Optimisation of the WWTP performance and design using computer simulation

Jacek Mąkinia, Ewa Zaborowska

Gdańsk University of Technology (Poland)

Department of Sanitary Engineering

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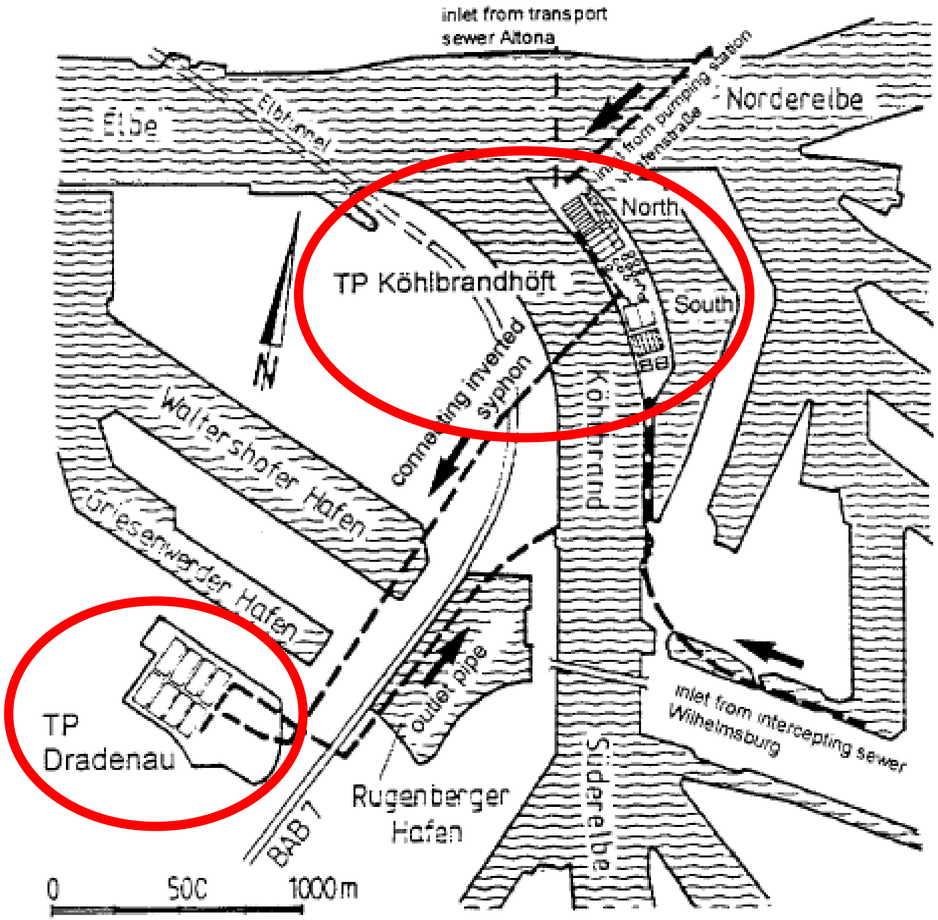
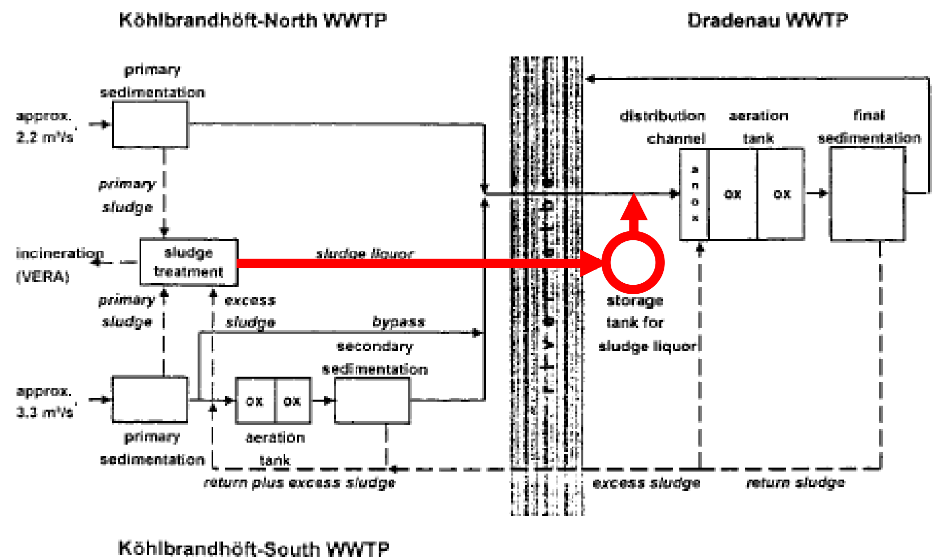
Maybe the best example of plant optimization… – Hamburg WWTPs





Preliminary cost of upgrade (ATV-131) – **100 mln Euro**

Preliminary cost of upgrade (simulation studies) – **1 mln Euro !!!**

Cost of simulation studies – **0.15 mln Euro**

*Ladiges, Gunner and Otterpohl (1999). **Optimisation** of the Hamburg wastewater treatment plants by dynamic simulation. Wat. Sci. Tech., 39 (4), 37-44.*

*Ladiges, Bertram and Otterpohl (2000). Concept development for the **optimisation** of the Hamburg Wastewater Treatment Plants. Wat. Sci. Tech., 41 (9), 89-96.*

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Traditional applications of mathematical modeling and computer simulation

Operation of existing facilities
(diagnosis and optimization)

Research
(development of new treatment concepts, process understanding)

Design of new facilities

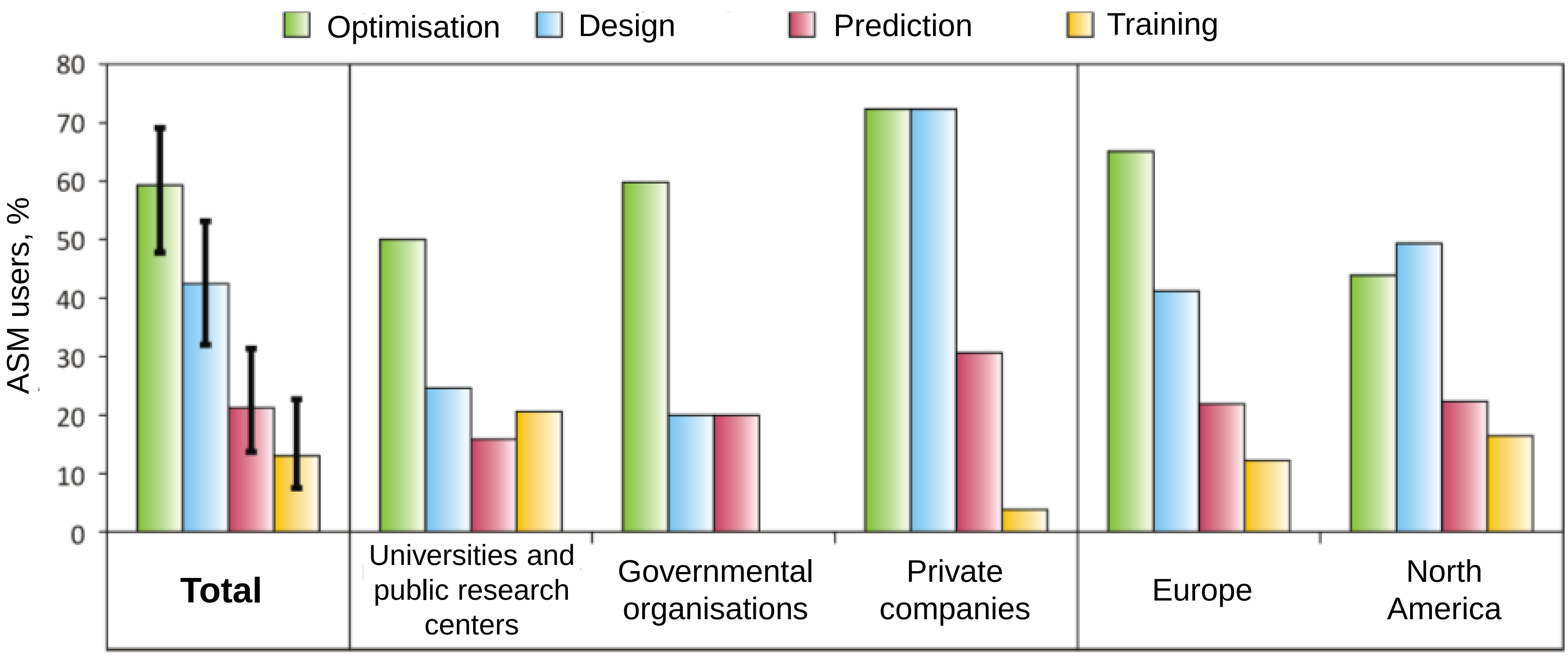
Mathematical modeling and computer simulation in wastewater treatment

Legal regulation
(evaluating the impact of new effluent standards)

Process control
(testing new control systems)

Education
(teaching and staff training)

Results of a survey on model applications (Hauduc et al., 2009)



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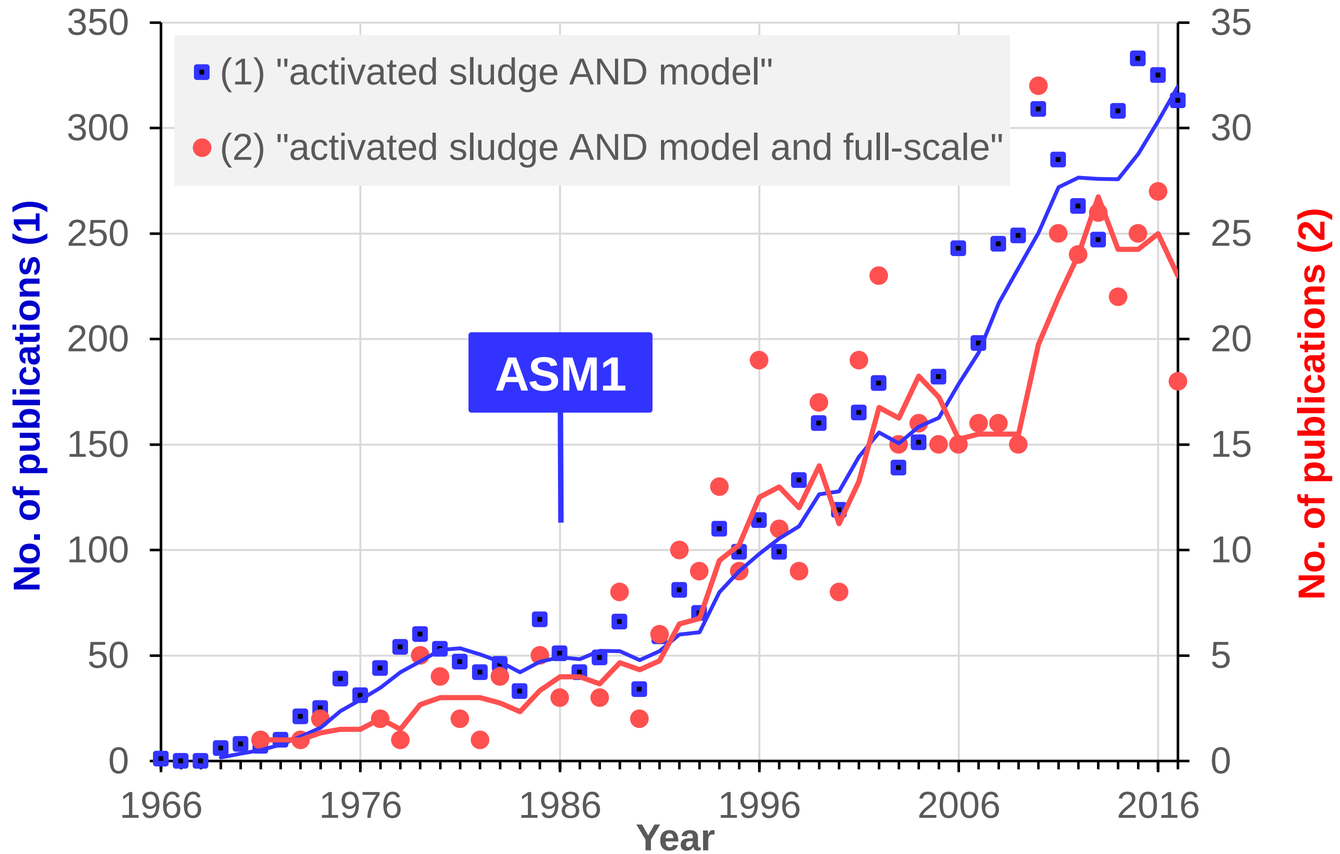
Number of publications on activated sludge modeling referenced in the SCOPUS database



