Use of control to improve nutrient removal

Perspectives (LCA and fault-tolerant control)

Lluís Corominas, Xavier Flores-Alsina, Henrik.F Larsen, Peter A. Vanrolleghem

Neptune workshop: Technical Solutions for Nutrient and Micropollutants Removal in WWTPs

Université Laval, Québec, March 25-26, 2010

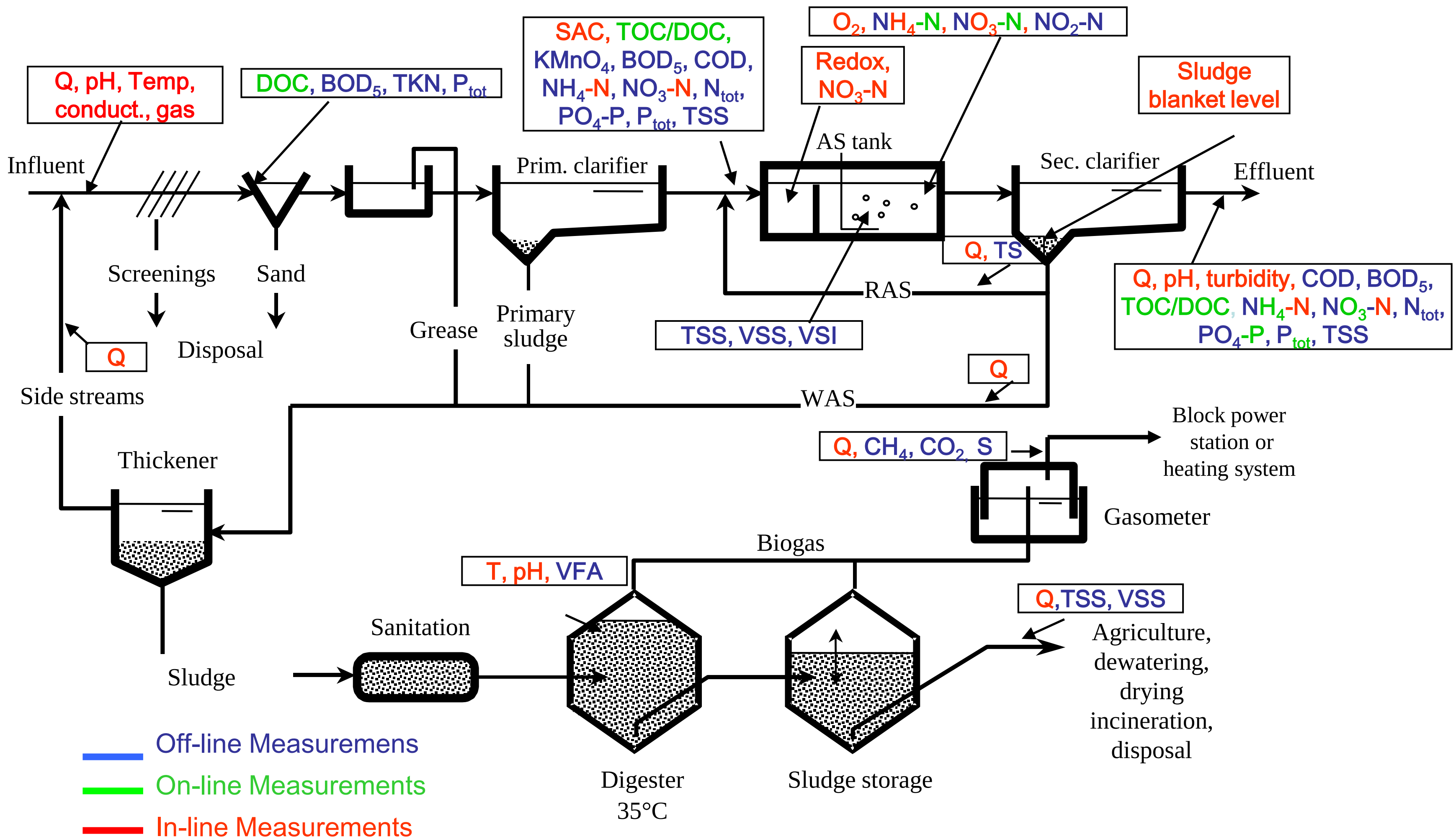
Overview

1. Introduction
2. LCA to evaluate control strategies
3. Fault-detection
4. Conclusions

1. Introduction

- ✓ Sensors are installed in WWTPs for monitoring and control purposes

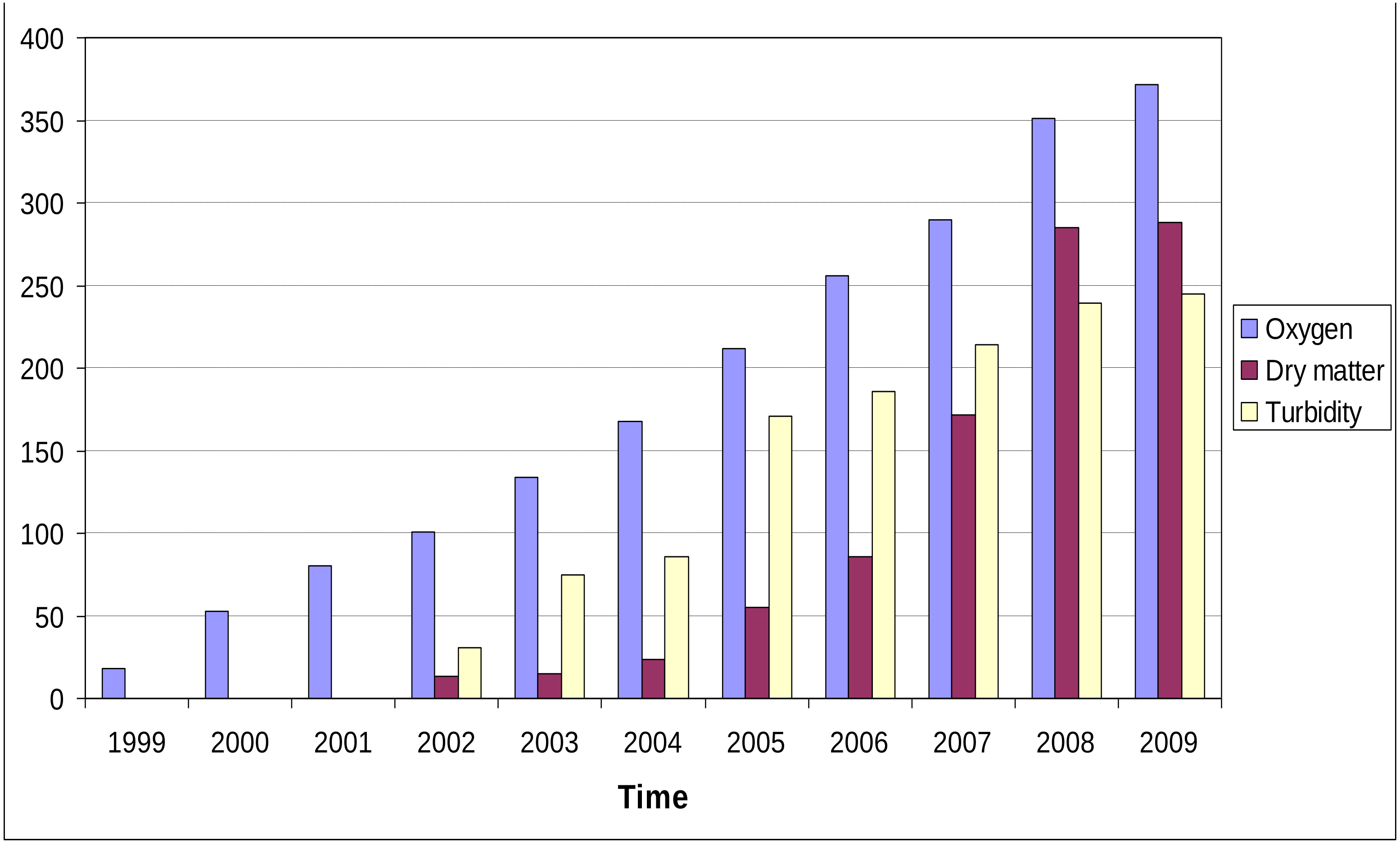
1. Introduction



Source: Hansruedi Siegrist

