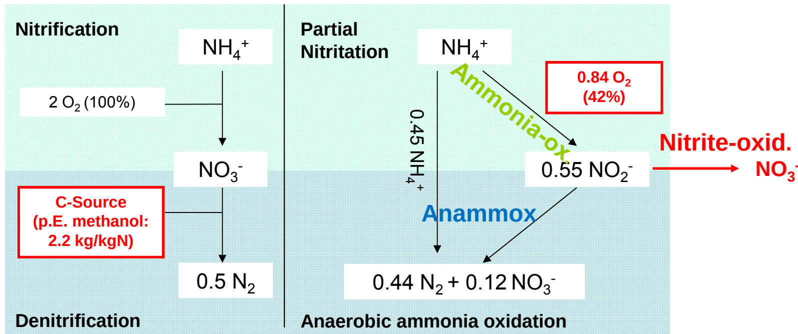
Nitrogen fluxes in wastewater treatment



Nitrogen fluxes in wastewater treatment



Nitrogen elimination: conventional or anammox?



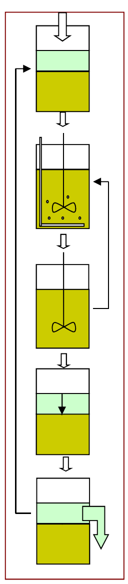
Advantages of anammox

- No organic carbon addition
- Reduced energy for aeration (58% saving)
- Less excess sludge produced
- Cost saving (1.55 €/kg$N_{elimin.}$ instead of 3.10 €/kgN_{elimin}) **= 50% less**

Disadvantages of anammox

- Sensitive to nitrite, oxygen and ammonia (substrates)
- Slow growth of anammox bacteria + competition with nitrite-oxidizers

Nitritation and anammox combined in a single SBR (sequencing batch reactor)

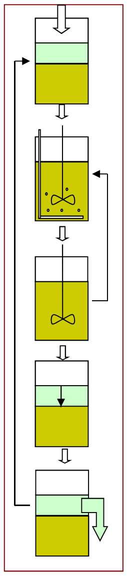


1. Fill with supernatant
2. Aeration: partial nitritation
   $NH_4^+ + 1.5\, O_2 + \rightarrow NO_2^- + 3\, H_2O$
3. Stirring: anammox
   $0.45\, NH_4^+ + 0.55\, NO_2^- \rightarrow 0.44\, N_2 + 0.12\, NO_3^-$
4. Sedimentation
5. Discharge

Piloting with a 400L reactor

DEMON®: first single reactor process with pH control
(B. Wett, Water Science & Technology, 2007)

Nitritation and anammox combined in a single SBR (sequencing batch reactor)



1. Fill with supernatant

2+3 Simultaneous nitritation/anammox

$NH_4^+ + 1.5\ O_2 + \rightarrow NO_2^- + 3\ H_2O$

$0.45\ NH_4^+ + 0.55\ NO_2^- \rightarrow 0.44\ N_2 + 0.12\ NO_3^-$

4. Sedimentation

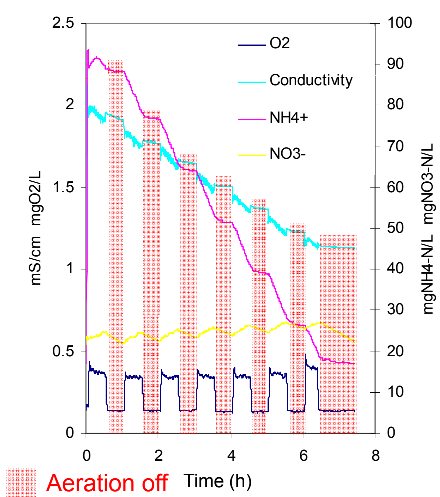
5. Discharge

Piloting with a 400L reactor

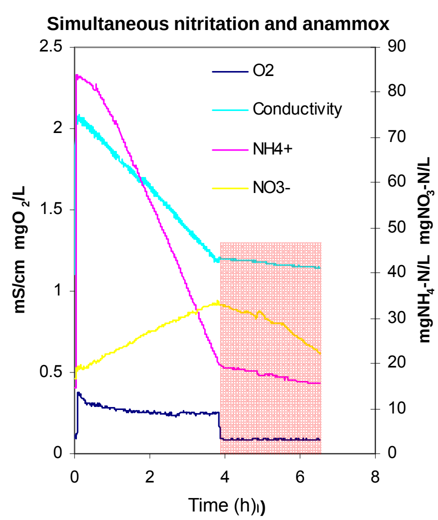
Joss et al., Environ. Sci. Technol., 2009