Popular simulation programs

Program	Company	Contact
GPS-X	Hydromantis (Canada)	www.hydromantis.com/
BioWin	Envirosim Associates Ltd. (Canada)	www.envirosim.com
STOAT	Water Research Centre (UK)	www.wrcplc.co.uk
SIMBA	IFAK (Germany) and InCTRL (Canada)	simba.ifak.eu
WEST	DHI (Denmark)	www.mikepoweredbydhi.com
SUMO	Dynamita (France)	www.dynamita.com

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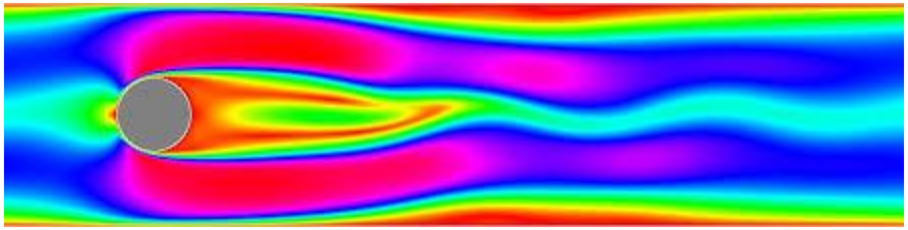
Advantages and disadvantages of computer simulation

ADVANTAGES

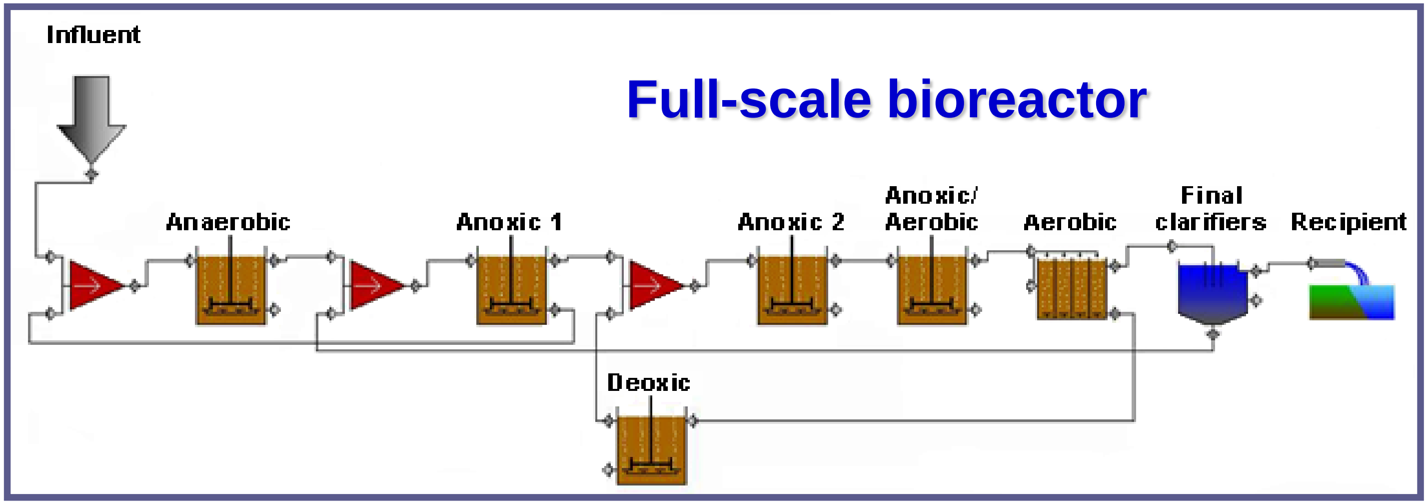
- No disruptions to existing systems
- Testing a concept prior to installation
- Detection of unforeseen problems
- Much greater speed in analysis (“time compression”)
- Savings in financial expenditures

DISADVANTAGES

- It is neither cheap nor easy to apply
- Simulation gives only approximate results
- Results can be no better than the model (and data),
- **Much cleaner job than physical experimenting (validation required!)**



Main steps in model calibration/validation

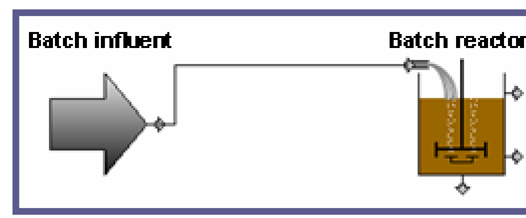


STEP 1: Steady-state and "phase" dynamic simulation of the full-scale AS system

STEP 2: Dynamic simulation of the batch tests during the summer study period

STEP 3: Dynamic simulation of the batch tests during other study periods

STEP 4: Dynamic simulation of the full-scale AS system



Batch reactor

Laboratory batch experiments

- **One-phase** experiments
  (**nitrification, denitrification**)

- **Two-phase** experiments
  (**P removal and nitrification**)
  (**P removal and denitrification**)

- **Three-phase** experiments
  (**P removal, nitrification and denitrification**)

Operating cost model – components in GPS-X

- **Aeration energy**
  (blower compression efficiency, headloss, etc., and the factors included in the oxygen transfer model)
- **Pumping energy**
  (water/air flow rate, hydraulic head, density of water/air)
- **Sludge handling**
  (disposal price and rate)
- **Miscellaneous energy**
  (operation of gates, arms, rakes, mixers, moving bridges, etc.)
- **Chemical addition**
  (chemical price and dosage rate)

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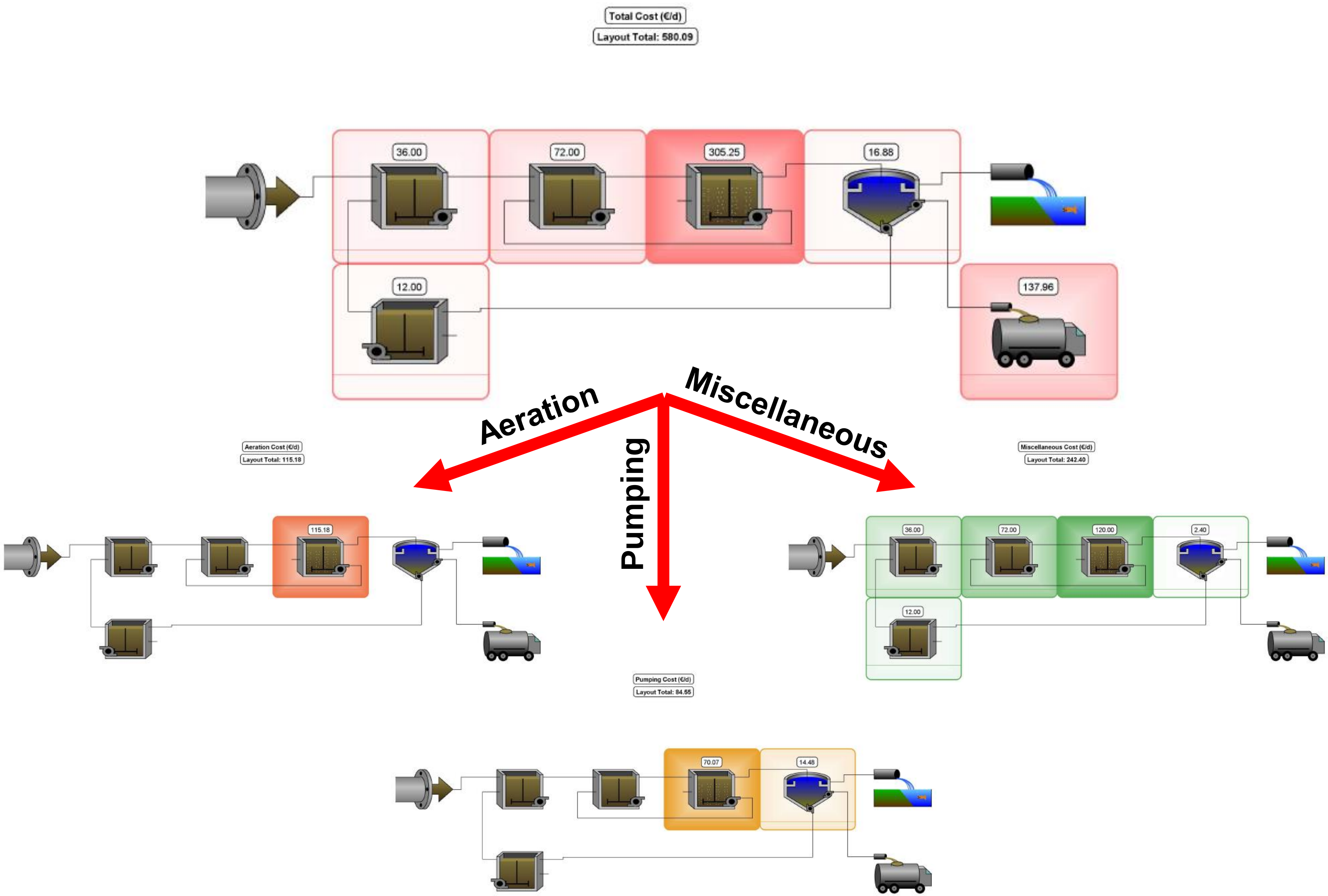
Operating cost model - example



SŁUPSK WWTP CASE STUDY

OPTIMIZATION OF OPERATIONAL STRATEGIES

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Characteristics of the Słupsk WWTP

Loading and hydraulic capacity			
Parameter	Unit	Design	Actual
Size	PE	250 000	200 000
Flowrate	m^3/d	25 000	20 000

Annual average concentrations				
Parameter	Unit	Influent	Effluent	Limit
COD	mg O_2/L	1130	33.0	**150**
Total N	mg N/L	82	9.7	**10**
Total P	mg P/L	12	0.7	**1**