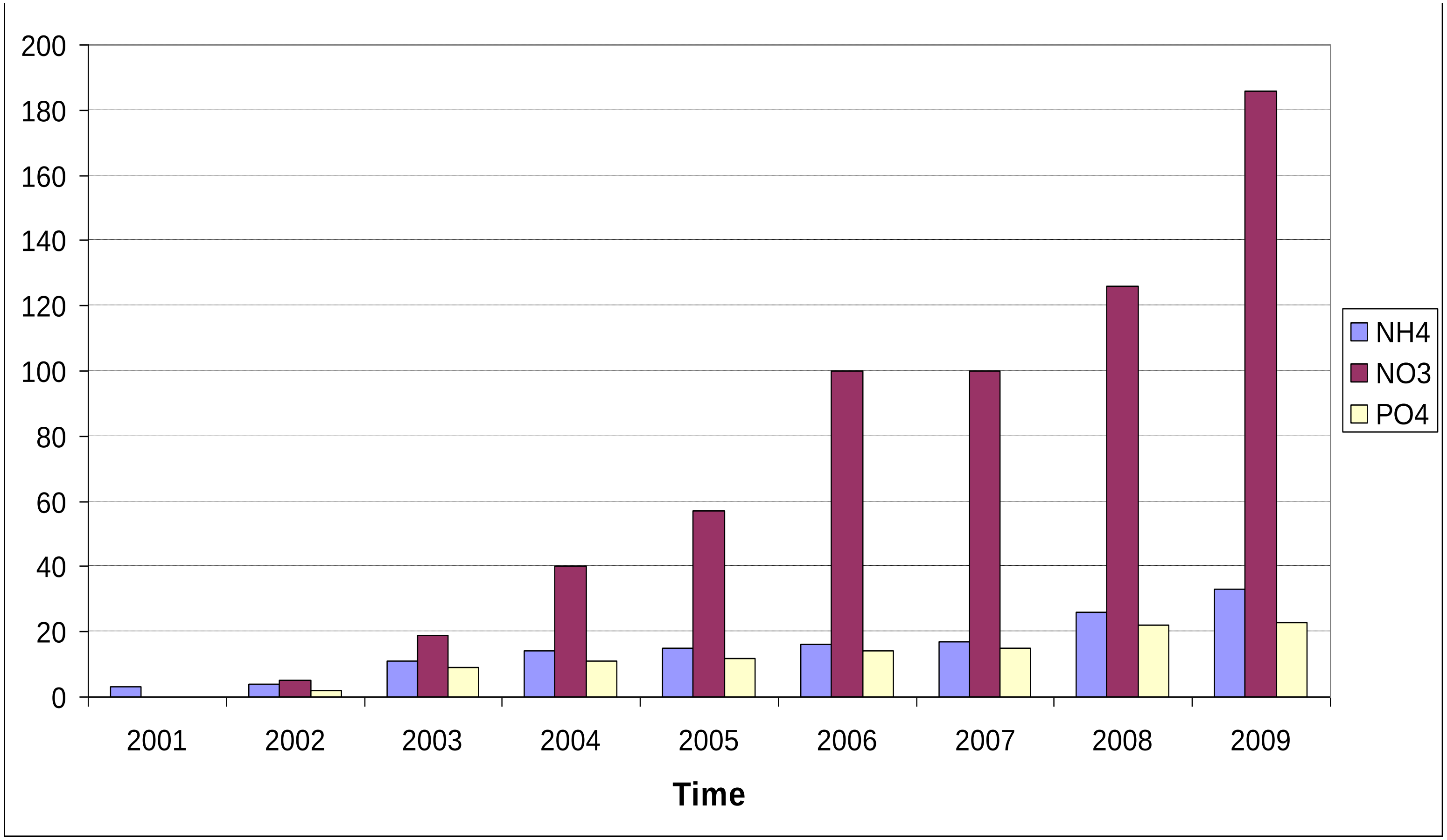
1. Introduction

Evolution of number of oxygen, dry matter and turbidity sensors at Aquafin plants (about 220 plants) *Source: Aquafin*



1. Introduction

Evolution of the number of nutrient sensors at Aquafin plants (about 220 plants) *Source: Aquafin*



1. Introduction

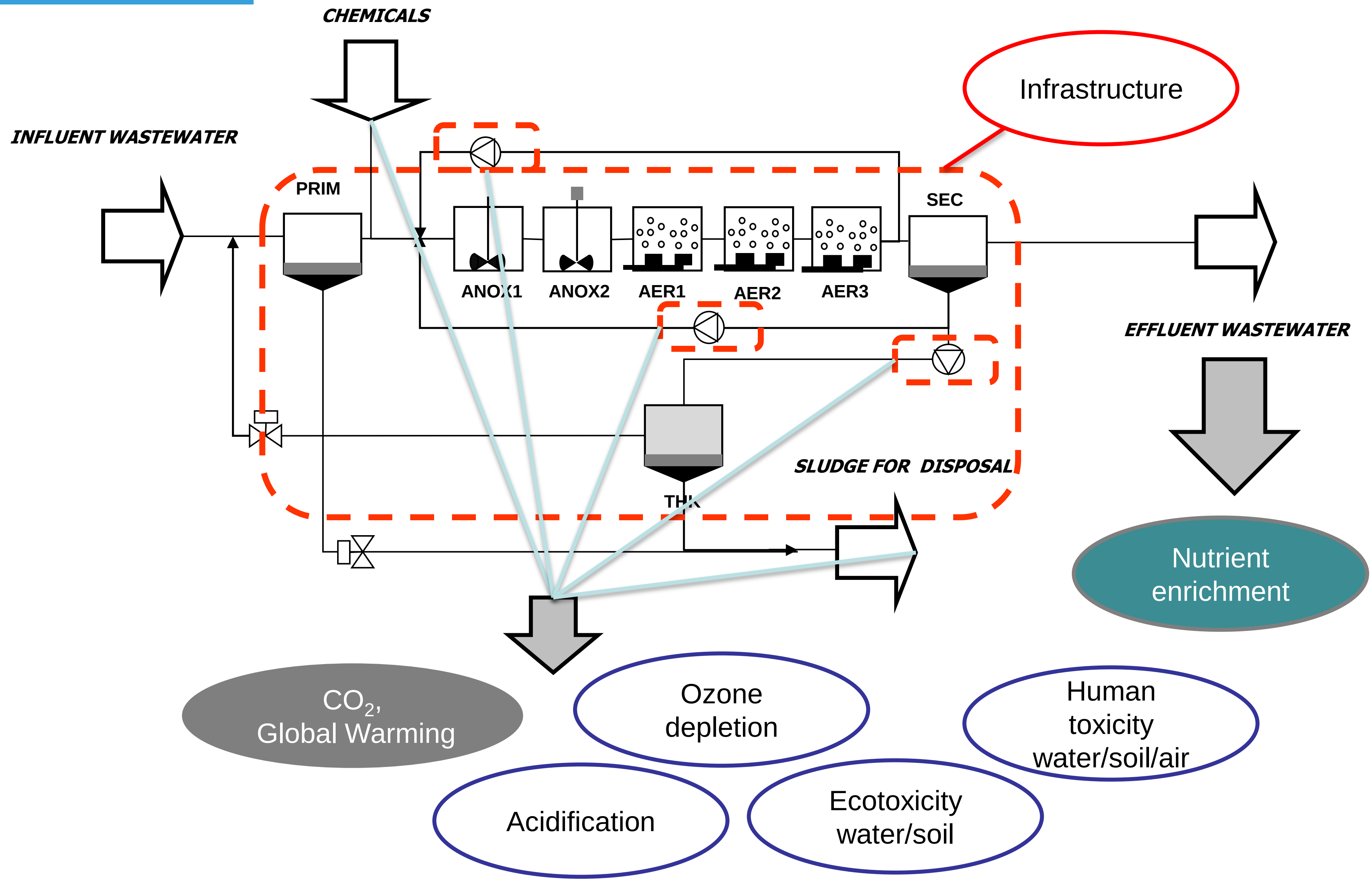
- ✓ Driving force: Water Policies
  - ✓ Sustainable development → need for tools to estimate GHG emissions and perform Life Cycle Analysis (LCA)
  - ✓ Increasing demands on treatment efficiency (new technologies/optimization and control)