SBR cycle: two options

Intermittent aeration



Continuous aeration



Joss et al., Environ. Sci. Technol., 2009

Sludge return liquor treament

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Control parameters

Crucial

O_2: inhibits anammox bacteria

- ≤0.5 mgO_2/L during aeration
- Substrate for O_2 consumption: always >10 mgNH_4^+-N/L

NH_3: toxic

- <10 mgNH_3-N/L corresponds to <200 mgNH_4^+-N/L (pH 7 to 8)

Sedimentation: avoid loss of biomass (bulking)

- Rarely required (start-up): flocculant addition

Nitrite oxidizers: „steal“ NO_2^-, accumulate NO_3^-

- Concentration of NO_2^- <1 mgNO_2^--N/L
- Sludge withdrawal: ≤60 d sludge age

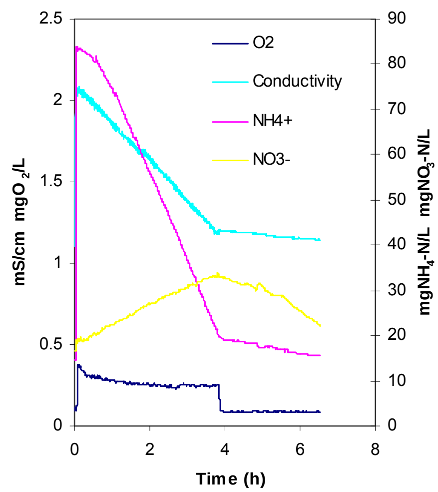
Control parameters

Crucial

O_2:

NH_3:

NO_3^-



Lower greenhouse gas emission

Aeration energy: $0.7\ kWh/kgO_2$

Energy equivalents: $3\ kgCO_2/kWh_{electric}$

Methanol equivalents: $1.4\ kgCO_2/kgMeOH$

N_2O equivalents: $310\ kgCO_2/kgN_2O$

		Conventional Nitrific./Denitr.	Combined Nitrit.-Anammox
O_2 consumption	kgO_2 / $kg_{N\ elim}$	4.3	1.9
Aeration energy	kWh / $kg_{N\ elim}$	2.4	1.0
Aeration (CO_2 equiv.)	$kgCO_2$ / $kg_{N\ elim}$	**1.4**	**0.6**
Carbon source	kg_{MeOH} / $kg_{N\ elim}$	2.2	-
Carbon source (CO_2 equ)	$kgCO_2$ / $kg_{N\ elim}$	**3.1**	**-**
N_2O production	gN_2O / $kg_{N\ elim}$	0.1 to 17[+]	4[°°]
N_2O production (CO_2 equ)	$kgCO_2$ / $kg_{N\ elim}$	**0 to 5.3**	**1.2**
Total CO_2 equivalents	**$kgCO_2$ / $kg_{N\ elim}$**	**4.5 to 10**	**1.8**

[+] Katrik Chandran, personal communication, 2010

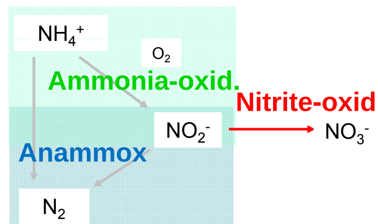
[°°] Joss et al. 2009, Environ. Sci. Technol.

Conclusion

Combined nitritation/anammox in a single SBR: a robust solution

On-line sensors for process control: O_2, NH_4^+, NO_3^-

3 microbial populations are important:



Avoid nitrite oxidation: low O_2 + NO_2^- and sludge wastage

Compared to conventional nitrification/denitrification:

…saves half of the costs for N removal

…reduces greenhouse impact

…allows energy neutral wastewater treatment

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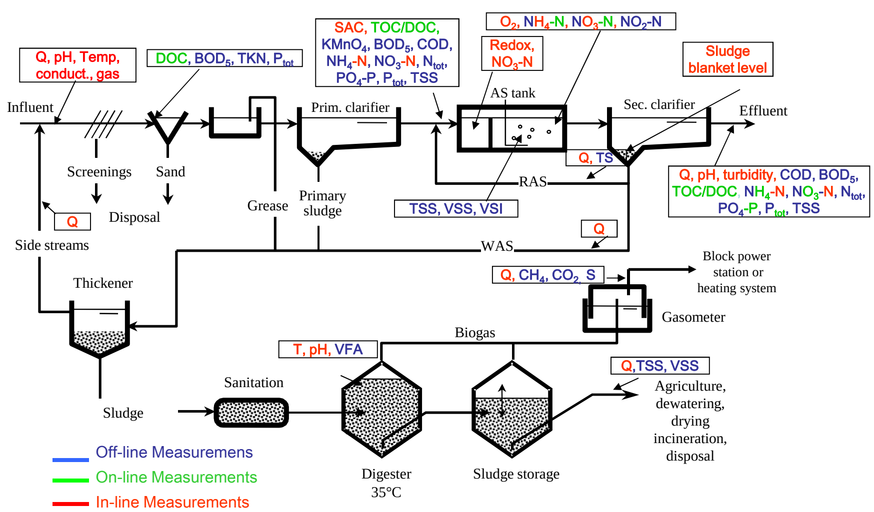
1. Introduction

✓ Sensors are installed in WWTPs for monitoring and control purposes

1. Introduction

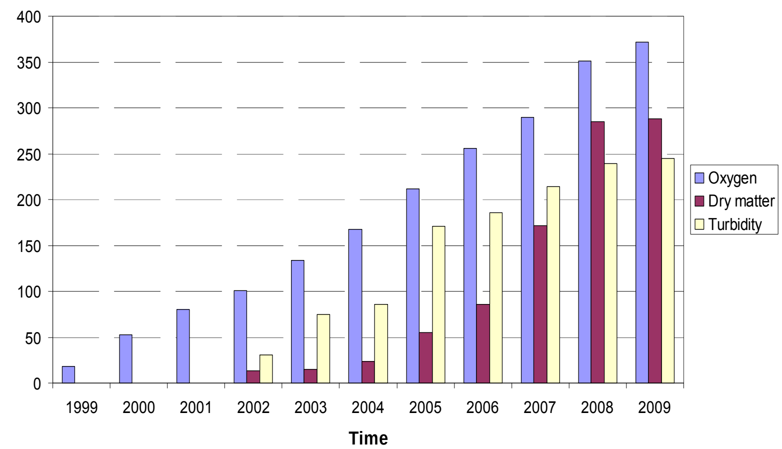


Source: Hansruedi Siegrist

1. Introduction

Evolution of number of oxygen, dry matter and turbidity sensors at 220 Aquafin plants

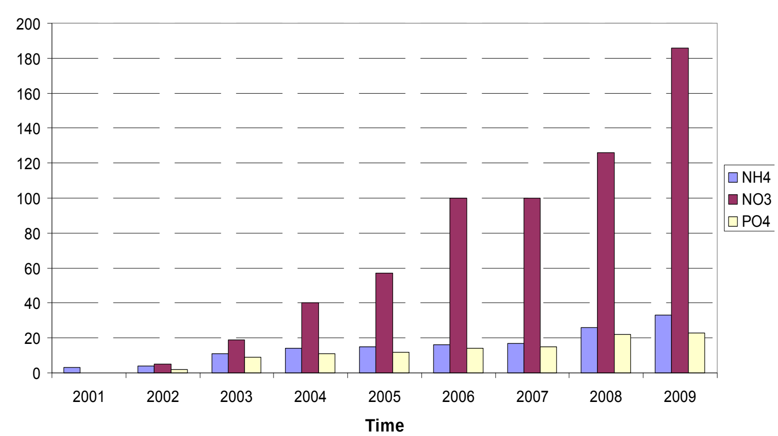
Source: Aquafin (B)