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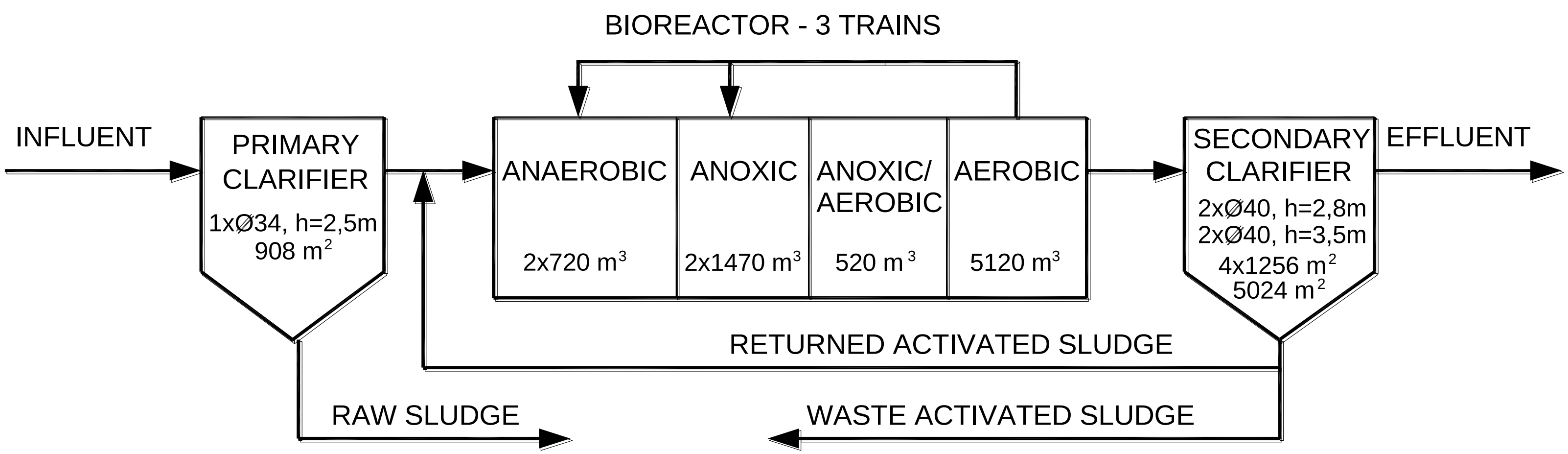
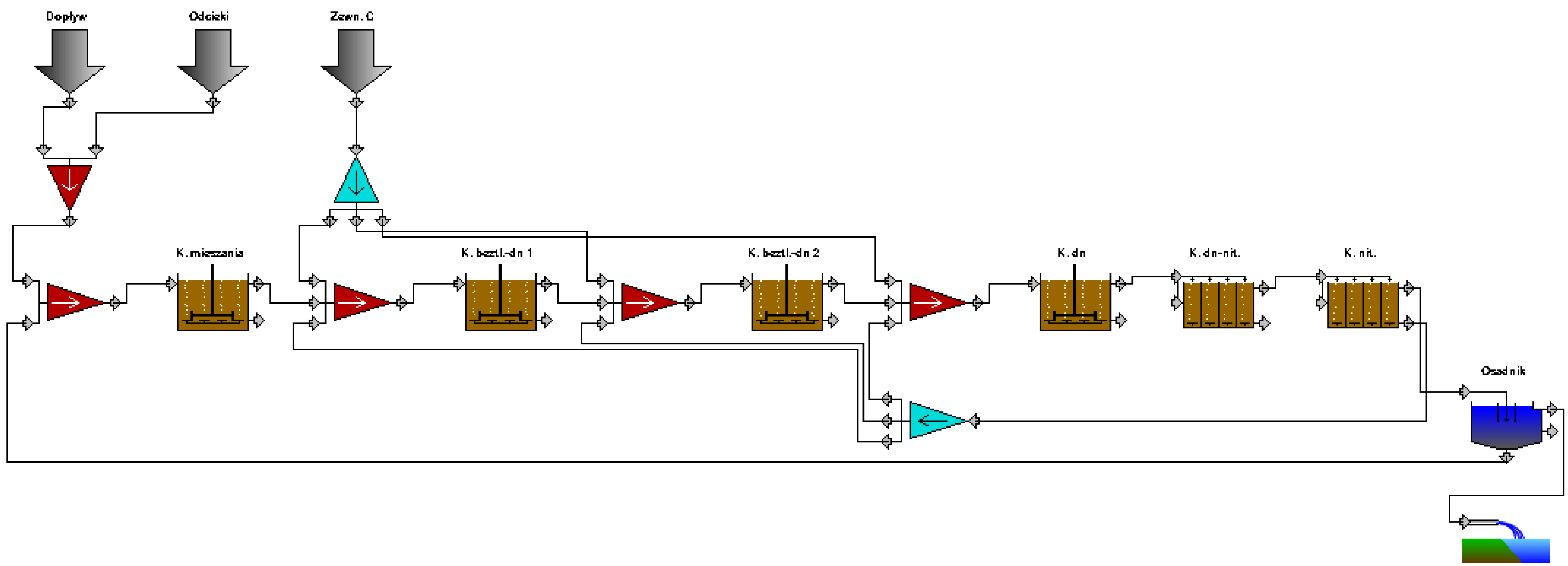
Flow diagram and computer model of the activated sludge system in the Słupsk WWTP





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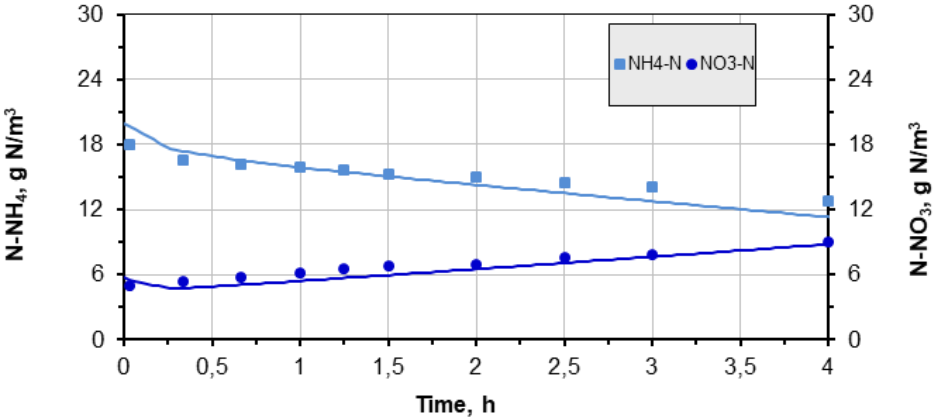
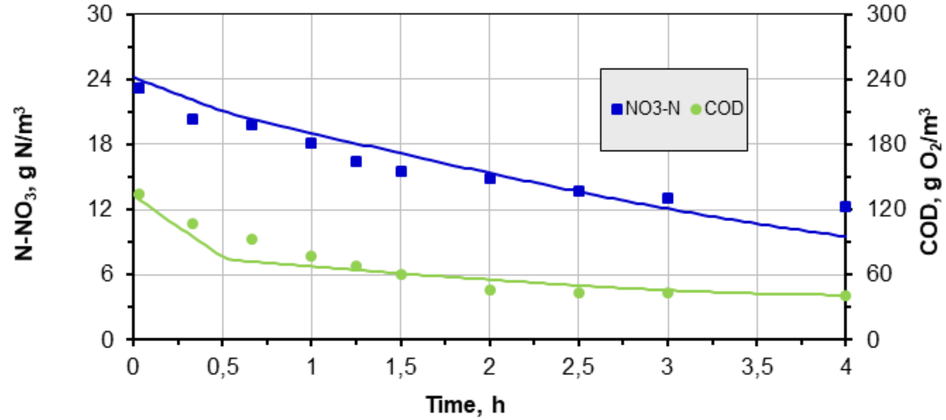
Model calibration in lab-scale

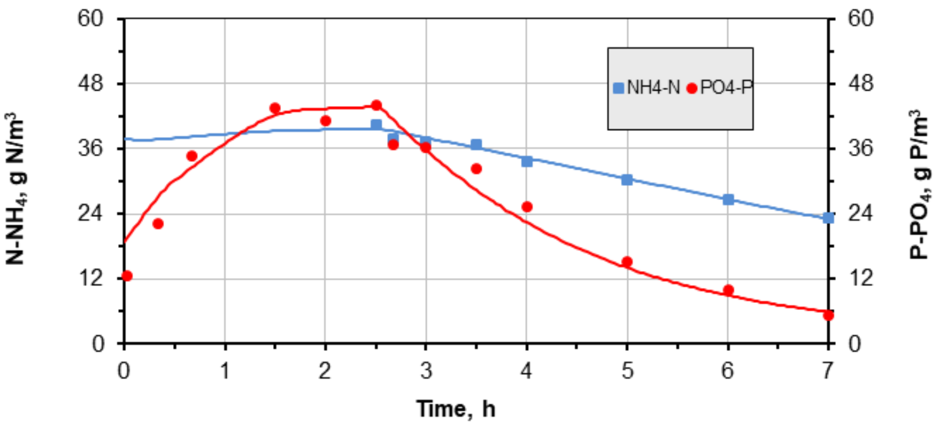
Nitrification



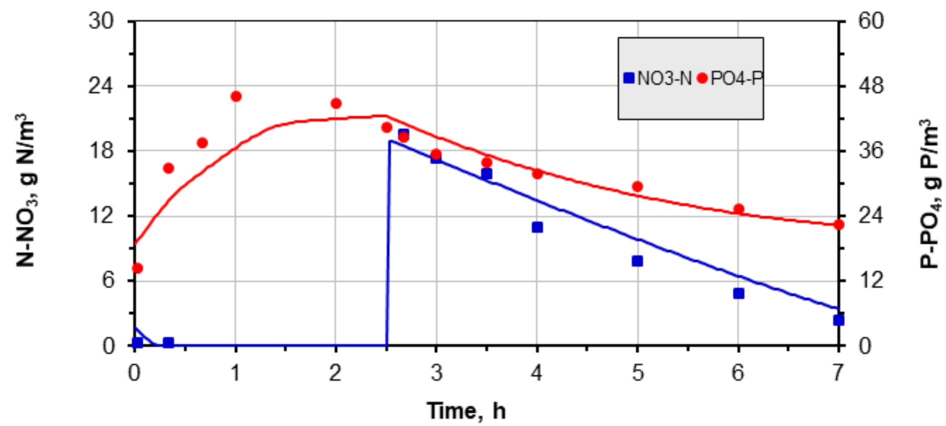
Denitrification



P removal / nitrification



P removal / denitrification



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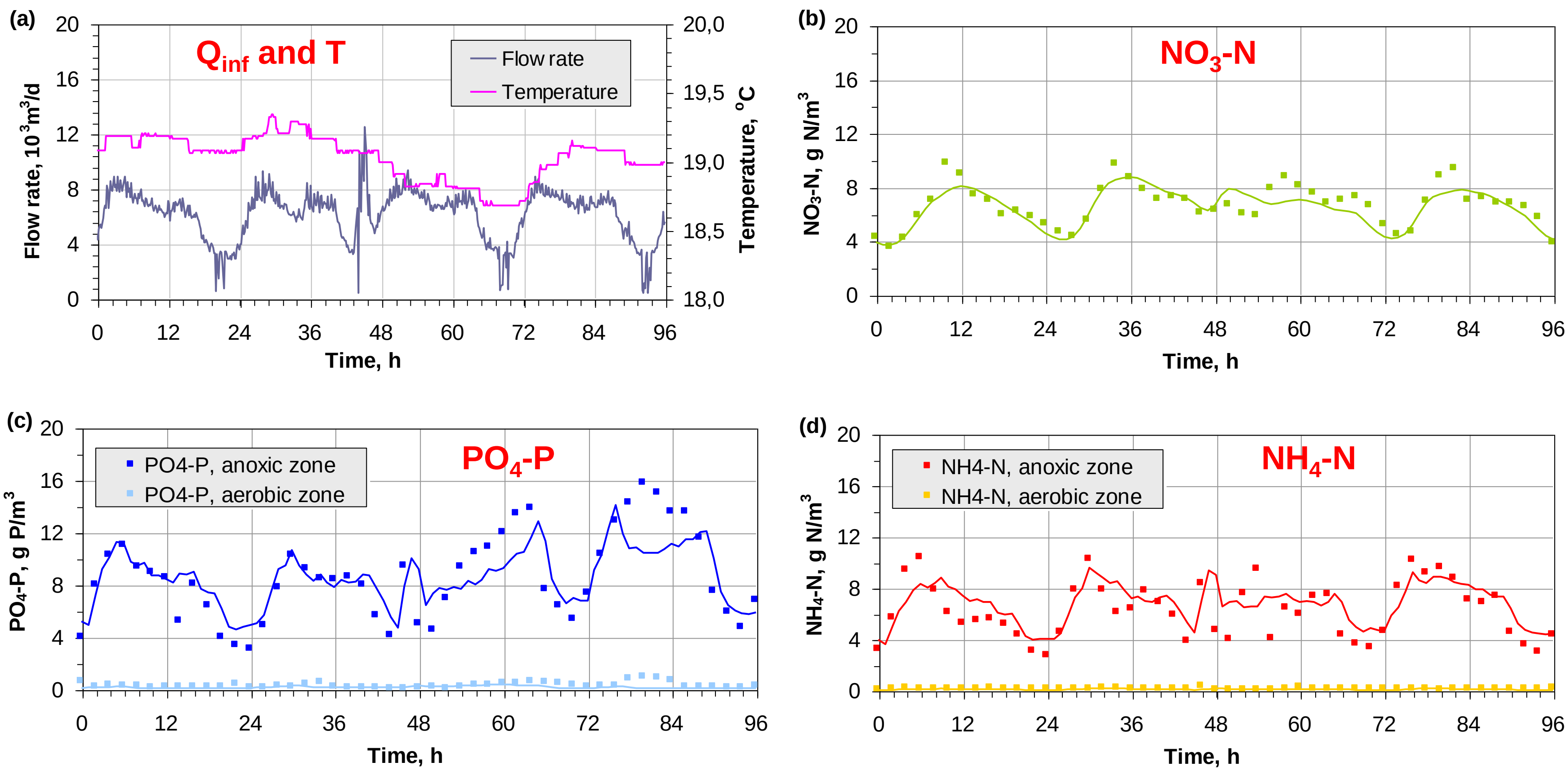
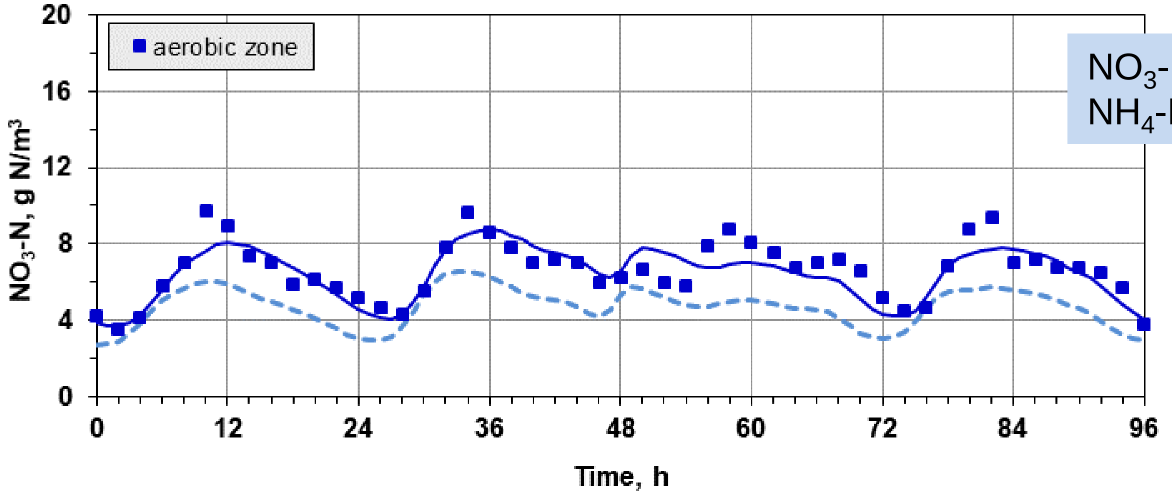
Model in full-scale - 4-day measurement campaign