    Draw-back with control: equipment failures (sensors and actuators) can cause severe effluent limit violations → Fault-tolerant control

Overview

1. Introduction
2. **LCA to evaluate control strategies**
3. Fault-detection
4. Conclusions

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

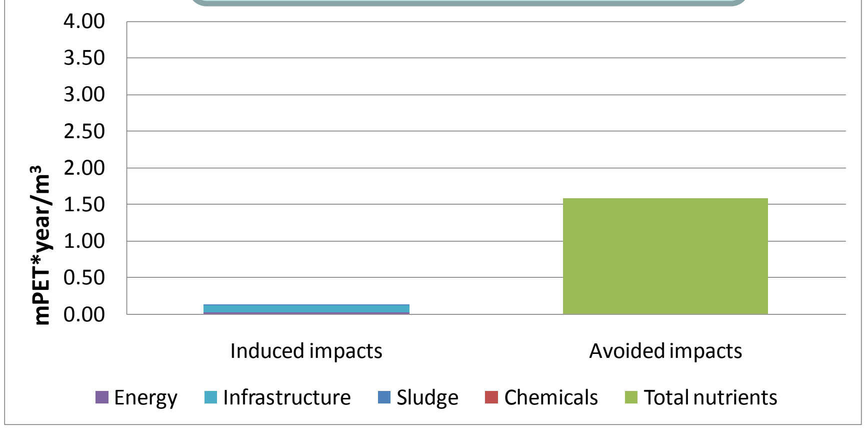
- Functional unit (1m^3 of treated wastewater)
- Calculation

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

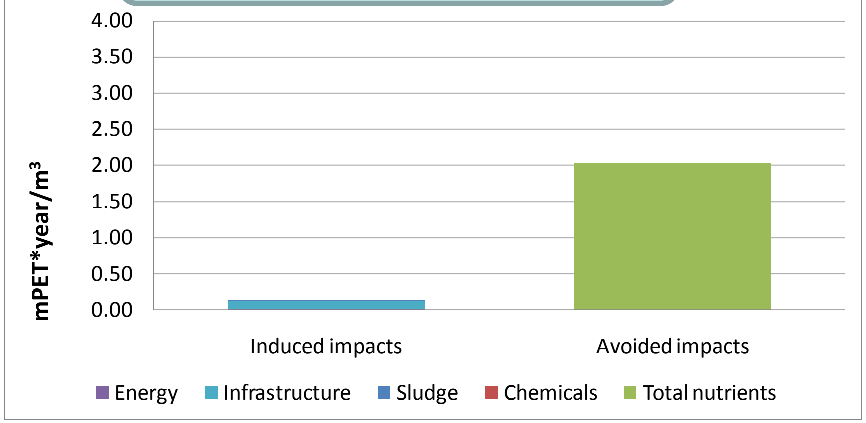
- Presentation of the results
  - Avoided impact: Influent – effluent nutrient impact
  - Induced impact: Effluent nutrient + Electricity + Sludge + Infr + chemicals

2. LCA to evaluate control

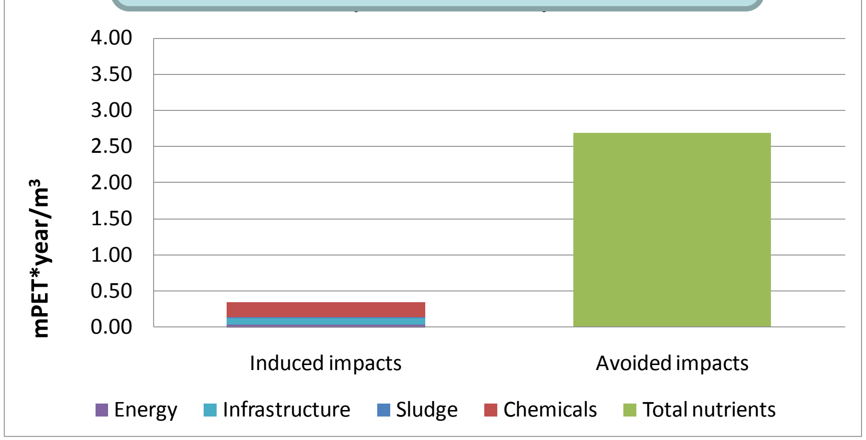
No controller



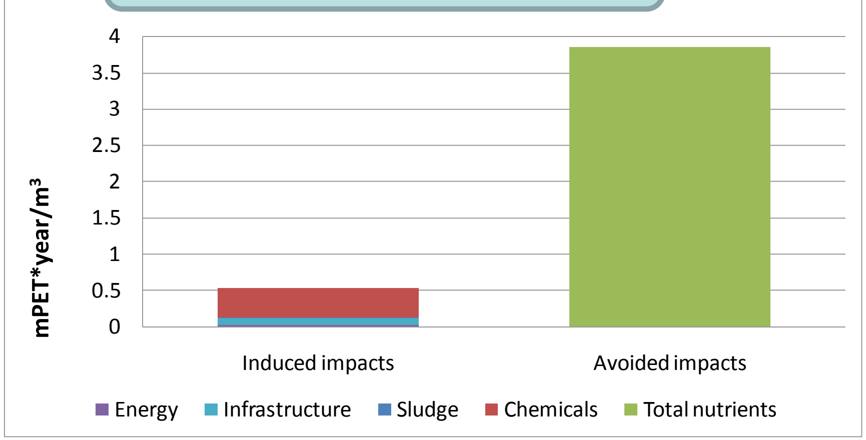
DO, NH_4^+, NO_3^- (internal recycle) and TSS control



DO + NH_4^+ + TSS + **NO_3^- and PO_4^{3-} controlled by adding external carbon source**