1. Introduction

Evolution of the number of nutrient sensors at 220 Aquafin plants

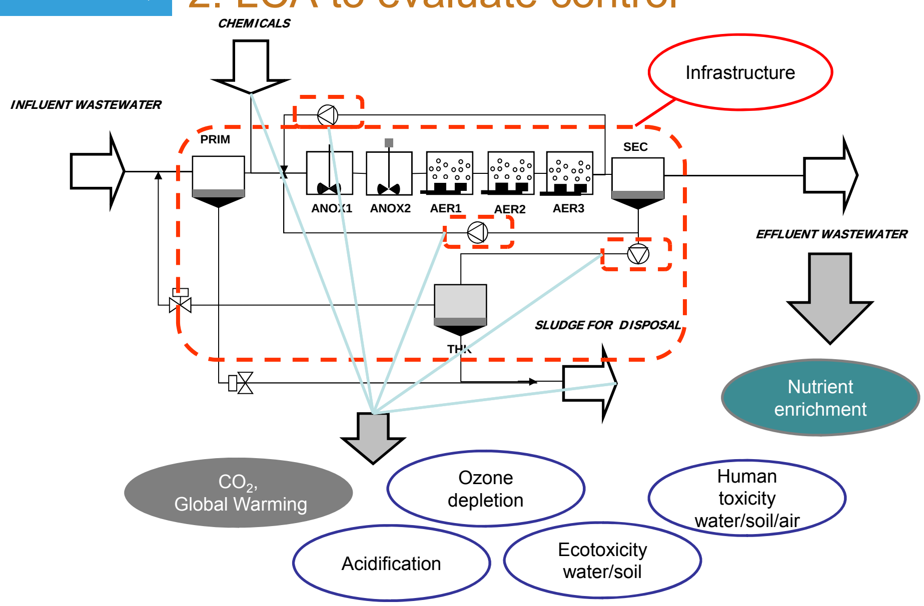
Source: Aquafin (B)



1. Introduction

- ✓ Driving force: Water Policies
  - ✓ Sustainable development
    → need for tools to estimate GHG emissions and perform Life Cycle Analysis (LCA)
  - ✓ Increasing demands on treatment efficiency (new technologies/optimization and control

2. LCA to evaluate control



2. LCA to evaluate control

- Variables and impact factors

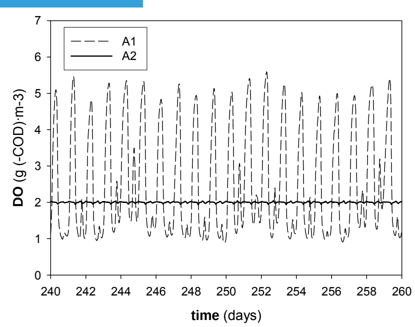
Variables (var)	Impact factors (mPET*year/unit) WF=1
Nitrogen (kg N)	37.23
Phosphorus (kg P)	269.2
Electricity consumption (kWh)	0.12324
Sludge production (kg sludge, 63% water)	0.1
Infrastructure (m^3 influent treated)	0.127
External carbon source (acetate)	3.8781
Metal ($FeCl_3$, 40%)	2.6110

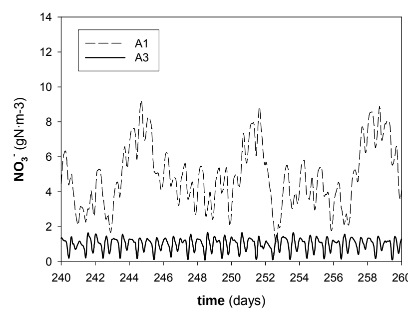
- Functional unit (1m^3 of treated wastewater)
- Calculation

$$NIP_{(var)} = \frac{Value_{(var)} \text{ x IF}}{m^3 \text{ treated WW}} \qquad \left[mPET * year / m^3\right]$$

- Presentation of the results
  - Avoided impact: Influent – effluent nutrient impact
  - Induced impact: Effluent nutrient + Electricity + Sludge + Infr + chemicals

2. LCA to evaluate control





<u>DO controller</u>

Improve Effluent Quality

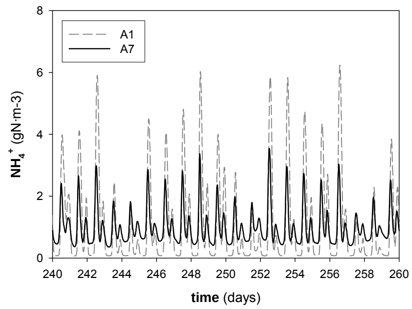
Decrease Costs (Aeration)