Zaborowska et al. (2016)

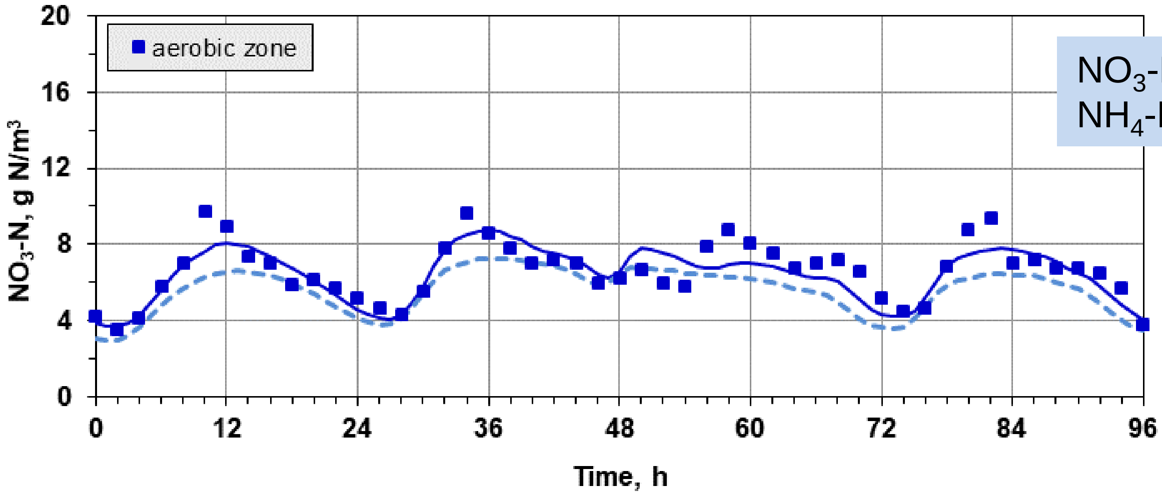
Scenarios for improving N removal (1)

N removal in sidestream



NO_3-N = 4.7 g N/m^3
NH_4-N = 0.07 g N/m^3

Additional treatment line



NO_3-N = 5.6 g N/m^3
NH_4-N = 0.07 g N/m^3

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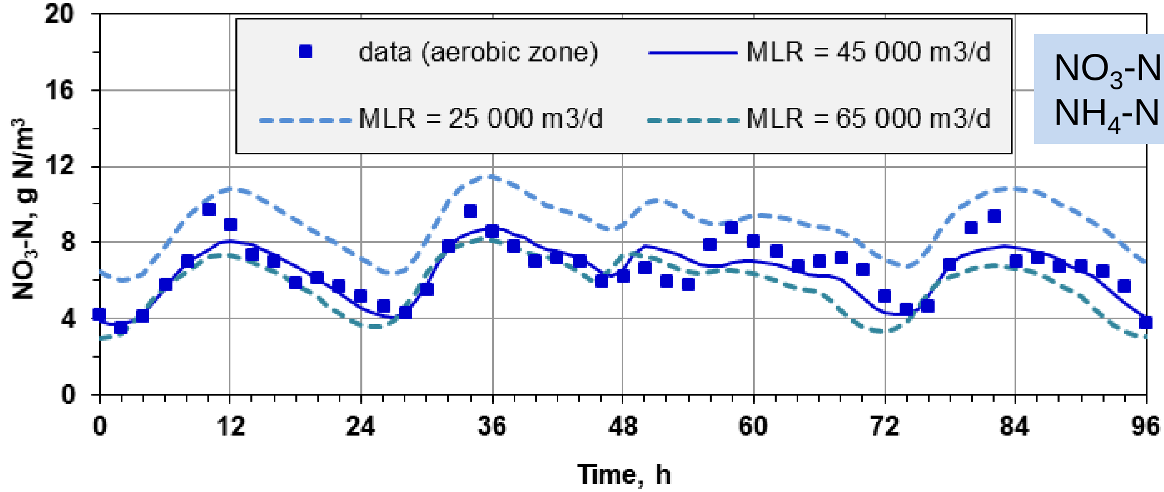
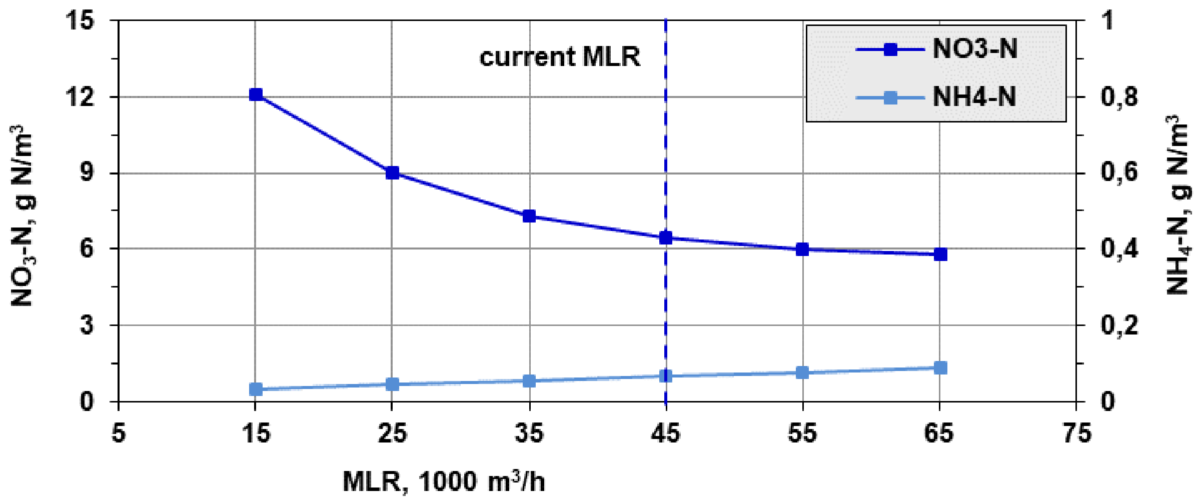
Scenarios for improving N removal (2)