DO + NH_4^+ + TSS + **PO_4^{3-} controlled by metal addition**

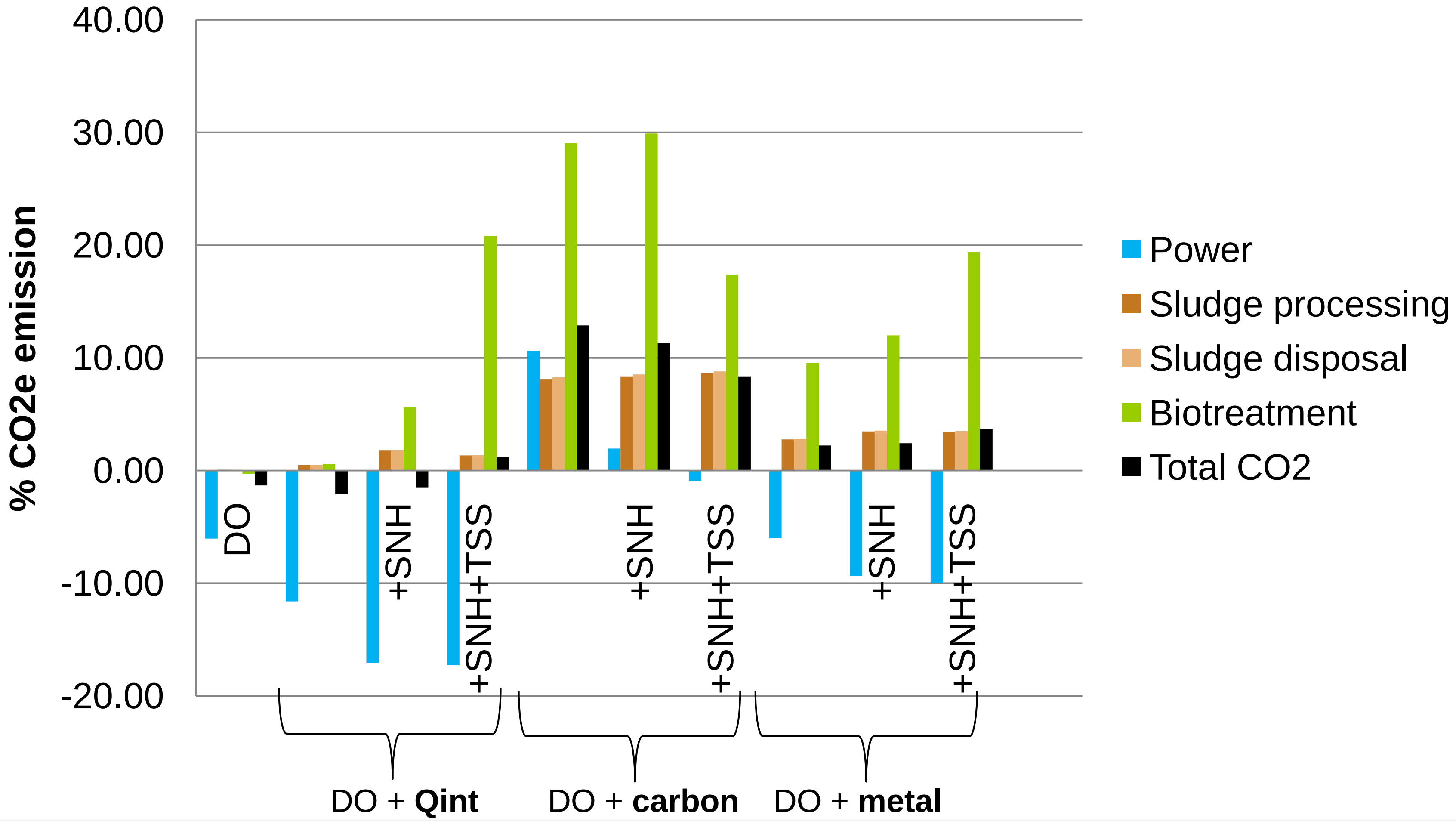


Reference: No treatment (impact of 4mPET·year/m3)

2. LCA to evaluate control

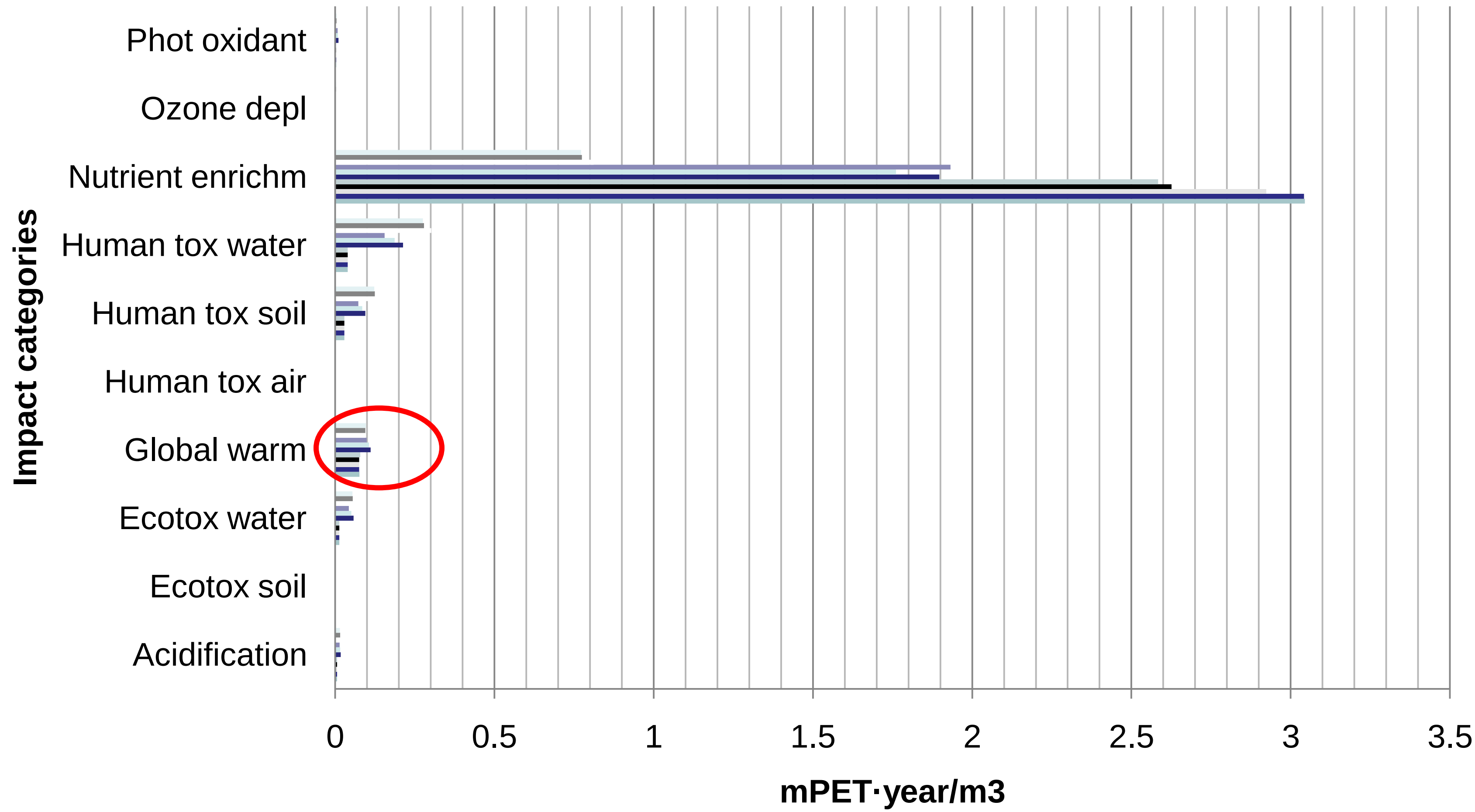
- CO_2 emissions compared to open-loop

(estimations using Monteith *et al.*, 2005 and Bridle *et al.*, 2008)



2. LCA to evaluate control

- LCA impact categories



Overview

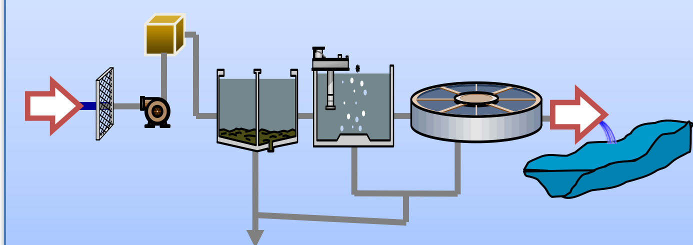
1. Introduction
2. LCA to evaluate control strategies
3. **Fault-detection**
4. Conclusions