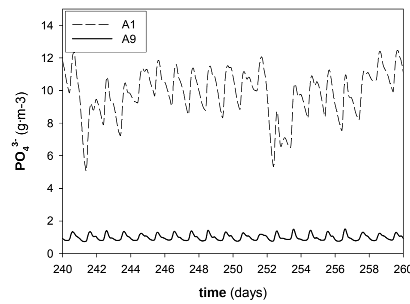
<u>NO controller</u>

Improve Effluent Quality

Decrease Costs (Pumping)

2. LCA to evaluate control





NH4 controller

Improve Effluent Quality

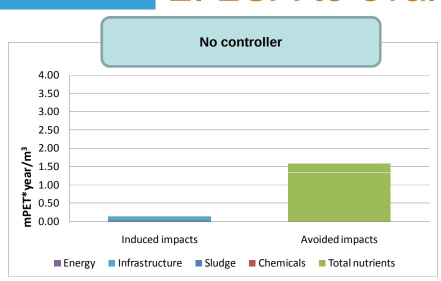
Decrease Costs (Aeration)

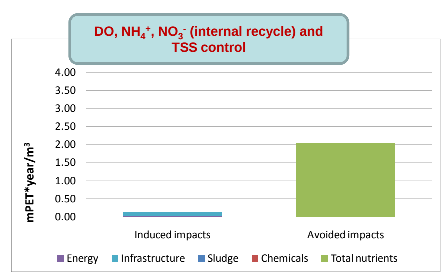
Qmetal controller

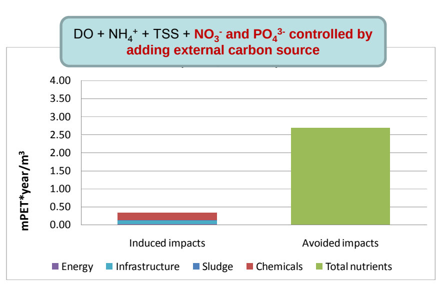
Improve Effluent Quality

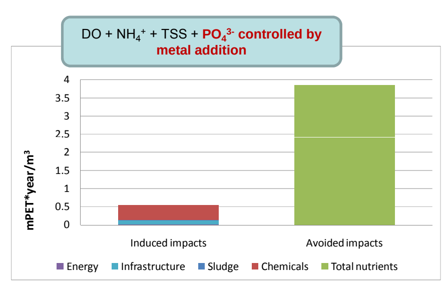
Increase Costs (Iron, Sludge)

2. LCA to evaluate control





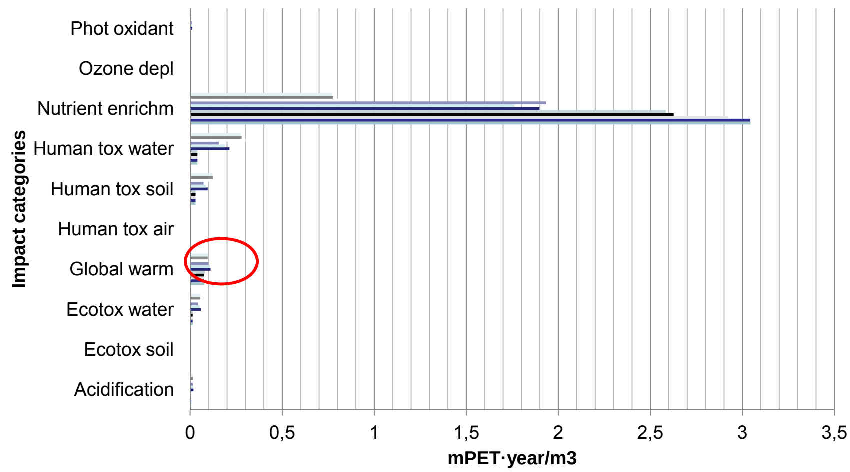




Reference: No treatment (impact of 4mPET·year/m³)

2. LCA to evaluate control

- LCA impact categories



3. Conclusions

- The implementation of control leads to
  - an increase of the avoided impact, and
  - a decrease in the induced impact
- The most environmentally friendly strategies are:
  - Metal addition: effluent phosphorous ↓
  - Carbon addition: effluent nitrate ↓ but GHG ↑
- In LCA
  nutrient removal gets more attention than global warming

Acknowledgements

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Neptune FP6 Project

NSERC CRSNG

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Special Research Opportunities