Increasing MLR



NO_3-N = 5.8 g N/m^3
NH_4-N = 0.07 g N/m^3



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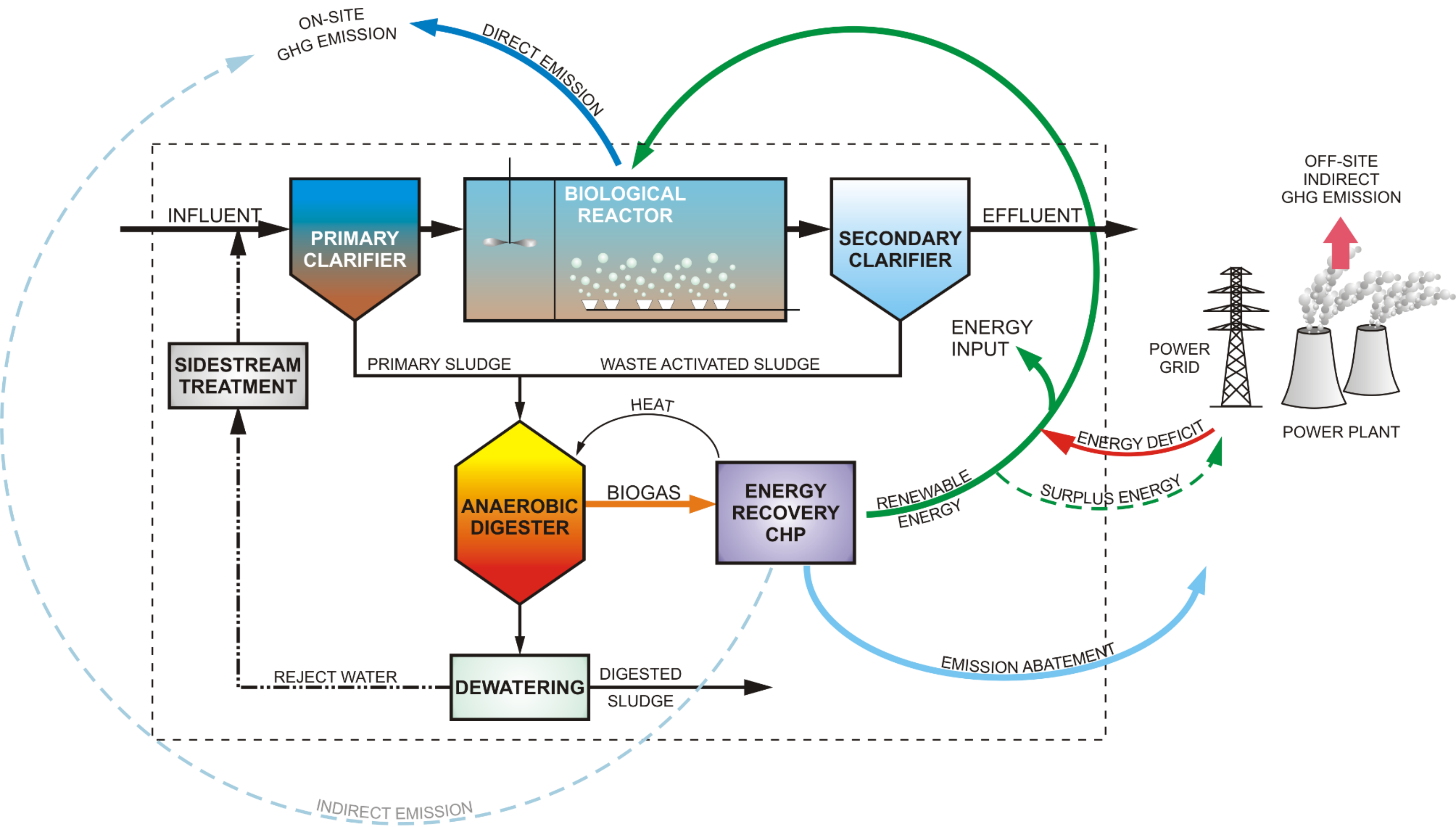
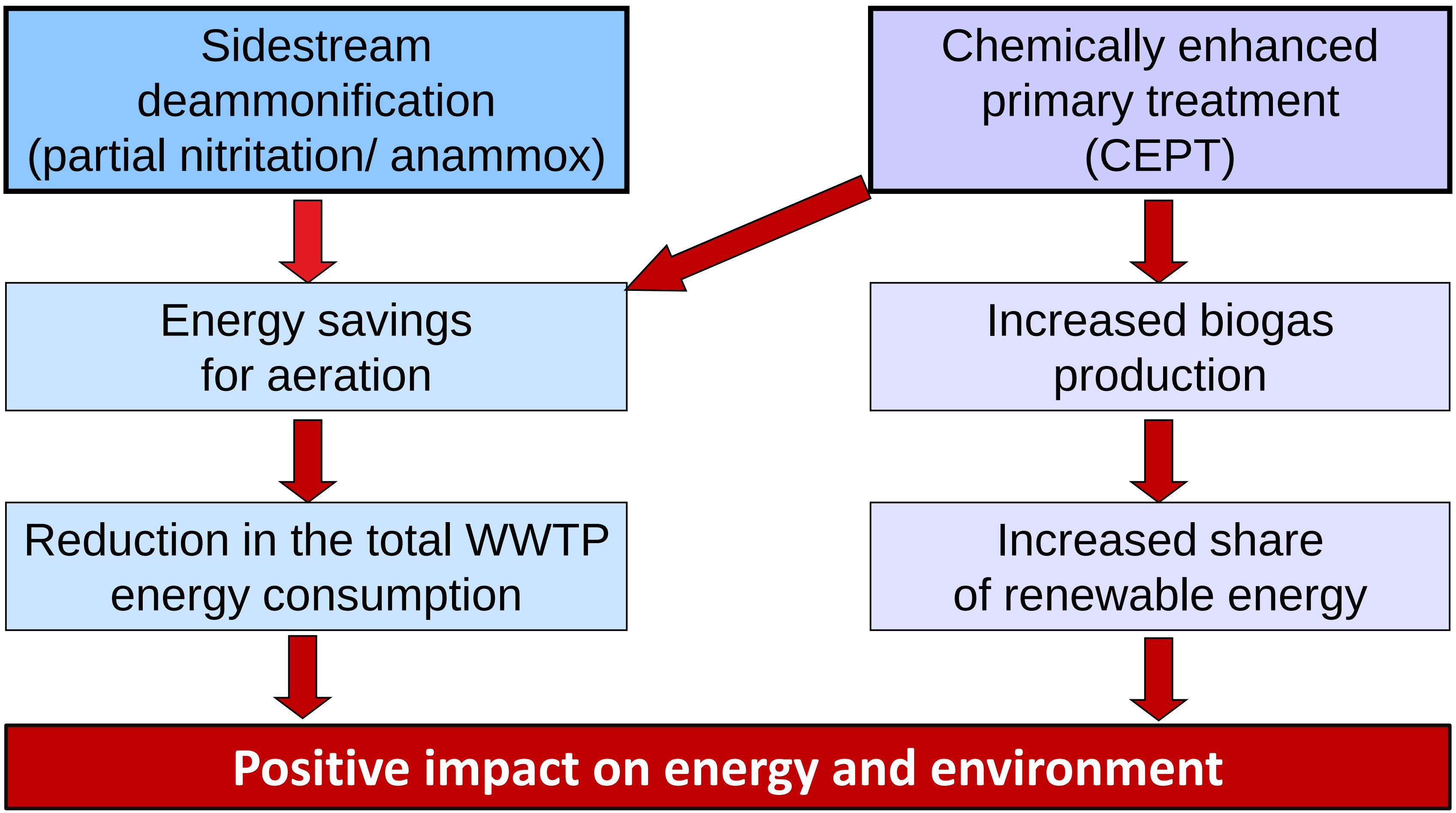
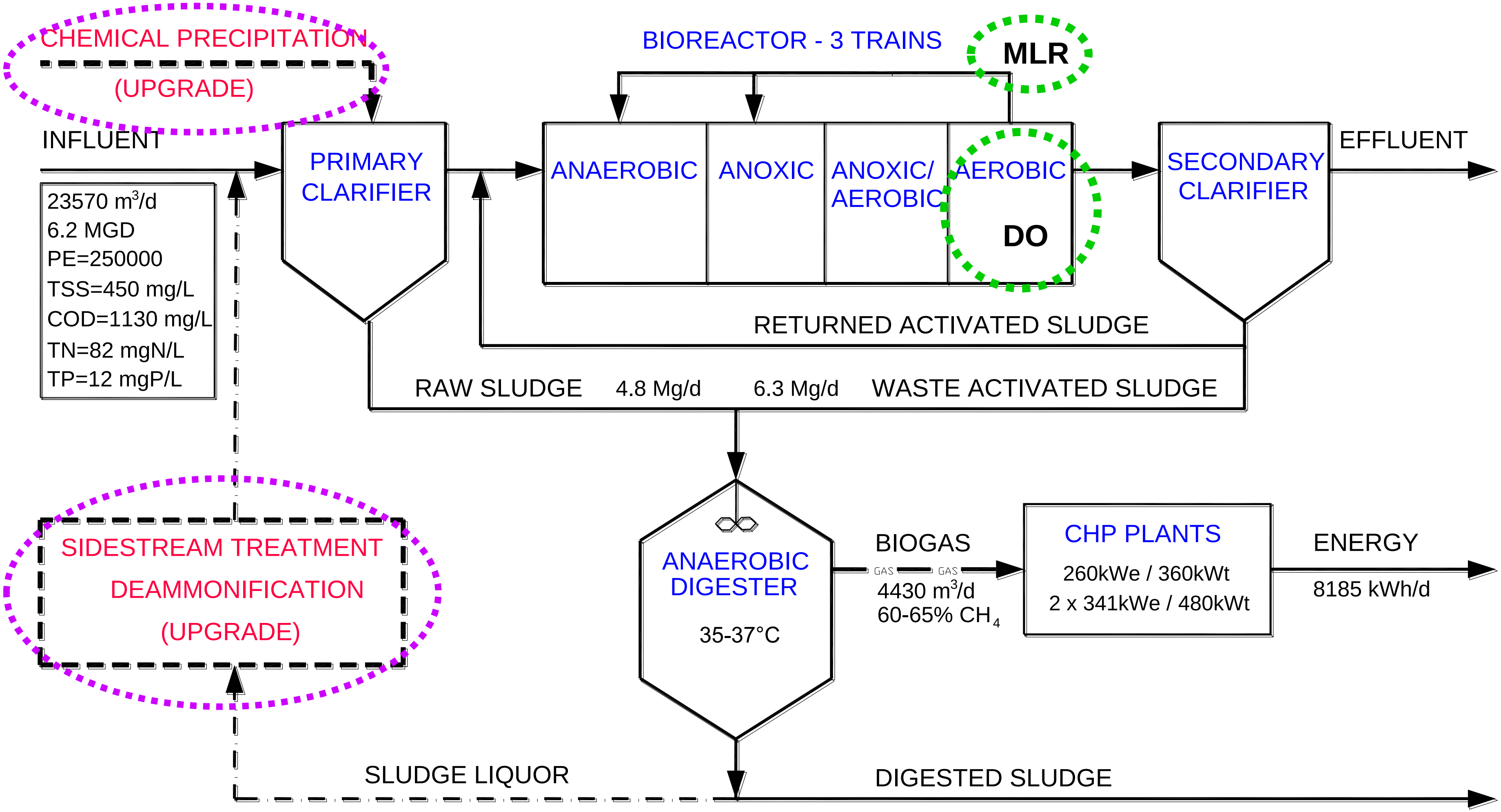
The idea of improving energy balance and reduction GHG emission



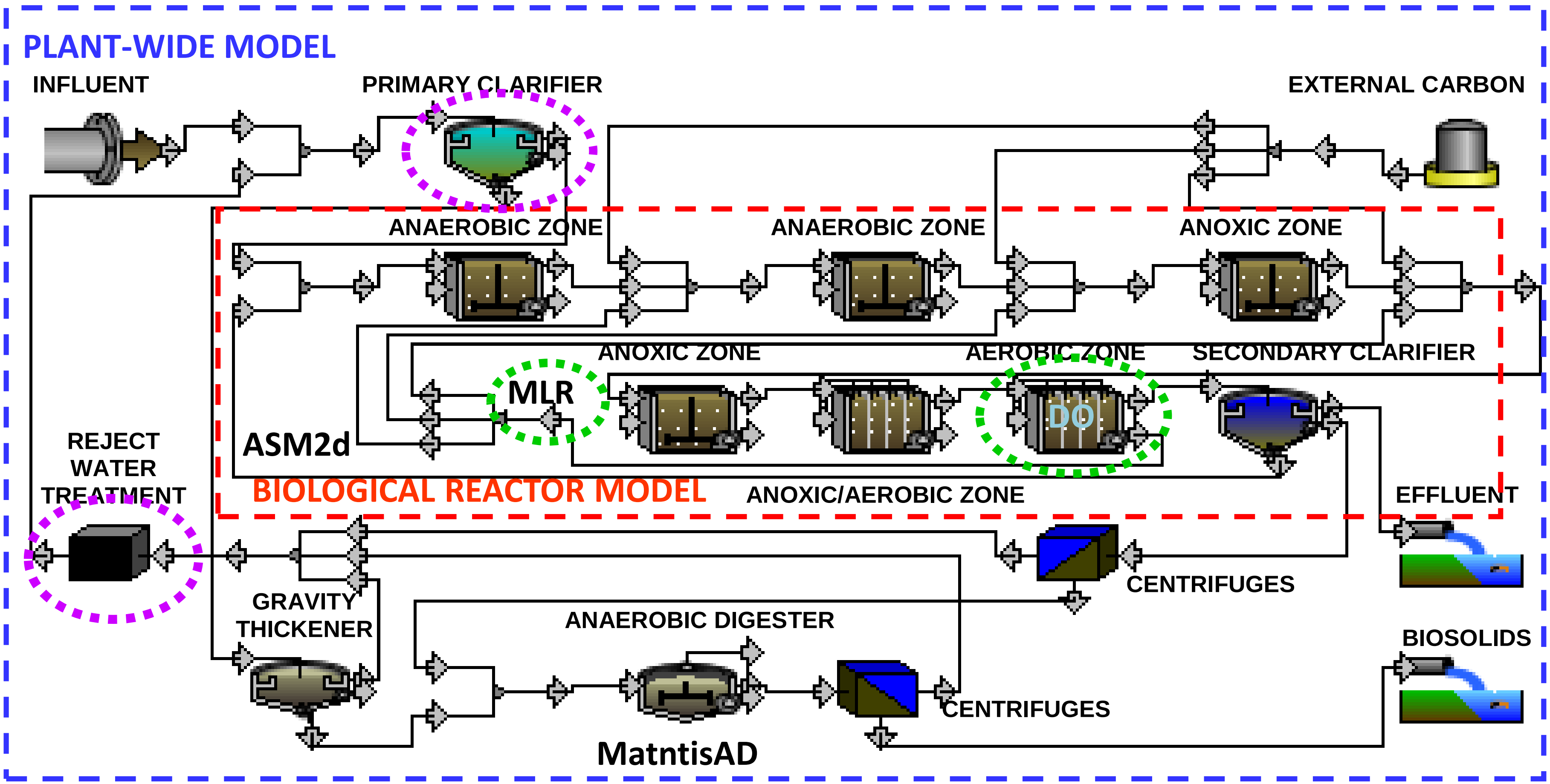
Strategies for improving energy balance and reduction GHG emission



Plant-wide layout



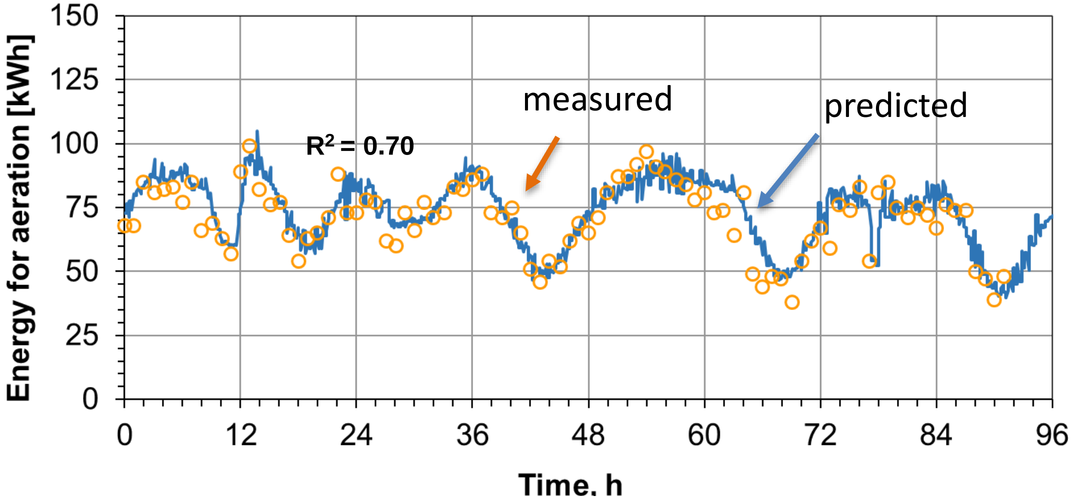
Plant-wide model of the Słupsk WWTP in GPS-X