3. Fault-detection

- Fault-tolerant control

Process

✓***WWTP***



Control

✓***Fault-tolerant***
✓***Efficient***

Data acquisition

✓***Data-quality check***

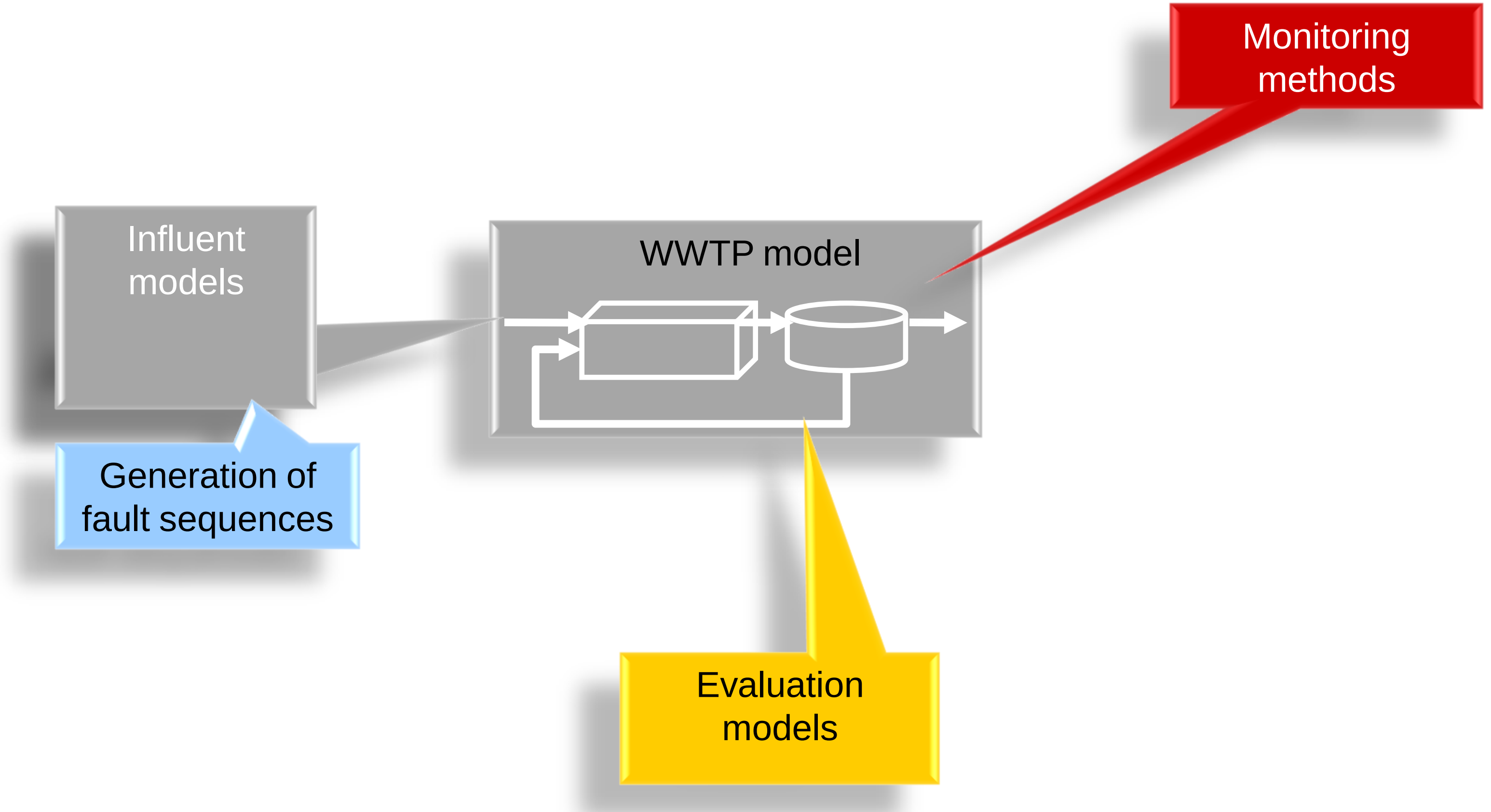
Monitoring and diagnosis

✓Fault Types:
✓***Sensors***
✓***Actuators***
✓***Process***

✓***Alarm system***

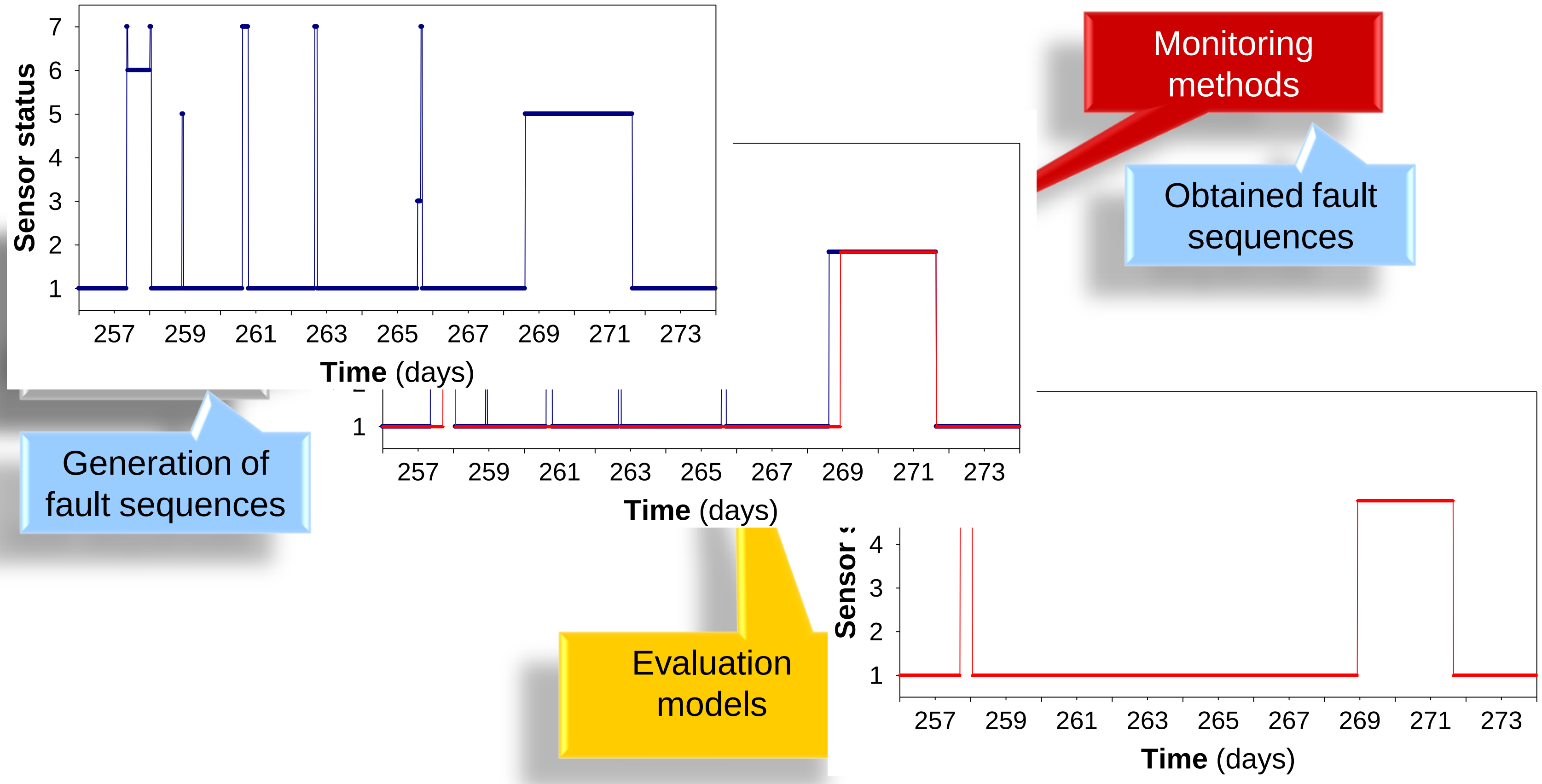
3. Fault-detection

- Goal: Compare performance of fault-detection methods



3. Fault-detection