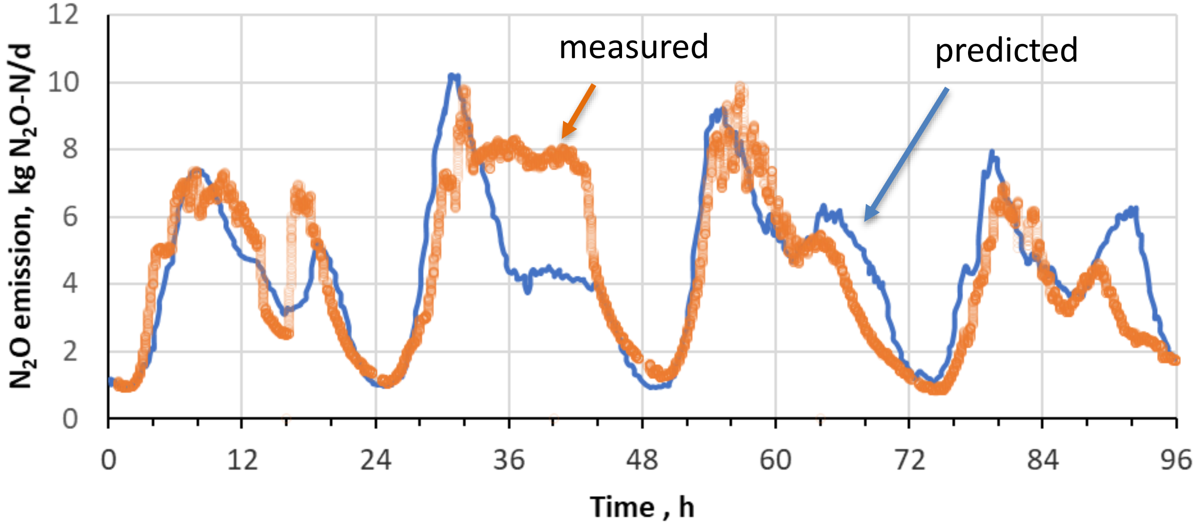
Zaborowska et al. (2017)

Measurements vs. model predictions. Model validation.

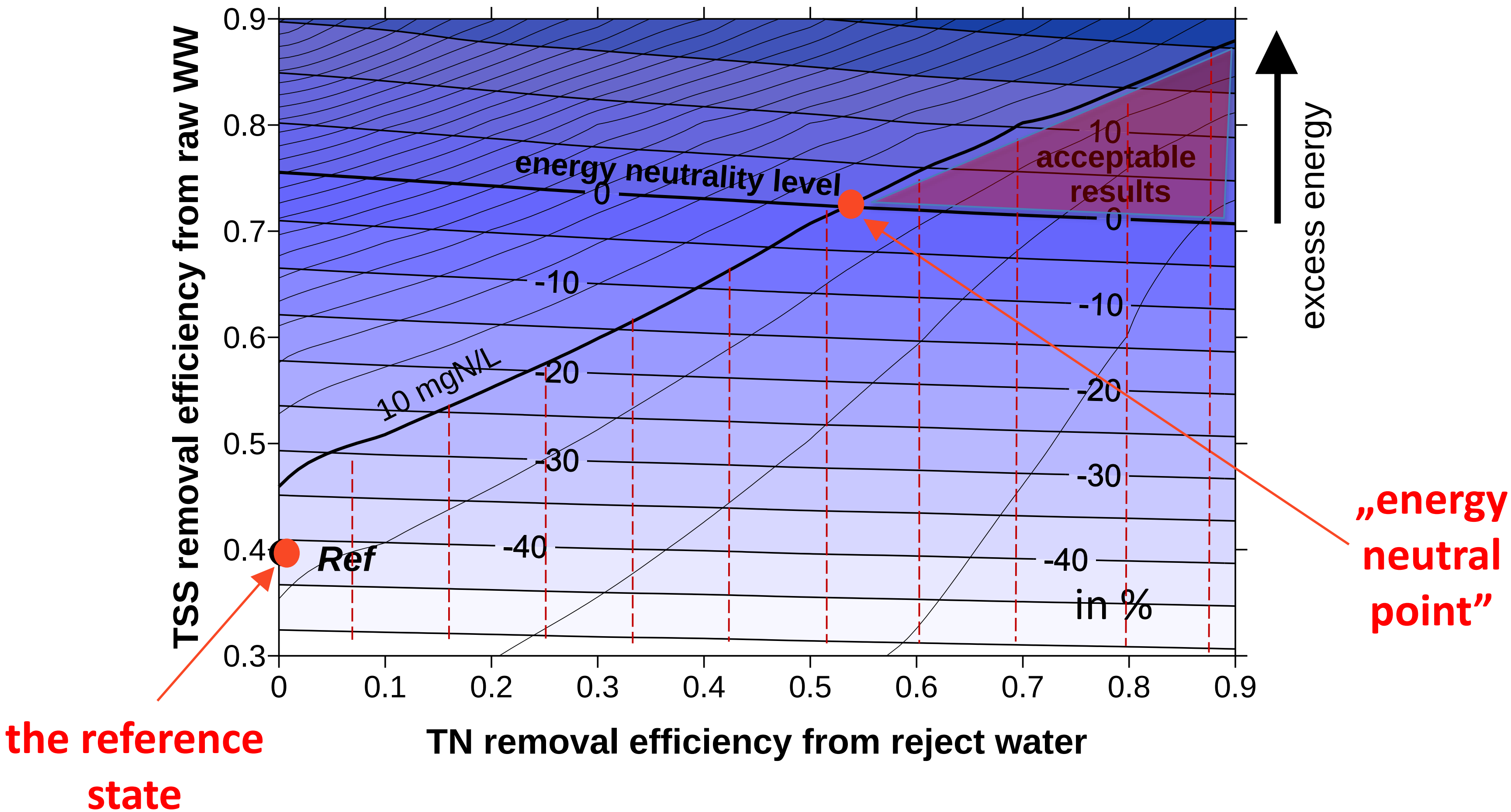
Energy for aeration



N_2O emission

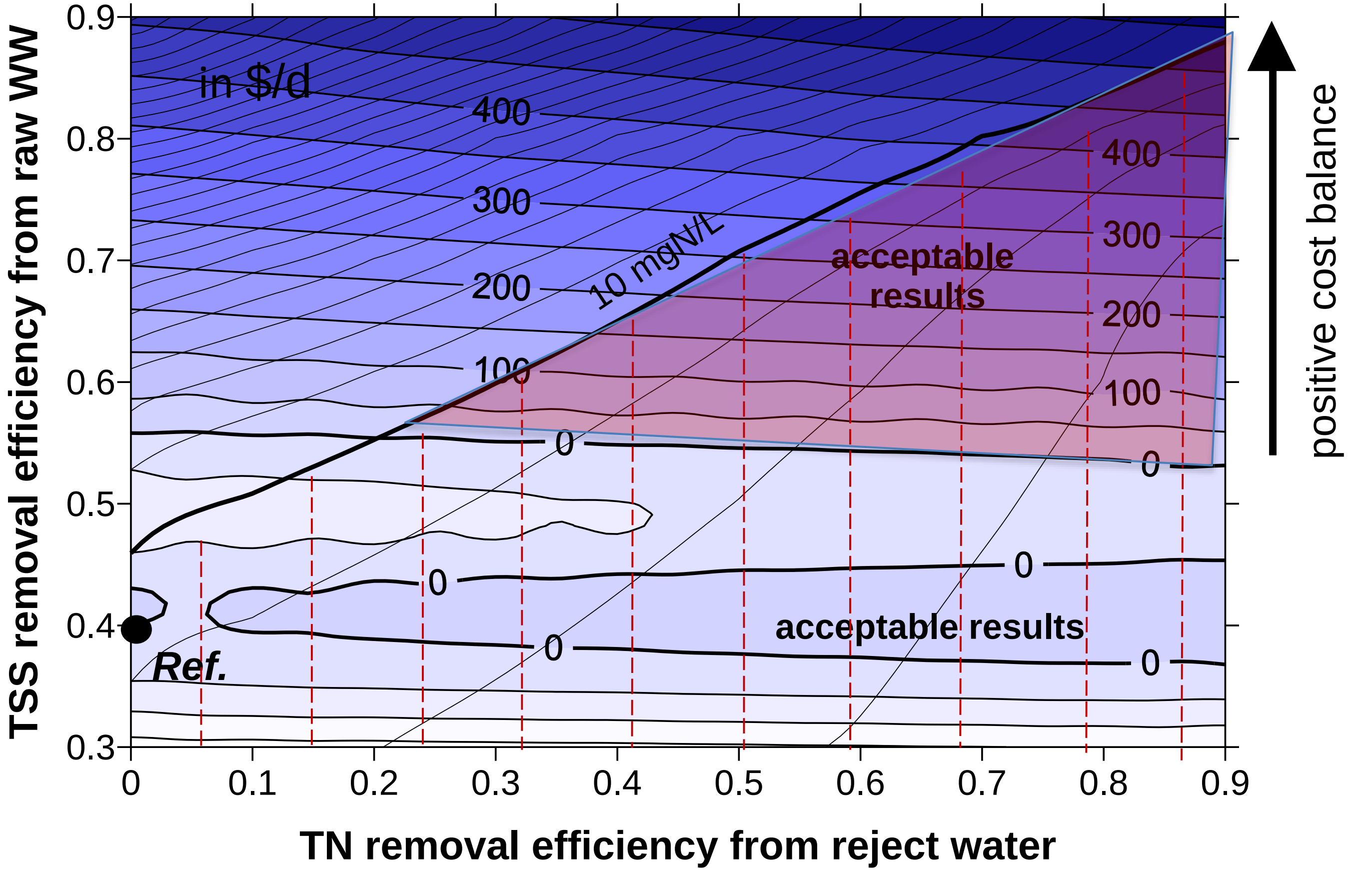


Model predictions under the energy neutrality conditions for the proposed upgrades



Energy recovery from biogas was found the most influential factor affecting the energy balance

Model predictions of the cost balance for the proposed upgrades



The price of the coagulant/flocculent was found the main factor determining a positive cost balance

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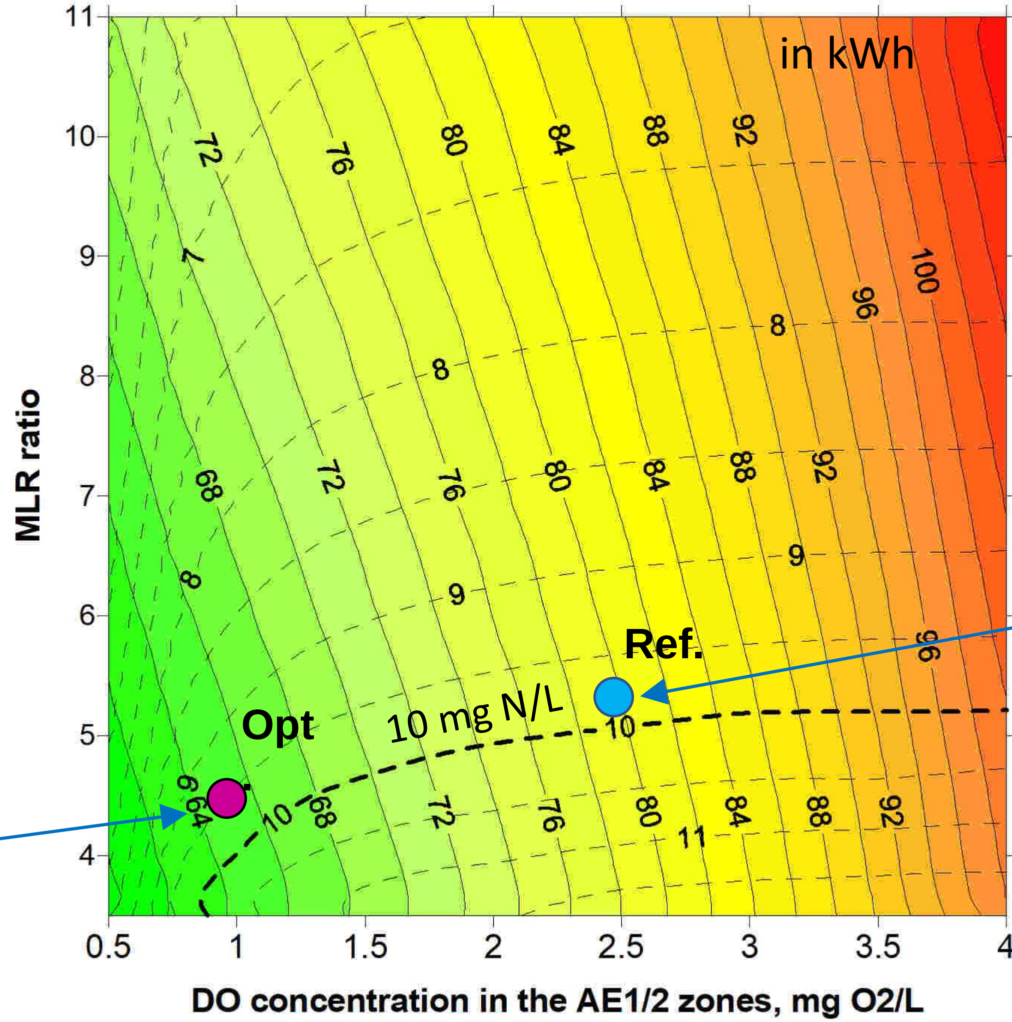
Model predictions of the energy consumption for the proposed operational strategies



the reference state

the optimal state

The energy balance affected mainly by aeration

Case study. Starogard Gd. WWTP

Optimization of upgrades in the sludge line

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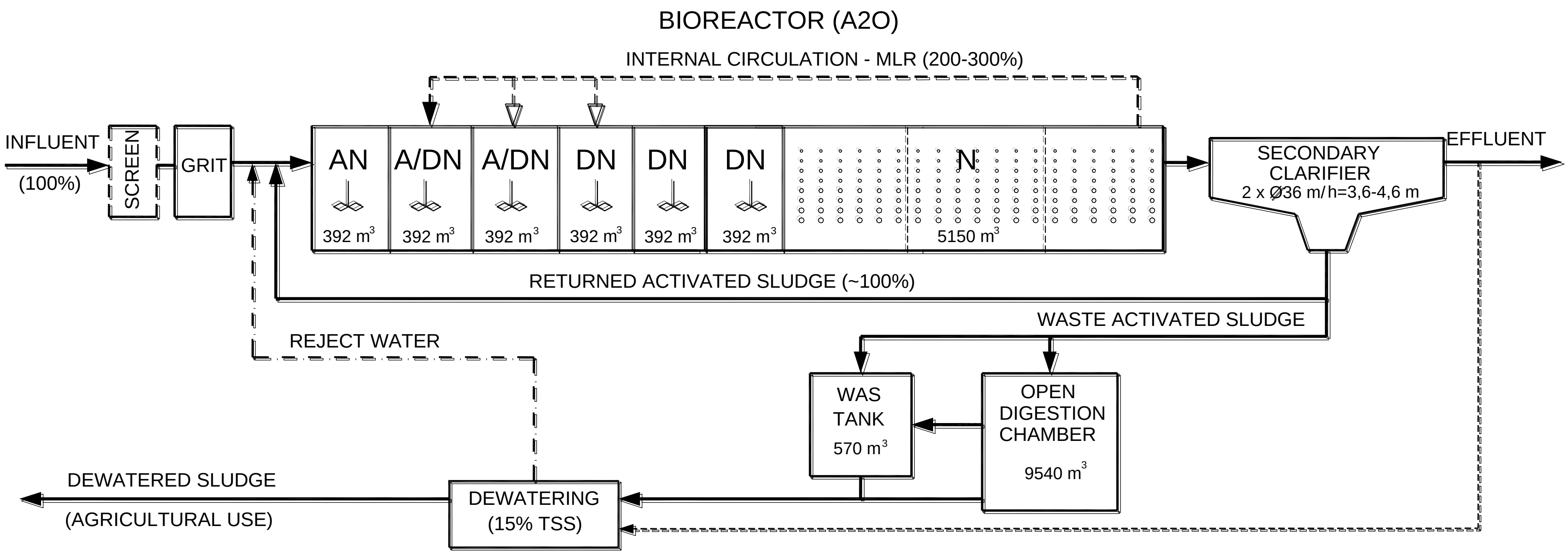
Characteristics of the Starogard WWTP

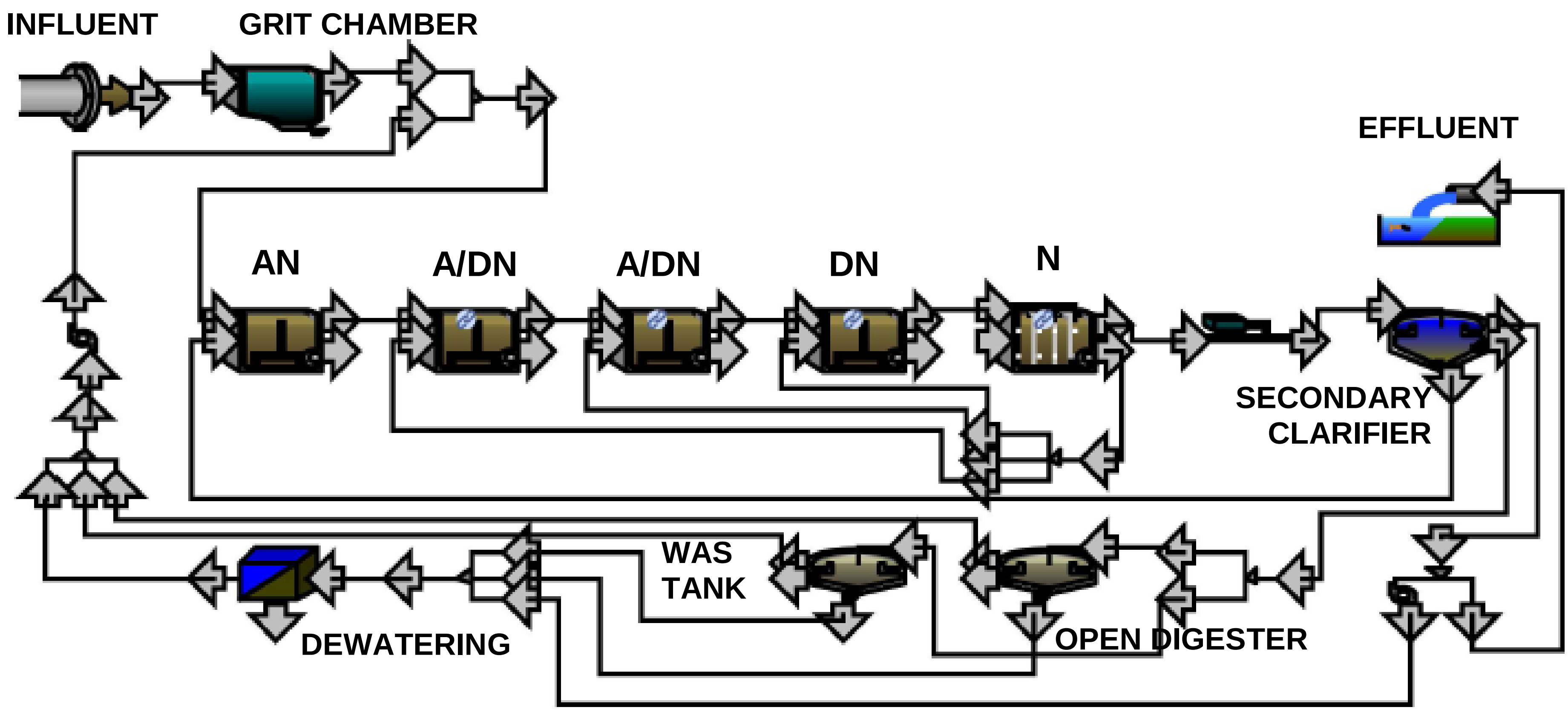
Loading and hydraulic capacity			
Parameter	Unit	Design	Actual
Size	PE	70000	55000
Flowrate	m^3/d	16000	10000

Annual average concentrations				
Parameter	Unit	Influent	Effluent	Limit
COD	mg O_2/L	730	60	125
Total N	mg N/L	70	11	15
Total P	mg P/L	7	0.8	2

Plant layout – the actual state



Plant-wide model in GPS-X – the actual state



Model calibration in lab-scale

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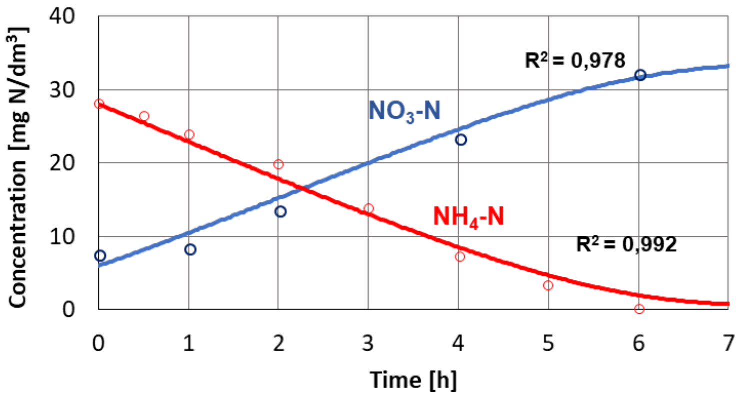
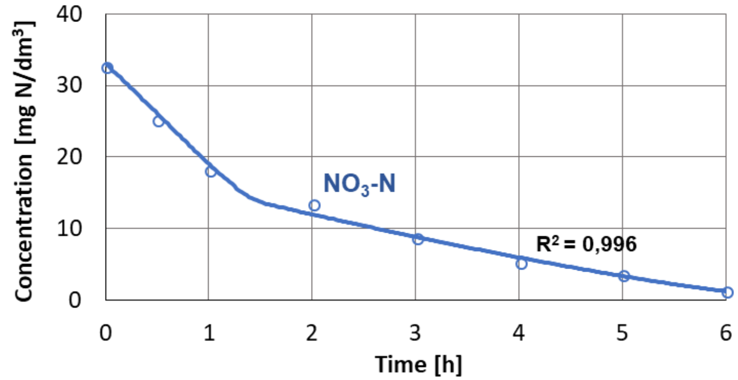
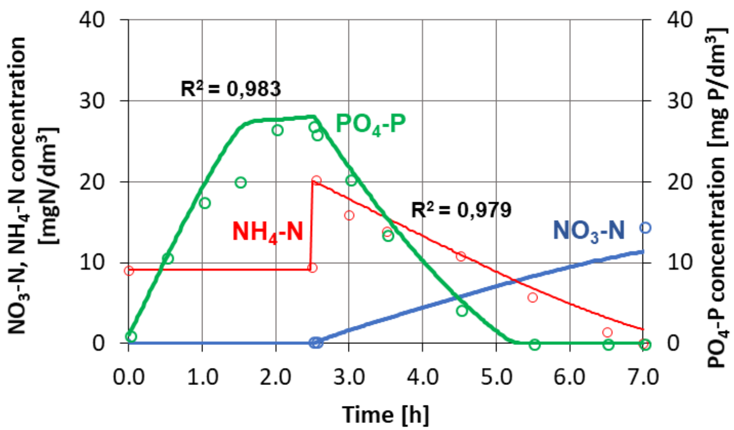
Nitrification