- Goal: Compare performance of fault-detection methods

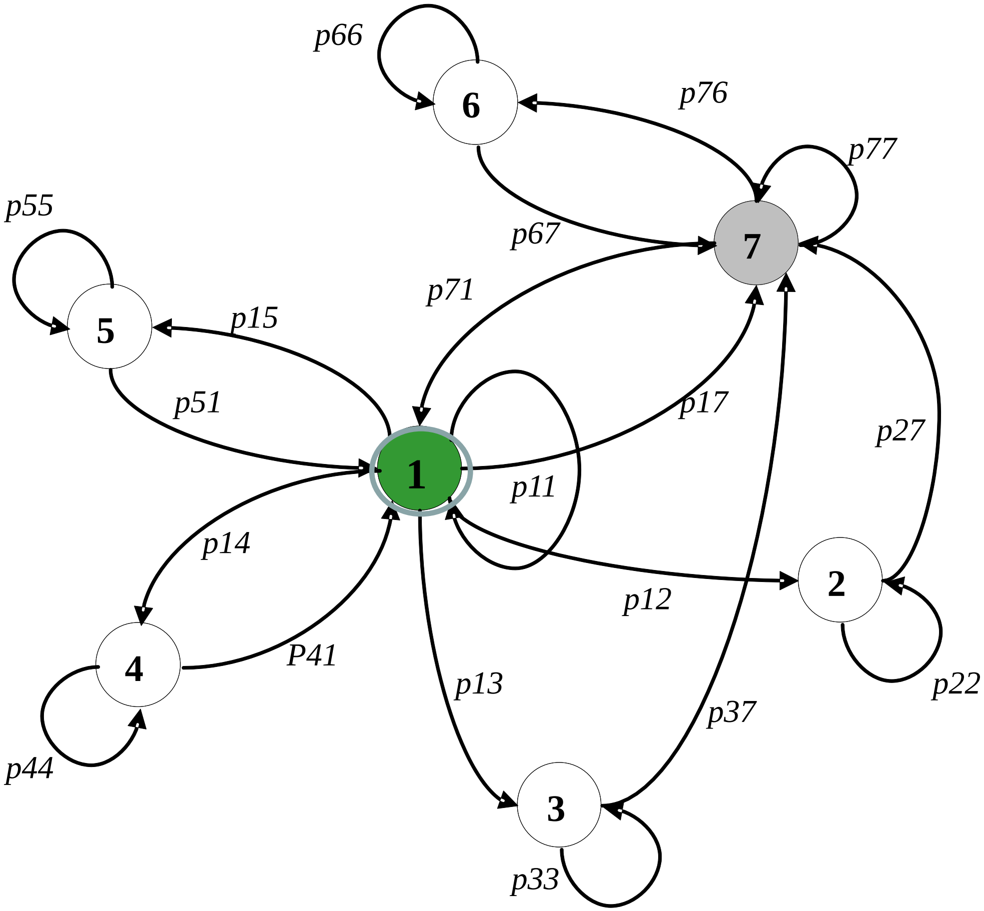


3. Fault-detection

- Sequences of faults using Markov Chains

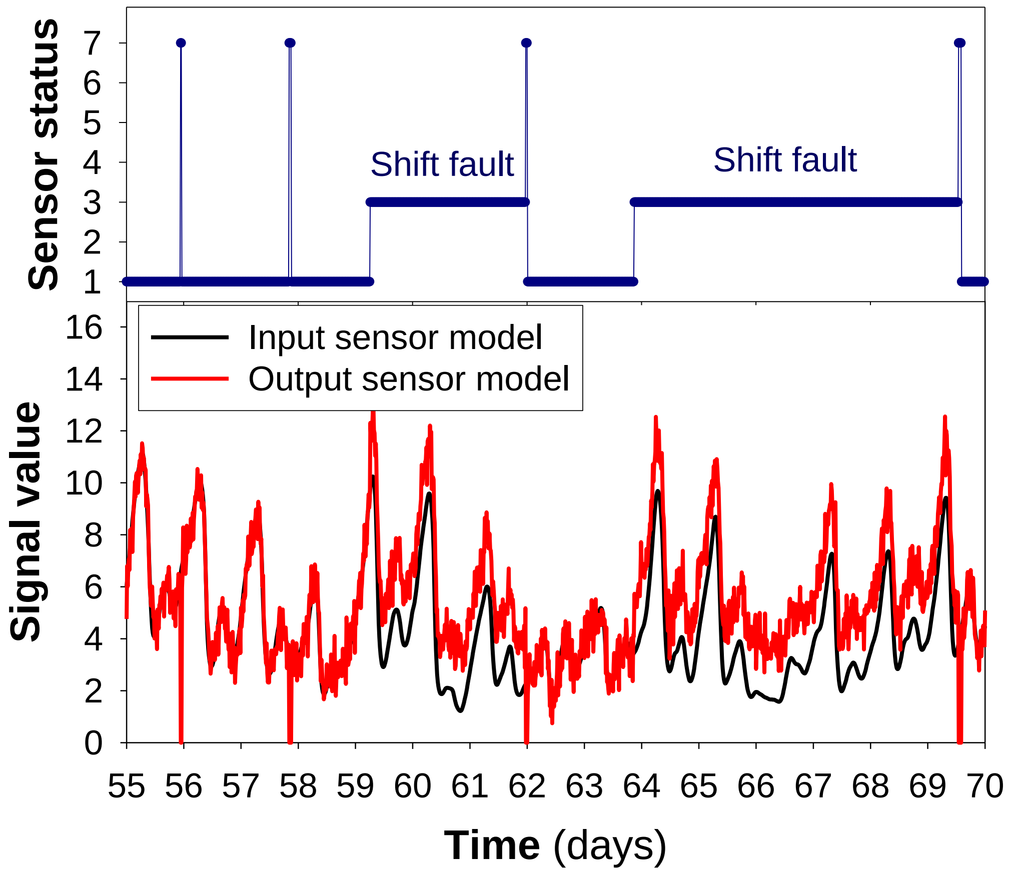
Sensor status:

1. Correct functioning
2. Excessive drift
3. Shift
4. Fixed value
5. Complete failure
6. Error gain
7. Calibration



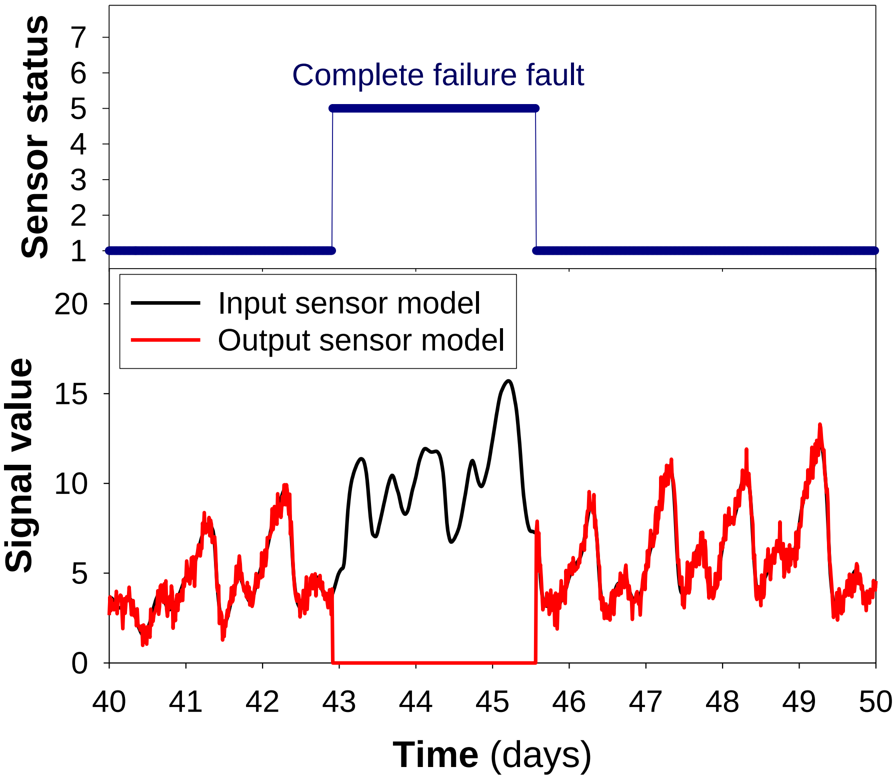
3. Fault-detection

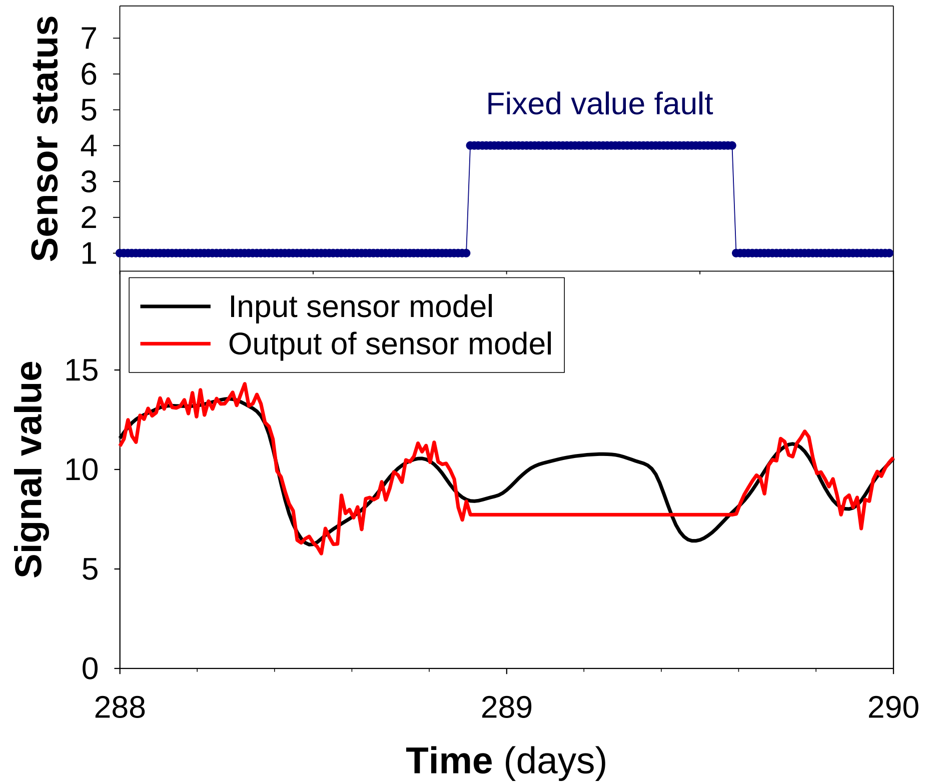
- Fault models (phenomenology)



3. Fault-detection

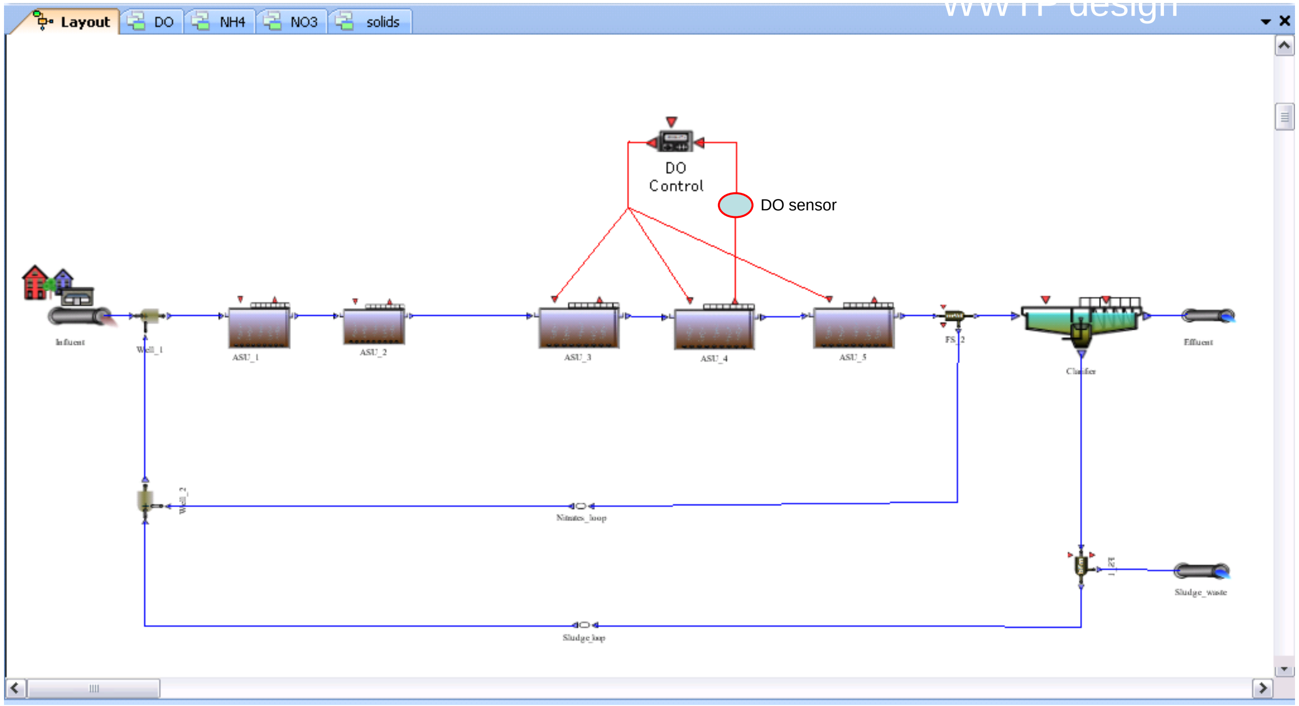
- Fault models (phenomenology)





3. Fault-detection

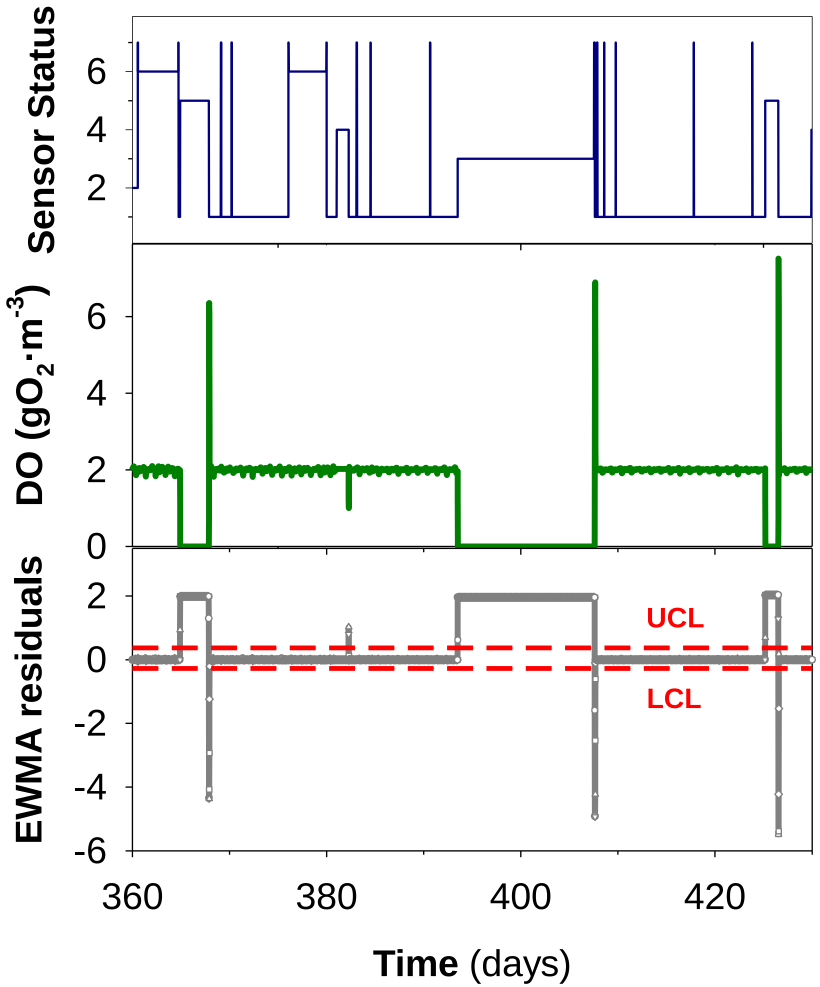
- Case-study:

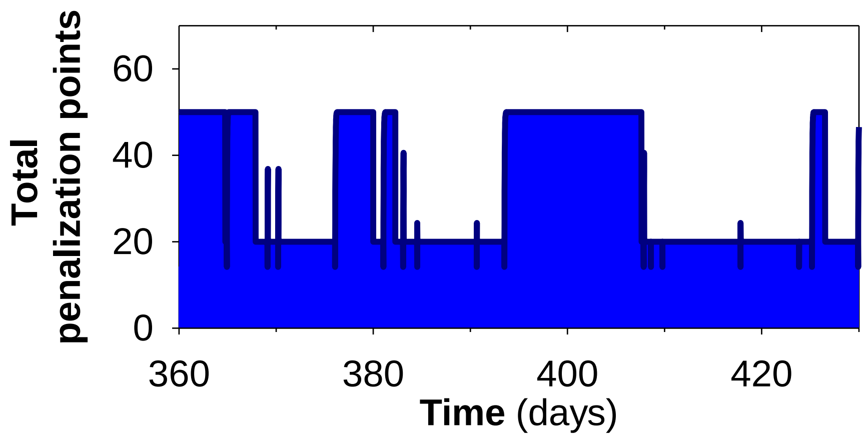


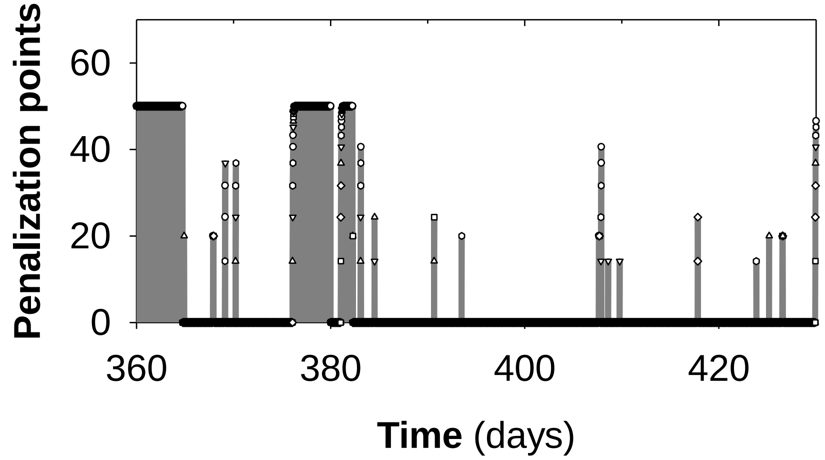
- Methods:
  - Shewhart (DO)
  - EWMA (DO)
  - Residuals on EWMA (DO, $k_L a$)