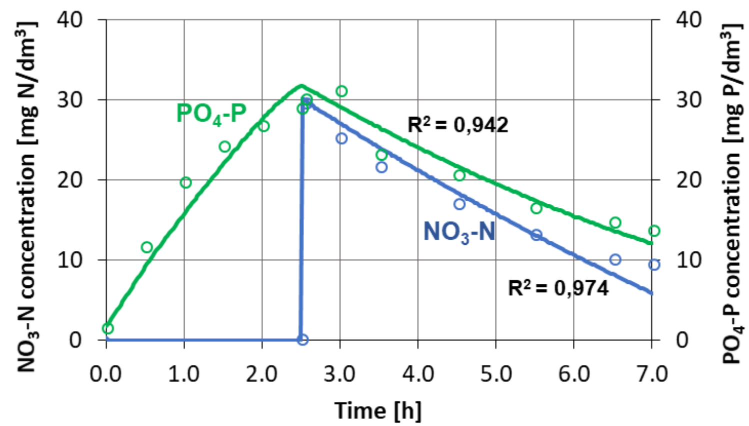
Denitrification



P removal / nitrification

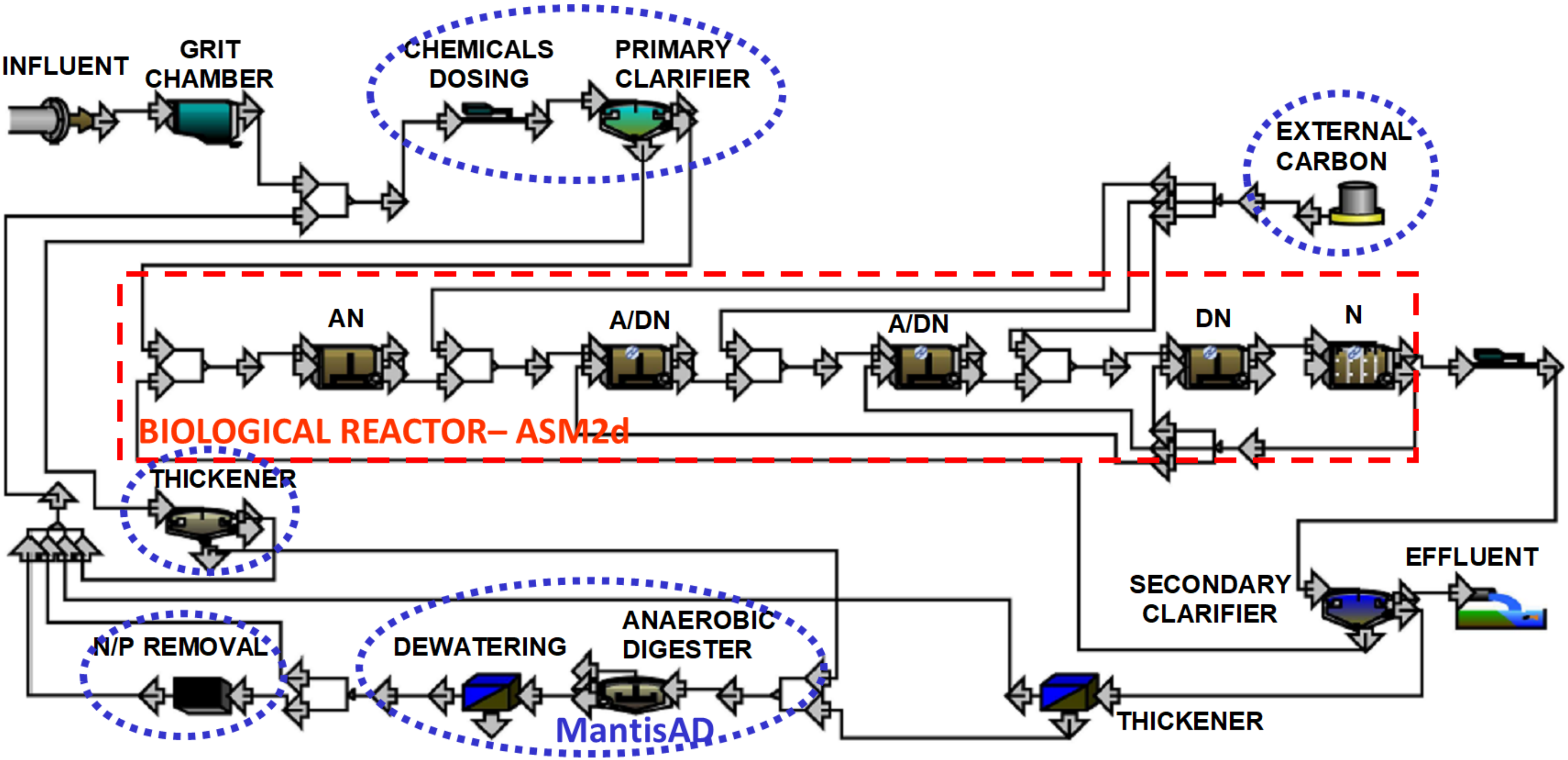


P removal / denitrification

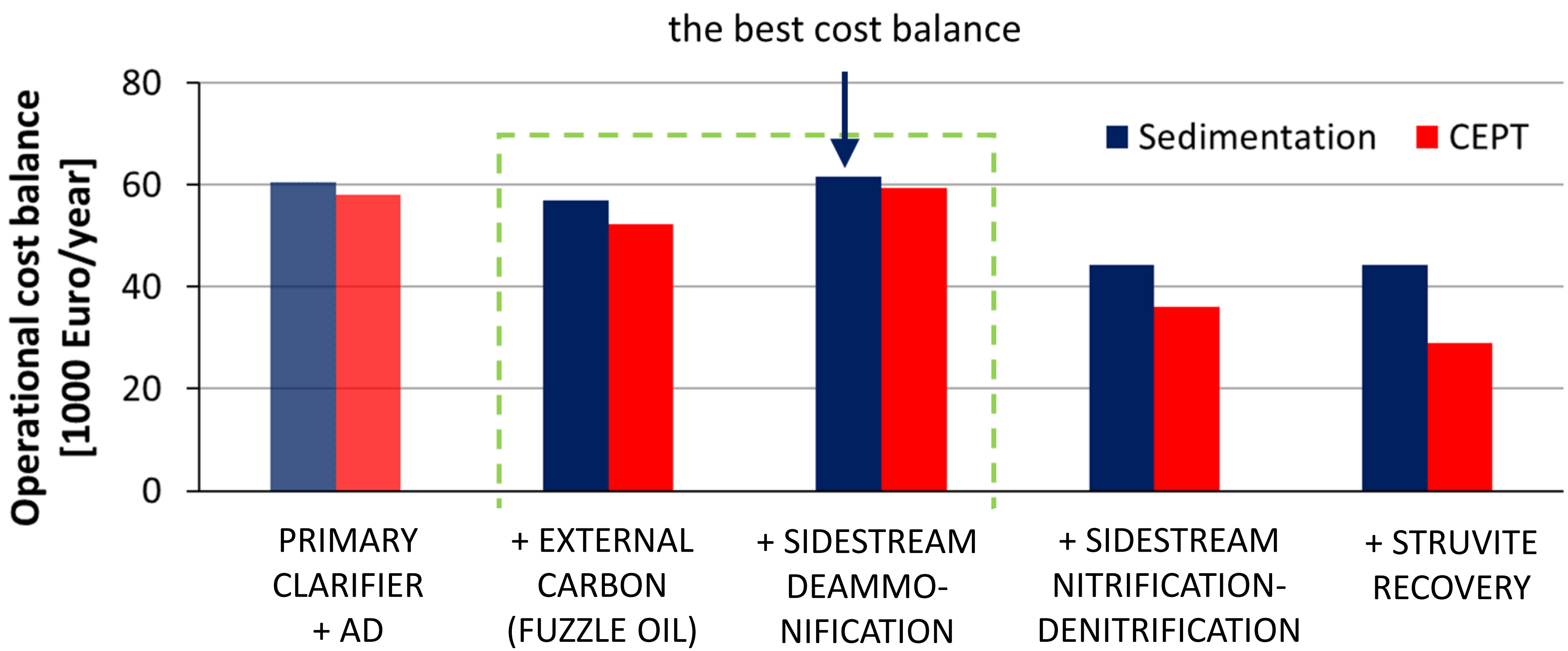


The calibration facilitated by the experiences from other Pomeranian WWTPs (comparable set of the kinetic parameters, except for the ones related to AOB growth)

Plant-wide model in GPS-X – with the upgrades in the sludge line



Model predictions.
Cost balance: sedimentation vs. CEPT



The operational cost balance includes energy and chemicals

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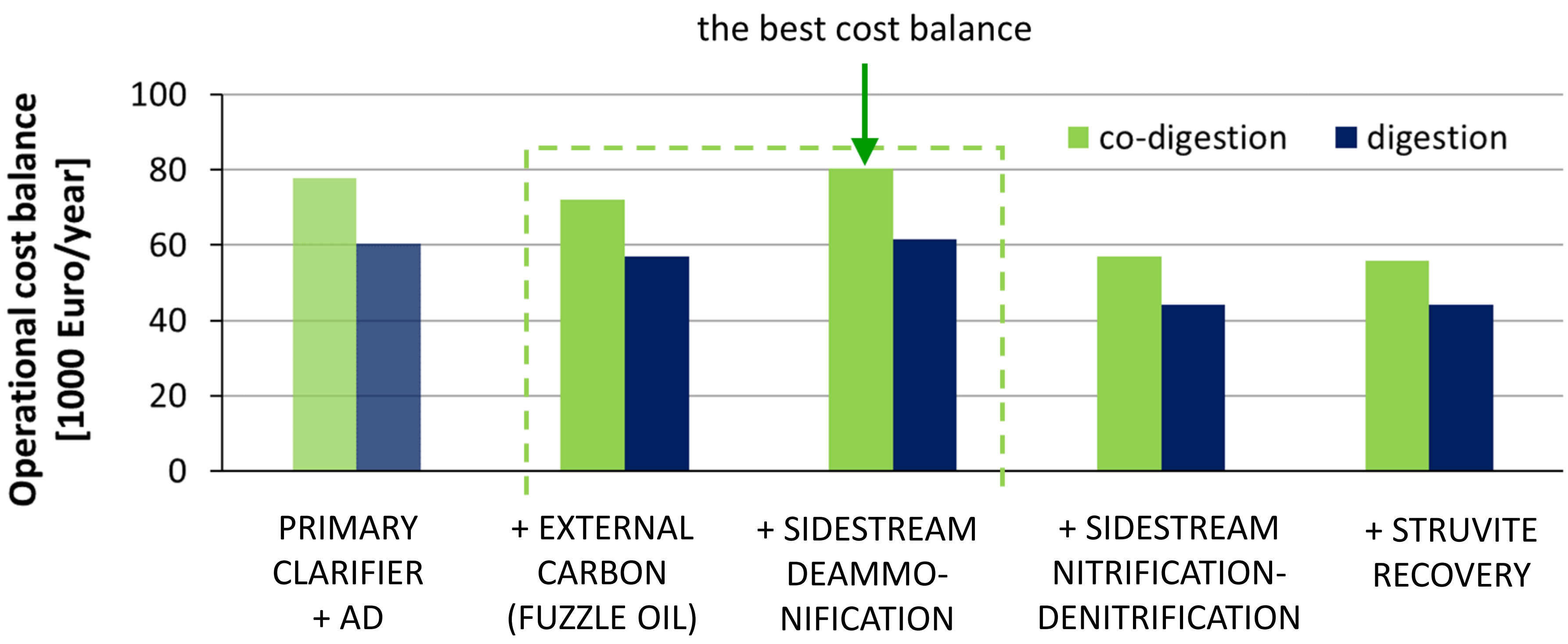
Model predictions.
Cost balance: co-digestion vs. digestion



The operational cost balance includes energy and chemicals

Conclusions

- Computer simulation is a **useful tool** for optimization WWTP performance and design (but requires **significant efforts and skills**)

- The example of a large WWTP (the Słupsk case) showed possible shift from the energy deficit to the **energy neutrality and a positive cost balance** by applying the CEPT and sidestream deammonification

- Regarding the actual operational conditions, the potential **reduction** was estimated as high as **19% for the energy demand and 32% for the C-footprint** by controlling aeration in the aerobic zone and the mixed liquor recirculation

Conclusions

- In the medium-size upgraded WWTP (the Starogard case), the **potential energy recovery was estimated up to 75%,** while maintaining the discharge limits, improving the operational cost balance and decreasing the total C-footprint

- The recommended option comprised a new primary clarifier with **gravitational (natural) sedimentation, co-digestion** with external substrates, **sidestream deammonification** as well as **agricultural sludge disposal**

Acknowledgements

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ReNEMo · POLITECHNIKA GDAŃSKA

Reduction of N_2O emissions in wastewater treatment plants - measurements, modeling and optimization of the process "RENEMO"

This project was co-financed by the National Center for Research and Development as part of the program of Polish-German cooperation for sustainable development in 2013-2016

POLITECHNIKA GDAŃSKA · WFOŚiGW w Gdańsku

Model of sludge management in a wastewater treatment plant focused on increasing the production of renewable energy and nutrients recovery

The project is financially supported by Regional Fund for Environmental Protection and Water Management in Gdansk/Poland in the "Pomeranian R&D projects" competition (2017 edition), grant no WFOS/D/201/3/2018.

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THANK YOU FOR YOUR ATTENTION !

Questions???

Contact:
Jacek Mąkinia
jmakinia@pg.edu.pl