3. Fault-detection

$$y = P_{sat} \times \left(1 - e^{(-t/tau)}\right)$$

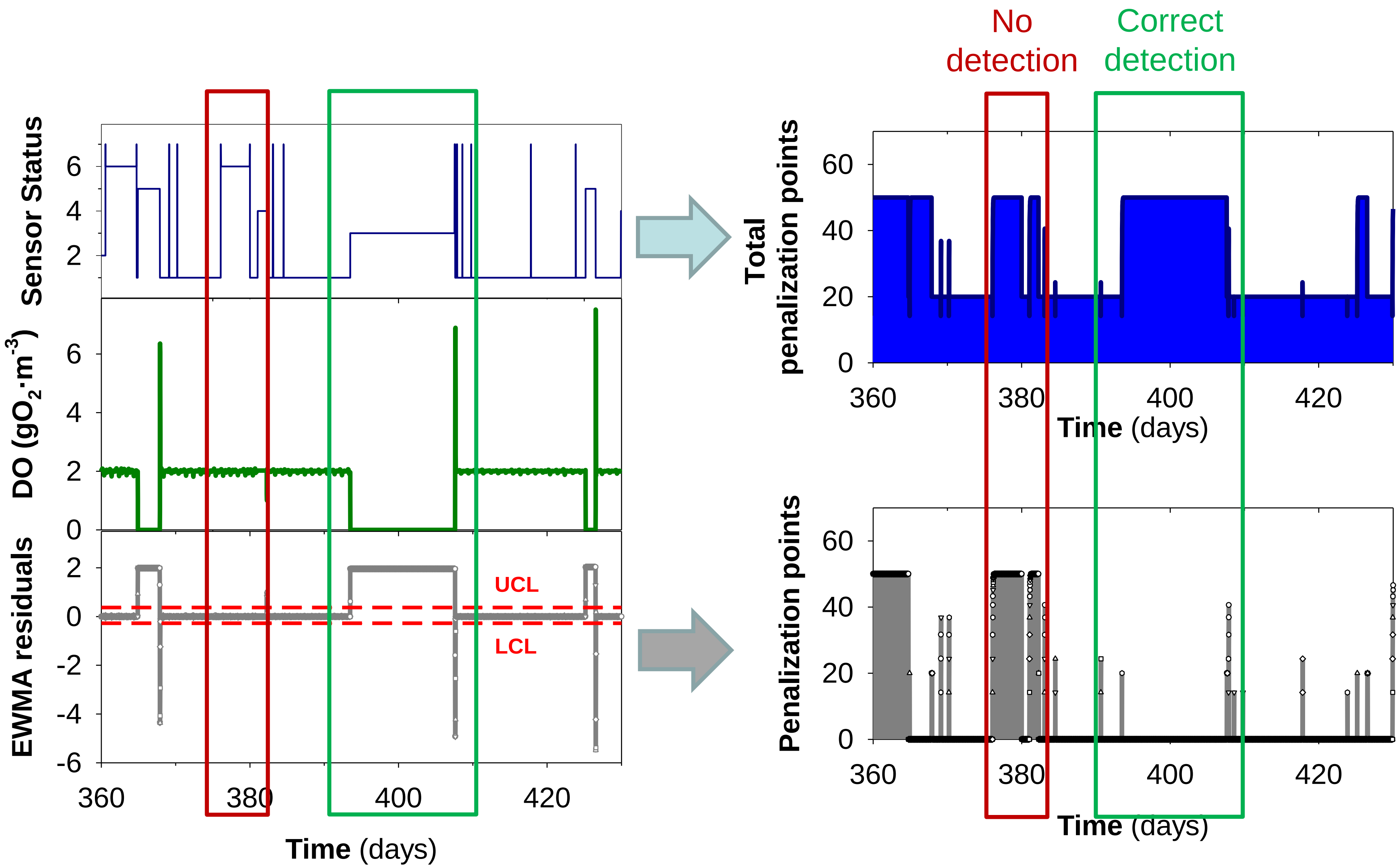






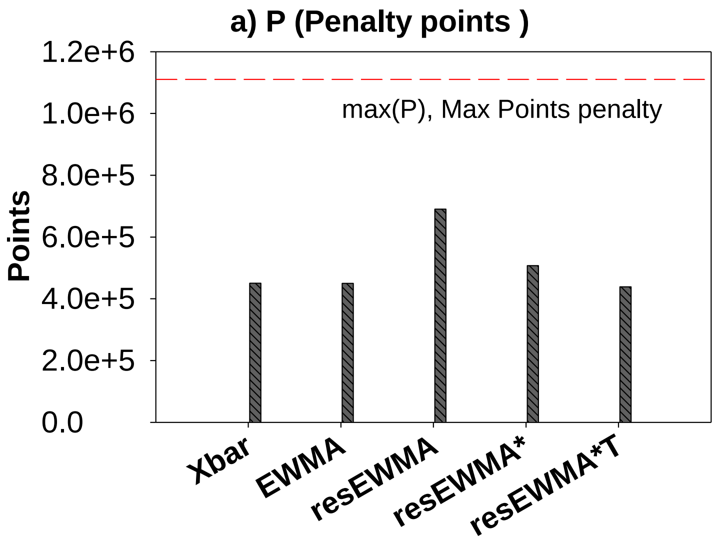
3. Fault-detection

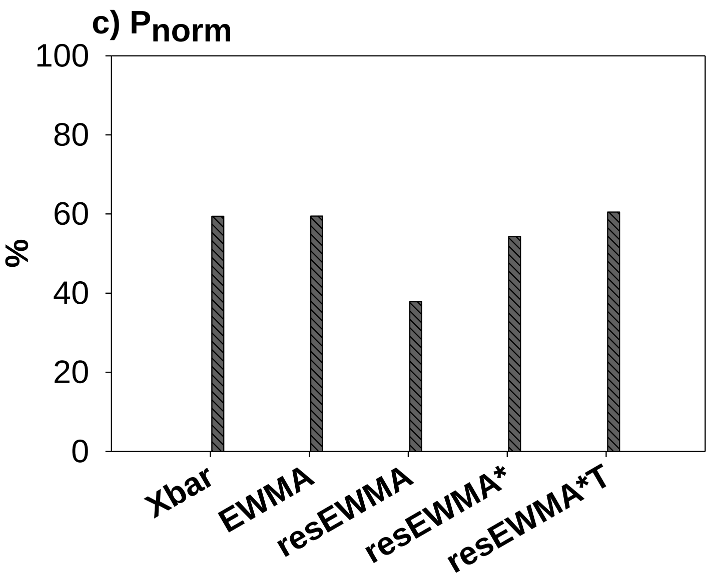
Pnorm = 1- (P/max(P))



3. Fault-detection

- Methods tested are at 60% of maximum fault-detection performance





- Increase of costs when faults are included in the DO sensor (Aeration energy increased by 32%)

Overview

1. Introduction
2. LCA to evaluate control strategies
3. Fault-detection
4. **Conclusions**

4. 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
- Fault-tolerant control is necessary since equipment failures can cause severe effluent limit violations
- Fault-detection methods tested so far are at 60% of maximum performance. Further research is warranted.

Acknowledgements

This research is supported by the Canada Research Chair in Water Quality Modeling and a NSERC Special Research Opportunities grant as part of the Canadian contribution to the European Union 6th framework project NEPTUNE. This study was part of the EU Neptune project (Contract No 036845, SUSTDEV-2005-3.II.3.2), which is financially supported by grants obtained from the EU Commission within the Energy, Global Change and Ecosystems Program (FP6-2005-Global-4).

Canada Research Chair in Water Quality Modeling